PRACTICAL

Television Engineering

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PRACTICAL TELEVISION ENGINEERING

PREFACE

Television has made tremendous strides in the United States since the close of World War II, developing into the country's first new postwar billion-dollar industry. The total television receiver sales for 1949 were estimated at $880,000,000, and the gross dollar volume in the entire field for the year (including transmitters, studio equipment, home antenna installations, servicing, warranties, and accessories) was estimated at $1,013,250,000. Receiver production by members of the Radio Manufacturers Association amounted to 2,413,397 units for 1949, and the total output for the entire industry exceeded 2,800,000, as compared with an estimated industry-wide TV receiver production of only 955,000 units in 1948. More than 4,000,000 television receivers have been manufactured and installed in American homes since the close of World War II.

Television engineers have been sorely pressed to keep up with the increasing demand for more improved equipment of all types, whether for TV transmission or reception. The constant demand for greater quantities of equipment of higher quality and of more advanced design has taxed the ingenuity and resourcefulness of practicing engineers in the profession. There has been a constant search for practical technical information with which to solve the many engineering problems that have arisen.

This book is an attempt on the author's part to include within the covers of a single volume much of the practical information which the practicing engineer in the field will find useful in solving his everyday problems. At the same time, it is hoped that the student will find the work sufficiently interesting and instructive to yield a broad insight into this interesting new field of human endeavor. The information contained has been organized with the needs of the student in mind, whether he is seeking instruction on a college or university level or is attending one of the recognized technical trade schools. Review questions are included at the close of each chapter. The engineer actively engaged in the field will also find these questions useful in a review of the science from time to time.

The author has endeavored to cover the entire field as thoroughly as possible in a book of this size, and it is regrettable that it has not proved possible to go into greater detail. The material was collected for the author's own use while serving as chief engineer of Du Mont Television Network, and earlier, while installing, servicing, or operating television studio and transmitting equipment in various parts of the United States for a prominent manufacturer of television apparatus. The accumulation of notes, references, and data was carried on while installing, servicing, or operating equipment for this manufacturer in New York City, Washington, Baltimore, Detroit, Dallas, Boston, Miami, and Los Angeles.

It was felt, therefore, that the benefit of this experience, as well as the research material collected while searching the literature from time to time, might be passed along to others who would find it useful in the solution of their technical problems. The ultimate result was the preparation of a manuscript from the collected material.

While a great deal of information is included on the theoretical concepts in television, manufacturing techniques, operating practices, and so on, great stress has been placed on television broadcasting. This is a rapidly advancing field. At the beginning of 1950 there were four operating television networks in the United States, 98 television broadcasting stations were on the air, and 13 applicants held construction permits for new stations. There were, in addition, 351 applications for construction permits on file with the Federal Communications Commission at Washington.

The author is indebted to a great many persons and organizations for their cooperation in supplying technical information and photographs for the text and wishes to thank particularly Allen B. Du Mont Laboratories, Inc., Radio Corporation of America, General Electric Company, Westinghouse Electric Corporation, North American Philips Co., Inc., National Broadcasting Company, Du Mont Television Network, American Broadcasting Company, Eastman Kodak Co., Amphenol Corporation, American Telephone and Telegraph Co., American Optical Co., and the many others who have cooperated. He is also indebted to Mr. Floyd Rogers who reviewed earlier portions of the text and extended helpful advice and suggestions. Material from other works in the field has been freely referred to and proper credit extended wherever others have been quoted.

It is sincerely hoped that the contents of the book will prove useful to the vast and expanding group of engineers, technicians, and servicemen who will have to design, develop, and supervise the manufacture, installation, and servicing of the great array of equipment which such a rapidly advancing field demands. For those who desire to do further research into the subjects covered, a bibliography, chronologically arranged, is included at the close of each chapter. A useful glossary of television engineering terms will be found at the close of the text.

Scott Helt

New York,
April, 1950

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ABBREVIATIONS AND SYMBOLS

Abbreviated Multipliers

$\mu\mu$	micromicro	10^{-12}
μ	micro	10^{-6}
m	milli	10^{-3}
c	centi	10^{-2}
d	deci	10^{-1}
k or K	kilo	10^{3}
M	mega	10^{6}
km or KM	kilomega	10^{9}
MM	megamega	10^{12}

Metric Prefixes

mega-	1,000,000	10^{6}
myria-	10,000	10^{4}
kilo-	1,000	10^{3}
hecto-	100	10^{2}
deka-	10	10^{1}
deci-	$\frac{1}{10}$	10^{-1}
centi-	$\frac{1}{100}$	10^{-2}
milli-	$\frac{1}{1,000}$	10^{-3}
micro-	$\frac{1}{1,000,000}$	10^{-6}

Abbreviations for Electrical Units

amp.	ampere
ma.	milliampere
f.	farad
Hy. or h.	henry
Ω	ohm
v.	volt
va.	voltampere
w.	watt
wh.	watthour
c.p.s.	cycles per second
kc. or KC	kilocycles
mc. or Mc.	megacycles
mc. per sec.	megacycles per second
kmc.	kilomegacycles
meg.	megohm
db.	decibel
dbm.	decibels of power related to one watt
dbv.	decibels referred to one volt peak to peak
mfd. or μf	microfarad
mmfd. or $\mu\mu$f	micromicrofarad
kw. or Kw.	kilowatt
kwh. or Kwh.	kilowatthour

Abbreviations and Symbols

A.	angstrom unit or area
α	absorption factor
abs.	absolute
a.c. or ac	alternating current
af	audio frequency
AM or A.M.	amplitude modulation
amp.	ampere
antilog	antilogarithm
B	brightness, luminance $\left(B = \frac{dI}{dA\cos\theta}\right)$
Btu or B.t.u.	British thermal unit
c	candle
C.	centigrade
C.c.	capacitance (permittance)

cm.	centimeter
c.m.	circular mil
cos	cosine
$\cos^{-1}$	arc or angle whose cosine is; anticosine of; inverse cosine of
cot	cotangent
$\cot^{-1}$	arc or angle whose cotangent is
c.p.	candle power
cps.	cycles per second
csc	cosecant
d	density; diameter; differential, as dx, that is, the differential of x
db.	decibel
dbm.	decibels of power related to one watt
dbv.	decibels referred to one volt peak to peak
d.c.	direct current
diam.	diameter
ϵ	damping constant, damping coefficient
E	electromotive force
e	electronic charge
E_i	voltage, input
E_o	voltage, output
E_t	voltage, total
emf. or e.m.f.	electromotive force
F.	Fahrenheit
FM or F.M.	frequency modulation
fluores.	fluorescent
ft-c.	foot candle
G, g	conductance
H.	horizontal
I	electric current
K	Kelvin
kva.	kilovolt-ampere
kw.	kilowatt or kilowatts
kwh. or Kwh.	kilowatthour
l	length
λ	charge, line density (or wavelength)
λ	wavelength in free space
log	logarithm
m	mass
m	meter
m^2	square meter
m^3	cubic meter
Mμ	millimicron
Max. or max.	maximum
m.h.c.p.	mean horizontal candle power
min.	minimum; minute
mL	milli-lambert
mm.	millimeter
mm^2	square millimeter
mm^3	cubic millimeter
mfd. or μf	microfarad
mmfd. or $\mu\mu$f	micromicrofarad
m.m.f.	magnetomotive force
m.s.c.p.	mean spherical candle power
Nl	number of lamberts
n	refractive index
ω	angular frequency ($\omega = 2\pi f$)
p. ct.	per cent
pf. or p.f.	power factor
pr.	prisms
Q	quality of an electrical circuit or component
P	charge, volume density of
rms. or R.M.S.	square root of mean square
r.p.m.	revolutions per minute

s.c.p.	spherical candle power
sec. or sec	second (mean solar unless contrary is stated)
sec	secant
σ	charge, surface density of
sin	sine
sp.	specific
SWR	standing wave ratio (voltage or current)
T	total capacitance
t_f	time of pulse fall
t_r	time of pulse rise
$\tan^{-1}$	arc or angle whose tangent is . . .
temp.	temperature
TV	television
U.S.	United States of America; universal system of lens apertures
V.	vertical
v.	volt or volts
vel. or veloc.	velocity
X_l	inductive reactance
X_c	capacitive reactance
Z_0	surge impedance, characteristic impedance

PRACTICAL TELEVISION ENGINEERING

CHAPTER 1

THE FUNDAMENTALS OF PICTURE TRANSMISSION

1.1 Characteristics of Light. Any modern electronic television system, designed to transmit the intelligence or information contained in a picture, functions to convert light energy into electrical energy. The light energy reflected from persons and objects on the studio stage and imaged through a lens system upon the target of the pickup tube in the television camera must be converted into a form of energy suitable for modulation of a radio-frequency carrier at the picture transmitter. The television receiver functions to convert the electrical energy back into perceptible light energy. The reconversion into light energy at the television receiver must result in an image identical with that scanned at the television camera in the studio. The image, reproduced in the home on a suitable screen, is then viewed by means of that light-sensitive organ we know as the human eye.

It should be apparent to the student that to obtain a thorough understanding of the principles of television transmission and reception, it is essential first to investigate the properties of that form of energy known as light. Only through an understanding of the basic principles relating to light energy may one perceive the intricate means by which that energy is first converted into electrical energy at the television studio camera and later reconverted into light energy at the television receiver, where the original image is reproduced.

The human eye obtains impressions of form and color by means of light. Through this same medium an object may be imaged upon the surface of a photographic film in a camera or upon the photosensitized surface of the plate or target of a light-sensitive pickup tube in a television camera. The sensitive plate in the television image-pickup tube known as the Iconoscope is termed the "mosaic." It is equivalent to the chemically treated plate in a photographer's camera. Whether the reflected light from the subject or object is imaged upon the sensitive plate of the photographer's camera or upon the mosaic of an Iconoscope tube in a television-studio camera, the physical principles are identical.

Light energy constitutes a form of wave motion, and in this respect it is similar to sound waves or to the electromagnetic waves employed in ordinary radio transmission and reception. Light has a finite wavelength, and its color is a function of that portion or range of the total frequency spectrum occupied by the particular light being viewed. It is evident that color depends upon the wavelength of light. The light waves, regardless of wavelength, follow a perfectly straight path after leaving the source, provided that they are not deflected by some object that intervenes or serves to block the path. The total band of light frequencies and wavelengths covers a clearly defined portion of the total known frequency spectrum. The higher light frequencies extend almost to that portion of the spectrum occupied by Xrays and gamma rays. The longer wavelengths of light, and conversely the lower frequencies of light, extend almost to that part of the frequency spectrum occupied by the radio-communication services. As a matter of fact, the carrier frequencies assigned to relay stations occupying some of the higher channels allocated by the Federal Communications Commission for television are termed "quasioptical," because they have similar propagation characteristics.

The human eye is light-sensitive, but only a limited portion of the total frequency spectrum is visible to this organ. The ear, for instance, is insensitive to light waves yet is perfectly capable of responding to the wave motion of air occurring at audible frequencies. The band of frequencies to which the eye is sensitive extends from the lower extreme of the invisible infrared-ray band to the invisible ultraviolet rays at the upper end of the light spectrum. The eye is ordinarily sensitive to the entire color range between these two extremes. This visible band of frequencies extends from 375,000 to 790,000 kmc. or includes wavelengths in the range of 0.00008 to 0.000038 cm. Visible light includes the colors of red, through orange, yellow, green, blue, and violet, and is usually measured in terms of the convenient Angstrom unit. One Angstrom unit is equivalent to a wavelength of 0.00000001 cm.

It is interesting to note that some electron tubes for image pickup employed in modern television cameras have greater spectral response than the human eye, although the response is not so uniform. The R.C.A. type 2P23 Image Orthicon tube, for example, is sensitive to infrared rays, which are invisible to the human eye. It is entirely possible, therefore, to flood a stage in the television studio with invisible infrared rays and to transmit a satisfactory television picture of a stage so illuminated, even though the action on the stage is invisible to persons present in the same studio. It is true that most electron tubes for image pickup lack sensitivity in other portions of the light spectrum and possess less sensitivity at some random frequencies than does the human eye. Thus, there is a never-ending effort in the research laboratories of television to develop camera tubes which approach the spectral response and relative sensitivity of the human eye. Also, there is a vigorous search for sources of light for studio illumination that approach the range of wavelengths included in daylight, the best form of light to which the eye is sensitive.

A beam of light is constructed of multitudinous small-diameter straight rays of light, the waves vibrating radially along the rays in all planes. Lighted space, as we know it, is completely filled with these tiny rays. When a space is completely illuminated, there is no darkness. Darkness is the complete absence of all visible light rays. It is said that light waves vibrate radially in all planes along the projected light rays. However, if light is passed, i.e., light rays, through specially selected prisms and filters, rays in only one direction or plane are allowed to be transmitted, and the light is then termed "polarized light." Such light demonstrates special properties with which we are not at the moment concerned.

Sunlight, sometimes called "white light," is that form of light to which the human eye is best accustomed. That is why physicists and engineers have been endeavoring for years to produce a fluorescent viewing screen for cathode-ray tubes of chemical phosphors, which, when luminescent, will yield light throughout the white light or daylight range. When this objective is achieved, then we may enjoy television images in our homes which approach or equal scenes bathed in bright sunlight outdoors. The portion of white light or sunlight visible to the human eye includes indigo, blue, green, yellow, orange, and red. Black indicates absence of light. In fact, the complete absence of any light (black) and white are the two extremes of the light spectrum. Neither is considered a color. In the principal system of electronic television in use today all colors are absent because a monochromatic system is used, black, through shades of gray, to white, being transmitted. It may be called a "color blind" system. The absence of color does not materially detract from the enjoyment of such pictures.

Light energy is seen to manifest itself in a number of ways. Light energy may be detected by the sense of sight which we find in practically all animal, bird, insect, and marine life. Light may be also detected if allowed to produce chemical or physical changes in certain materials. When light energy is allowed to strike a photosensitive surface, such as the photosensitized mosaic of the Iconoscope, an electric current is produced. This is another form of light-energy detection. The common photoelectric cell is still another widely known light detector, and its electrical output is a function of the incident light falling upon its sensitized element. (Of lesser importance is the spectral response of the photocell receiving the light.) Light may also be produced by electrical current flowing through a conductor, by high-temperature combustion, by certain chemical reactions, and by conversion from other forms of energy. We may bombard the phosphors, which coat the screens of cathode-ray tubes, with high-velocity electrons, thereby producing light.

Light may be produced by increasing the temperature of the tungsten filament of a lamp to the point of incandescence, and high-temperature combustion may be brought about by firing a Bunsen burner. Light may thus be created in many different ways.

A light ray is reflected from its original path if it strikes the surface of any object. If light strikes an object, it may rebound and be impressed upon the eye. In the same manner the light from some suitable source may strike a subject, rebound, and enter the lens of a television camera. It should be noted that we make use of reflected light in the television studio. The stage, before which the television camera is set up and focused, is bathed in brilliant light. The original light, obtained from some suitable source, strikes the stage and rebounds or is reflected into the lens system of the camera. The object or objects in the scene being televised are thus imaged upon the photosensitized target or mosaic of the television camera pickup tube.

The nature and the amount of light transmitted (reflected) depend to a large extent upon the form and composition of the reflecting surface. Therefore, if the flats, or stage backdrops, in the television studio are treated with a high-gloss enamel, more light will be reflected into the camera lens than if the same flats were coated with a dull matte finish. However, the camera must move about as the production proceeds, and the criterion is not always that the flats transmit the maximum reflected light, since this might result in undesirable flare and other deleterious effects. If the surfaces of the flats and backdrops are dull and rough, the reflected light takes the form of diffused light. This form of light is more evenly distributed and softer. In general, the brighter colors reflect the most light and are used in treating stage flats and backdrops, and care must be used to have the reflected light take the form of diffused light. The result is a softer, warmer picture. Any objects placed before the television camera must be capable of reflecting enough light to create a satisfactory image. Dull, dead surfaces treated with darker shades of paint will be found to reflect little or no light, for the light thrown upon such surfaces is almost entirely absorbed. Quite often an undesirable effect is obtained when the television camera is trained upon a black or dull object. Instead of producing a dark image, the lack of reflected light reaching the target of the pickup tube results in so much flare that the object appears to be gray or light, and the desired effect is not obtained.

When flats, or backdrops, are treated with certain pigments, selective reflection takes place; i.e., the light rays reflected will be of a different color than the white incident rays. When a surface treatment is used which absorbs all the light rays except those of blue frequency, only blue light will be reflected to the camera. In the final television picture the blue will appear as a shade of gray because of the monochromatic nature of the present television system. Paints are really substances that absorb all the colors in a beam of light except the desired color or color combination which the substances reflect. This property is termed "selective reflection."

When a ray of light is transmitted through a transparent body possessing a density greater or less than the density of air, the ray of light is subjected to a deviation from its original path, and this deviation is termed "refraction." The amount by which the ray of light is bent out of its original path is a function of the nature of the transparent body and the wavelength of the ray of light. The angle of refraction of the transparent body, through which the ray of light is passed, is an acute angle produced by the reflected ray and the perpendicular. The measure of deviation of a light ray from its original or normal course, when passing from one medium to another medium, is termed the "index of refraction." This deviation is important in the study of lenses associated with the television camera. When a light ray enters the camera lens system, it passes into a medium of unlike density, and the light is divided into two rays: One ray is a reflected ray; the other is a refracted ray. The refracted ray represents a loss of light, since part of the incident light is reflected, and some portion of the refracted ray is lost through absorption in the glass as well as by internal reflections in the lens system.

When light is admitted through a prism of glass, the white incident light is separated into a band of colors. This reaction is termed "dispersion," and the various colors are separated according to wavelength. The prism, or lens, brings about greatest deviation (or refraction) in the high-frequency colors. Therefore, it is known that violet or blue suffers more deflection or refraction than red or yellow.

1.2 Television-Studio Stage Lighting. It is unfortunate that so little attention has been given in the past to the problem of proper light for television-studio set and stage illumination. Some studios are still equipped with filament or incandescent lamps in great profusion, and the type PAR–38 lamp is employed in many typical installations. The type PAR–38 is a filamentary-type projector lamp constructed within a hard-glass precisely molded bulb which also forms the reflector. It is rated at 150 w. and provides unusually good control of the light. The bulb is made of heat-resistant glass, and when used outdoors it may be exposed to rain or snow. Like all filament-type lamps, it is fundamentally a high-brightness concentrated light source. However, incandescent lighting of this type provides a preponderance of energy in the red and infrared portion of the total light spectrum. This energy serves to increase the temperature of the television studio beyond comfortable limits, and to no useful purpose, since most electron tubes for image pickup (camera tubes) do not demonstrate optimum sensitivity in the red and infrared region of the spectrum. Therefore, when filamentary or incandescent lighting is exclusively and extensively used, studio talent must work under a glaring-hot light source which must be increased beyond reasonable limits in order to obtain a satisfactory output signal from the pickup tube in the camera.

The type PAR–38 incandescent lamp emits maximum light from 9,000 to 10,000 A. When the light sensitivity of the commonly used image pickup tubes are studied later in the text, it will be found that the type 1850–A Iconoscope and type 1840 Orthicon indicate maximum sensitivity at 4,600 A., or in the blue-green region of the light spectrum. Therefore, they provide maximum signal output when a light source nearly equivalent in color emission to the maximum color sensitivity of the tube is employed.

It will be found that the type 2P23 Image Orthicon pickup tube indicates maximum spectral sensitivity at about 4,000 A., or in the ultraviolet region. The type 5655 studio Image Orthicon camera pickup tube is most sensitive to light having a wavelength of 3,750 A. The fallacious reasoning responsible for providing filament or incandescent lighting exclusively in the television studio becomes immediately apparent. We must not neglect the fact, however, that the human eye is sensitive throughout the daylight range, and that daylight includes the full range of the visible light spectrum and *all* colors within the spectrum which are apparent to the eye. It follows that to obtain "realistic" pictures, the light source in the studio must provide, and the camera pickup tube must be sensitive to *all* colors within the visible portion of the light spectrum.

It is well, therefore, to use a combination of light sources, with each individual source of light contributing a portion of the desired total "color range" of illumination. It has been discovered through practical experience that three types of lighting are desirable in the television studio:

1. Basic or general lighting (sometimes termed "key" lighting)
2. Modeling lighting
3. Backdrop lighting

Basic, key, or *general lighting* refers to the general lighting on which the exposure is based. Such lighting should be evenly distributed over the entire studio stage or set; i.e., the illumination should be essentially of the same value from all angles at which the cameras must work. In the selection of equipment for basic, or general, lighting, a good criterion for comparison is the percentage of the total illumination made to fall upon the stage, or set, in the 0- to 30-deg. zone, i.e., in a cone 60 deg. wide. The light in this zone is ordinarily the most effective in illuminating the stage. For uniformity of lighting across the set, or stage, the candlepower of lighting used at 30 deg. should not be less than half that occurring at 0 deg.

Modeling lighting consists of side and back lighting to model or emphasize actors, advertised products, or specific objects or portions of the set being televised and is also used to separate the actors from the background. Such lighting brings out and accents the contours and shapes of objects on the set. Filament-lamp spots are often used to provide modeling. In the proper selection of lighting for this purpose, it is first essential to ascertain the greatest length of throw required of the light. "Throw" is the distance the light beam must traverse from source to object. An important consideration is the footcandle intensity required throughout the staging area. Richard Blount of General Electric Company has suggested that the designers of television studio lighting systems estimate the total electrical capacity required on the basis of 15 to 20 w. per sq. ft. of staging area. The lighting level on staging areas should approximate 200 ft.-c. Effective illumination for modeling should not be greater than double the general lighting (expressed in foot-candles), and more often it should be only 50 per cent greater. (The use of Image Orthicon tubes is assumed.)

Backdrop lighting is employed to illuminate properly the backdrops, or flats. Overhead fluorescent fixtures are often used for the purpose, with the units mounted overhead, above, and in front of the backdrops. The reflectors of the units or the lighting units proper are tilted at an angle experimentally found to be proper for even illumination of the front surfaces of the backdrops, i.e., the surfaces exposed to the camera. Two-lamp General Electric type 96T8 Slimline 4500 white fluorescent fixtures have been used satisfactorily for the purpose. Theater strip lights may also be used to satisfy this requirement.

Some television studios have been equipped with fluorescent lighting as the basic, or key, lighting. Such lighting has demonstrated a number of advantages, most important of which is the fact that for the same level of illumination, the sensation of heat is approximately 20 per cent of that due to filamentary, or incandescent, lighting. Another advantage is the high efficiency of fluorescent lighting, since the average efficiency exceeds that of incandescent lamps by 2.5 to 3 times. A disadvantage in the use of fluorescent lighting for basic lighting lies in the fact that the wattage range of these lamps is more limited than that of filament types. The maximum rating in watts of commercially available fluorescent lamps is 85 w., though the type T–6 Slimline lamp rated at 40 w. is proving a most useful lamp of this general type. The type T–12 lamp has also enjoyed widespread popularity as a key lighting source. It is not so desirable, however, for this purpose as the more elongated Slimline lamp.

A disadvantage of the type T–6 Slimline lamp is the fact that control of the light may be obtained in only one plane. Ordinarily, long troughlike reflectors of approximately parabolic cross section are employed for best results. These Slimline lamps are instant-starting, no external starter being necessary, and this is a considerable advantage. Since fluorescent lamps of any type are rather long and constitute relatively low-wattage light sources, a distinct problem is presented in their use for basic lighting for studios equipped with Image Orthicon cameras. A great number of the lamps must ordinarily be used to provide the requisite candlepower at the source, which, in turn, dictates the requirement of sufficient space to accommodate the numerous fixtures. Ordinarily, not too many fixtures can be of the mobile type, since they occupy floor space and thus reduce the mobility of the cameras. If the fixtures are mounted overhead, then more light at the source must be used to compensate for the increased distance between light source and subject. Fluorescent fixtures alone cannot be used where Iconoscope cameras are employed, since they do not produce enough light. They are nevertheless widely used with Image Orthicon cameras.

Many television stations have successfully used both filament and fluorescent lamps where Image Orthicon cameras are used. With this arrangement, the advantages of both types are combined. In combining the two sources of light, the fluorescent lighting has been made the basic, or key, lighting, and the filament-type lighting has been employed to provide the accent, or modeling, illumination, as well as for back lighting. Back lighting dictates the use of highly directional light sources as well as excellent control of the beam of light. Filament-type lighting answers the requirements very well and has been widely used. Fluorescent lamps are well suited to the purpose of general lighting, since the freedom from radiant heat permits the cast to work without discomfort. The type 4500 white fluorescent lamp produces excellent rendering of skin tones, and its development of the maximum signal per lamp watt when employed with the Image Orthicon type of camera has made it a popular choice. Because of the low wattage rating per lamp, however, fluorescent lamps of any type are impractical where Iconoscope-type cameras are used. This type of pickup tube is rapidly being replaced with those of the Image Orthicon type, although they still find widespread application in motion-picture film scanning.

When various types of camera tube and light source are used, the rendering of skin tones is of much interest at the present time. It has been pointed out that if the spectral sensitivity of the camera tubes for image pickup were identical with that of the human eye, no problem of tonal rendering in television would result. Unfortunately, however, the currently popular Image Orthicon tubes demonstrate greatest spectral sensitivity in the ultraviolet region. The result is that some colors appear darker and some brighter when viewed on a television monitor tube or on the picture-tube screen at a receiver. This effect has been demonstrated by "bathing" color samples with ultraviolet radiation. Under this condition of illumination, the red, green, and yellow samples are reproduced as black, although the latter two are normally reproduced as brighter tones of gray under fluorescent and incandescent lighting.

Tonal rendering may be improved through the use of Wratten K2 and Corning 9788 filters directly over the camera lens. When the type 5655 Studio Image Orthicon tube is employed, the addition of these two filters results in a spectral sensitivity approaching that of the human eye. Richard Blount of General Electric Company has shown that the use of K2 filters (minus blue) under incandescent lighting reduces the camera output signal to approximately 60 per cent of its original amplitude. The use of the Corning 9788 (minus red) filter brings about a further reduction to approximately 70 per cent of its original amplitude. The combination of the two filters at each camera lens, therefore, serves to reduce the individual camera output signal to 35 per cent of its original amplitude. This reduction requires the increase of the lens aperture at least one full stop and can be compensated for by increasing the light at its source; provided that the degradation of illumination cannot be compensated for through advancing the lens one full stop. Ordinarily, it is better to employ a little more light than is necessary to get a good picture. The cameraman can then stop the lens down by a sufficient amount to obtain good depth of focus.

The addition of the Wratten K2 filter will provide desirable correction of the blues and violets when fluorescent lighting is employed. When tungsten-filament sources are added for modeling and back lighting, the addition of the Corning 9788 filter to the system eliminates the possibility of excessive red sensitivity. The addition of these two filters to a filament lighting system or to a combined fluorescent and incandescent lighting system results in very satisfactory rendering of the skin tones without the use of facial make-up. A very excellent study of tonal rendering can be made through the use of an Agfa color chart, which has been so prepared that the various colors shown are made up of true color pigments. When the chart is bathed in various types of light and the camera focused on the chart, the rendering of the colors in the monochromatic scale can be viewed on a suitable picture tube at some point in the camera chain. Such a study was made during 1947 by the author, in collaboration with a group of Westinghouse lighting engineers. The results were conclusive evidence of the types of lighting best suited to studio lighting requirements. William Till, of the Westinghouse Lamp

Division, has made a very thorough analysis of studio lighting sources and camera tubes by this method, and the study has been of great assistance to operating engineers interested in the subject.

Of considerable interest has been the use of the Westinghouse Type AH-12 1,000-w. air-convection-cooled high-pressure mercury-vapor lamp,

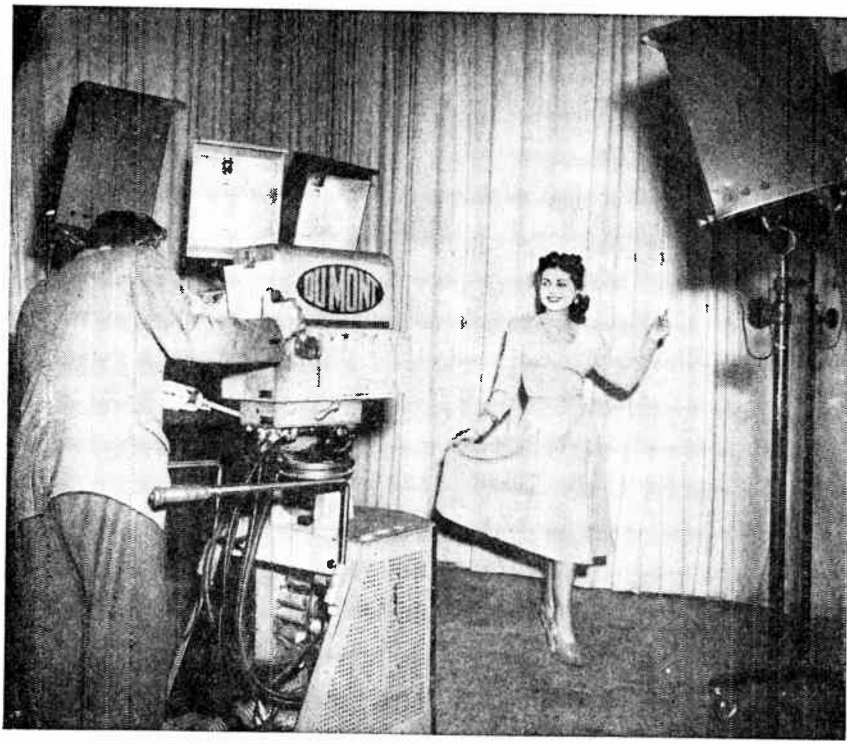


Fig. 1.1 Testing the new mercury-vapor lighting. The stifling heat conditions which have plagued people in front of television cameras are relieved in new mercury-vapor lighting system shown being tested at Station WTTG of the Du Mont Television Network. The new system utilizes a bank of 1,000-w. mercury lamps developed by Westinghouse engineers. The lamps radiate only one third as much heat per watt and provide more than twice as much light as the incandescent lamps they replace. (Courtesy of Westinghouse Electric Corp.)

usually in combination with fluorescent and incandescent sources. A combination of these lighting sources has been successfully used with both Iconoscope and Image Orthicon types of camera pickup tubes. Of considerable importance is the fact that the AH-12 mercury-vapor lamp has a peak at 3,650 A., another at 4,047 A., and a third at 4,358 A. Since this lamp is peaked about where the Image Orthicon tubes are most sensitive, it may be used to advantage for basic studio lighting. The use of the lamp results in the maximum signal amplitude obtainable from an Orthicon camera chain equipped with the type 2P23 or type 5655 pickup tubes. Supplementary incandescent lighting must be used to increase the reds, and fluorescent lighting may also be used in combination to advantage. Important too is the fact that the AH–12 lamp provides a cold source of high-intensity basic lighting. It is well known that at the present time fluorescent lighting can most closely approach true daylight. As was pointed out, however, it is a comparatively low-intensity source, and much of it must be employed to provide the desired output signal from the camera.

Many stations are investigating cold mercury-vapor lighting as a source of basic lighting, with incandescent and fluorescent lighting added to provide the complete color range desired. All medium- and high-pressure mercury arcs are brilliant sources of light, the type AH–12 possessing a brightness of 60,000 lm. (lumens) at the source. The arc length of the lamp is 5 in. and the effective arc diameter 7⁄16 in. At 9 deg. from the axis of the arc stream approximately 2,700 c. (candles) per sq. in. of projected arc area are produced. The spectral sensitivity of this lamp is shown in Table 1 on page 14.

These mercury-vapor lamps are air-cooled, and no circulating water or forced air cooling is required. A stroboscopic effect is developed when they are used for studio lighting but is easily eliminated. The effect is due to the fact that the arc of the lamp is extinguished 120 times per second when operation is from a 60-c.p.s. source. Therefore, there is a tendency for the eye to see in flashes, with the result that rapidly moving objects appear to move in jerks. This stroboscopic effect is eliminated by operating pairs of the lamps on lead-lag two-lamp transformers or by operation of three lamps on separate phases of a 3-phase a-c supply source. The special transformers can be supplied by the lamp manufacturer. The use of incandescent lamps in combination with the mercury sources reduces the stroboscopic effect to the minimum even without the use of the special transformers. When AH–12 lamps are used for basic lighting, it is always desirable to provide incandescent lighting in the form of spots for any desired highlighting or modeling as well as for purposes of back lighting.

Of great interest is the new Westinghouse color-corrected mercury-vapor lamp, evidencing improved tonal rendering of the skin. Recently, an installation of Westinghouse mercury-vapor lighting (AH–12) has been made at Station WTTG, the Washington station of Du Mont Television Network. The success of this particular installation demonstrated the practicability of mercury-vapor lighting in the television studio, and it is believed that other installations will follow, though possibly they will use lamps that are color-corrected.

The new Westinghouse color-corrected cadmium-mercury-vapor lamps rated at 1 kw. are also free air-cooled. They produce nearly 40,000 lm. per lamp. This highly efficient television studio lighting source employs a relatively small remotely located ballast. Several minutes are required for it to reach maximum light output, but this is no serious disadvantage since the studio stage is always illuminated well in advance of shooting. It is a strong light source in the characteristic blue-white color of standard mercury lighting, but the addition of cadmium increases the yellow as well as the red emission. This results in flesh tones becom-

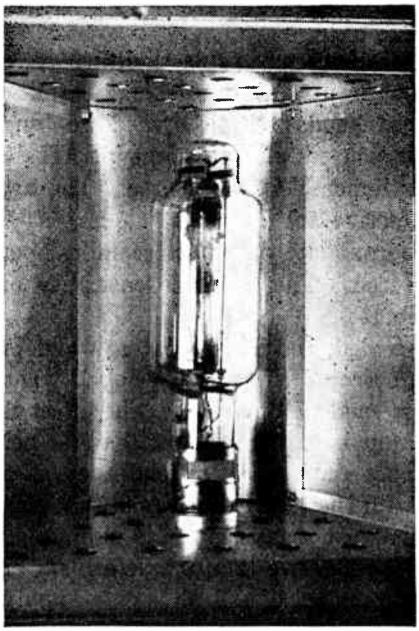


FIG. 1.2 Westinghouse type AH-12 1,000-w. mercury vapor lamp mounted in a Capital Stage Lighting Company olivette to provide a highly efficient light source at television Station WTTG, Washington, D.C. (Courtesy of Du Mont Television Network.)

ing more pleasing to the eye. The lamps may be burned in any position, and lamp life is reasonably long. Possessing less infrared than filament-type lighting, they are exceptionally cool and easy to work under. The arc tube is 5 in. long and made of quartz. The outer envelope is 3.5 in. in diameter and 14 in. in length and effectively stops any harmful radiation.

The disturbing skin-penetration effect, which is noted when incandescent lighting is used with the Image Orthicon type of camera equipment, is completely absent. This skin-penetration effect is the result of the infrared rays of the studio lighting source penetrating to the roots of the beard through the layers of skin on an actor's face. Thus, the actor appears to have a beard, even though he actually may be cleanly shaved. The effect is due to the infrared sensitivity of certain commercial types of Image Orthicon camera tubes.

Since mercury lamps possess the negative current characteristic common to all electric-discharge sources of light, the current increases indefinitely. Therefore, a current-limiting device must be used. Because the striking voltage is high and 110–120-v. power is used at the source, high voltage must be provided. In a proper installation, all voltage-control ballasts should employ high-reactance transformers designed to provide not only the proper lamp voltage but the necessary current ballasting through the winding of the inductance. The low power

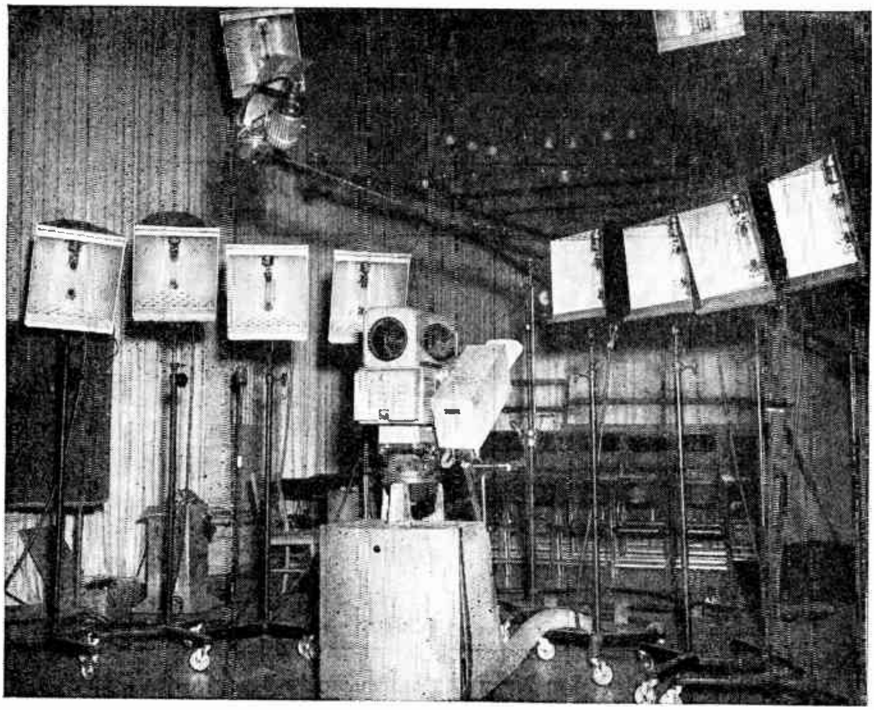


FIG. 1.3 Westinghouse type AH-12 1,000-w. mercury vapor lamps in olivettes of spun aluminum provide a suitable high-intensity cold light source where Image Orthicon or Iconoscope cameras are used. Here, some of the lamps are mounted on portable floor stands, some are suspended overhead on a pipe grid. Some supplementary incandescent lighting is used to provide the full color range. (Courtesy of Du Mont Television Network.)

factor is corrected by a capacitor, which is usually built into the reactor-lamp unit. Power factors greater than 90 per cent are readily obtainable.

It is felt that cadmium-mercury vapor (color-corrected lamps) for basic studio lighting, together with some incandescent sources for high-lighting and back lighting, may well become a principal source of illumination for the television stage. Fluorescent lighting, reinforced with sufficient incandescent lighting for modeling, back lighting, and highlighting has also proved to be a good arrangement, especially when the recommended filters at the camera lens are used. Some stations have even made use of inside-frosted pear-shaped lamps such as are used in the home with interesting results. It remains to be seen, however, just what lighting source will become the principal choice. Perhaps the improvement in camera tubes and improved lighting techniques will bring about a new conception of just what arrangement will prove most suitable.

TABLE 1

SPECTRAL DISTRIBUTION OF WESTINGHOUSE TYPE AH-12 AIR-COOLED MERCURY-VAPOR LAMP

New Image Orthicon Tubes Indicate Maximum Spectral Sensitivity in the Violet and Blue-Green Regions of the Total Visible Light Spectrum

Portion of spectrum	Angstrom units	Relative energy
Ultraviolet	3,341	0.4
	3,650	35.8
	3,655	19.3
	3,663	17.5
Visible (violet through blue-green)	3,906	0.5
	4,047	32.6
	4,078	7.9
	4,339	4.9
	4,347	8.1
	4,358	69.0
	4,916	2.5
	5,461	100.0
	5,770	72.7
	5,791	71.4

The Du Mont Television Network has recently made a quite thorough study of incandescent, fluorescent and mercury-vapor lighting from the standpoint of first costs, annual operating costs, and heat dissipation attributed to each type. For the purpose of evaluating these three types of light sources upon some compatible basis, it was proposed to illuminate uniformly a 10- by 20-ft. stage set with an average illumination equivalent to 300 ft.-c. The sources of light compared were 150-w. PAR-38 incandescent flood lamps, 40-w. instant-start fluorescent tubes, and 1,000-w. type AH-12 mercury-vapor lamps (air-cooled). To illuminate the subject stage to the intensity indicated, the following quantity of each type of light source is required:

1. Sixty type PAR-38 incandescent lamps
2. Ninety 40-w. fluorescent lamps
3. Four type AH-12 mercury-vapor lamps

To obtain the incident light upon the stage at the desired level, the first cost of 60 PAR-38 lamps was estimated at $620. The power cost, based on 4,000 hr. of light per annum, at 2 cents per kwhr., is $720. The annual replacement cost, based on an average life expectancy per lamp of 1,000 hr., is $336. Over a five-year period of operation the total annual operating cost was estimated to be $1,200.

The first cost of the ninety 40-w. fluorescent lamps and fixtures was estimated at $1,200. The power cost for 4,000 hr., including ballast loss, was calculated to be approximately $400. The annual replacement cost, based on an average life expectancy of 4,000 hr. per lamp, was calculated to be $90. Over a five-year period of operation the total annual operating cost was estimated at approximately $750.

The first cost of four type AH-12 mercury lamps and fixtures was estimated at $500. The power cost over an annual operating period of 4,000 hr. was calculated to be $360. The annual replacement cost, using a life expectancy rate of 2,000 hr. per tube is estimated at $240. Over a five-year period of operation, the total annual operating cost for the mercury-vapor lamps was estimated at $700.

The heat dissipated by the three lighting systems was calculated to be 31,000 B.t.u. per hr. for the incandescent lamps, 17,000 B.t.u. per hr. for the fluorescent lamps, and 15,500 B.t.u. per hr. for the mercury-vapor lamps. In the case of the fluorescent and mercury-vapor systems, 10 to 20 per cent of the heat dissipated develops in necessary transformers and ballasts, though it is best that they be not located in the studio. Such an arrangement may lead to hum pickup by the sensitive camera preamplifiers.

The study resulted in the following summary:

Type of light source	Annual cost	Heat dissipation, B.t.u. per hr.
Incandescent	$1,200	31,000
Fluorescent	750	17,000
Mercury vapor	700	15,500

While mercury-vapor lighting appears to be the most inexpensive source possible, it cannot be used alone for reasons already stated. Although the mercury-vapor lighting provides a high-efficiency high-intensity low-area light source, tests have indicated that either incandescent or fluorescent lighting must be used in conjunction with the mercury vapor in order to provide the proper spectral response for the pickup tube (Orthicon type 5655 or 2P23). Tests made by Du Mont Television Network indicate that mercury-vapor and fluorescent lighting provide the proper spectral response for basic flat lighting. Incandescent spotlights may be used for highlighting where the Orthicon tubes are used, though the use of such sources should be held to a minimum to keep studio operating temperatures within reasonable limits.

In another initial test, with a type 5655 Studio Orthicon tube in the pickup camera, two mercury-vapor lamps totaling 2,000 w. and seven clusters of six (each) PAR–38 (150 w.) incandescent lamps were used to bathe a standard R.M.A. test chart with light. A total of 6,300 w. were employed. This combination yielded 800 ft.-c. of incident light, 175 ft.-c. of reflected light from the R.M.A. test chart, and 60 ft.-c. of reflected light at the camera lens. With this combination of light and an f/3.8 lens (fully open) in the test camera, a satisfactory image of the test pattern was obtained on station monitors.

A magazine cover was used for a color test for both mercury-vapor and incandescent lighting. The yellows and whites of the magazine cover appeared almost the same shade, blue was darker, and red darkest. With mercury-vapor lighting only, the signal output of the camera chain was still high, but skin texture appeared almost black and had an unusually heavy reflection from perspiration, with the result that the pictures appeared unnatural. Adding incandescent lamps in the following ratio:

Mercury		*Incandescent*
3	:	1

restored the appearance of the skin texture to normal and generally improved the quality of the picture. Thus, while the mercury-vapor lighting alone ensured a camera output signal of requisite amplitude, some incandescent lighting had to be added to provide the proper spectral response for the pickup tube.

With mercury lighting alone, the yellow of the magazine cover darkened indicating a marked difference between yellow and white. Blue rendered about the same shade of gray as when a combination of incandescent and mercury-vapor lighting was used. Red resulted in a jet-black shade when viewed on a tube employing a P4 phosphor.

A typical studio installation of incandescent studio lighting is shown in Fig. 1.4. This particular set is bathed in light provided by typical Birdseye or PAR–38 lamps, the lamps being provided in banks of six lamps each and each bank dissipating 900 w. at the source. Therefore, approximately 25 kw. of incandescent lighting are being applied at the source to this one stage or set. *Iconoscope pickup tubes* are used in the cameras shown. One reason for providing so much light is to enable the camera lenses to be stopped down, thereby resulting in greater depth of focus, although a high-intensity light source is mandatory when Iconoscope tubes are made use of. The cameras shown were later replaced with units equipped with studio Orthicons.

The American Optical Company has developed a new heat-absorbing color-transmitting glass which may be employed as a heat screen in

FIG. 1.4 Incandescent-lighting installation in use in Studio A, Station WABD, New York. Iconoscope cameras are being employed. They were later replaced with studio-type Image Orthicon cameras. (Courtesy of Du Mont Television Network.)

spotlights and floodlights to protect television actors against the severe temperature rise developed by the high-intensity incandescent light

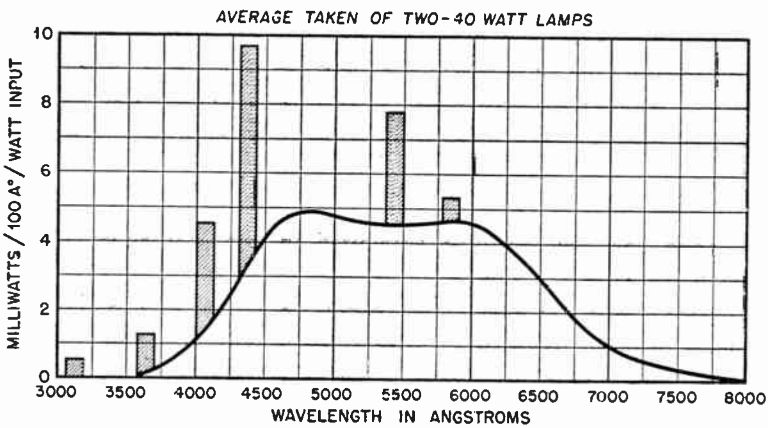


FIG. 1.4A Spectral energy distribution-daylight fluorescent. (Courtesy of General Electric Company, Nela Park, Cleveland.)

sources. Approximately 90 per cent of the present almost unendurable heat developed by the hot lights is absorbed by the glass. Actually, when this glass is used as a screen directly in front of the incandescent light source, it absorbs approximately 90 per cent of the infrared (heat) radiation and transmits approximately 85 per cent out of a possible 92 per cent. (Seven per cent is lost because of reflections.)

Small circular screens of this glass, mechanically supported just in advance of the faces of the 150- and 300-w. reflector-type incandescent

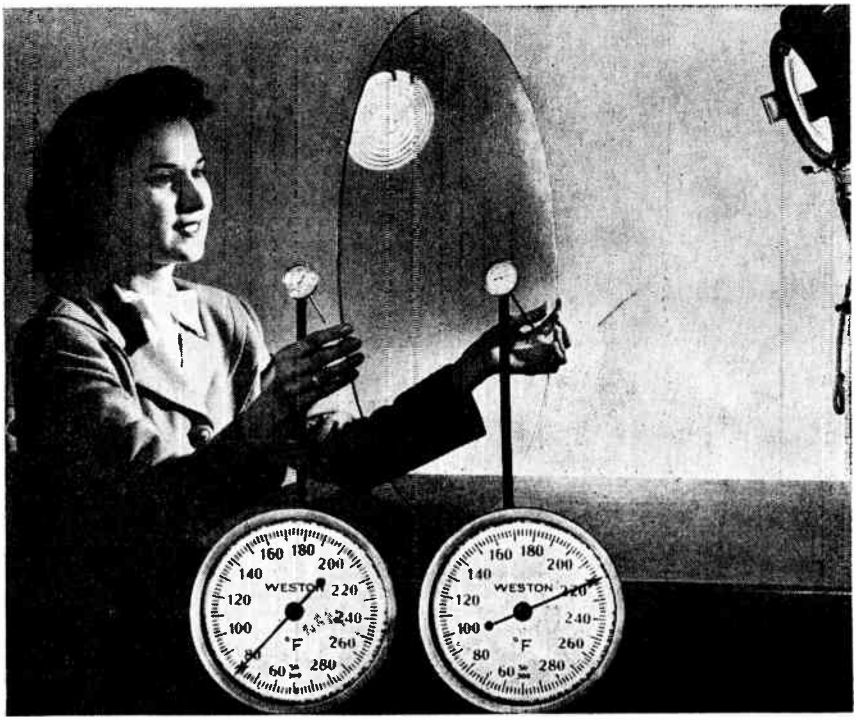


FIG. 1.5 (Courtesy of American Optical Company.)

lamps, have been successfully employed in the studios of Du Mont Television Network stations.

The glass transmits color accurately, is chemically stable, resists weathering without requiring surface treatment, and can be molded, ground and polished, or fabricated like ordinary glass. It is formed from carefully balanced proportions of phosphorus, aluminum, and silicon oxides, supplemented by various conditioning ingredients, together with ferrous iron as the heat-absorbing agent. The new glass was developed under the direction of Dr. E. D. Tillyer, Head of Research, American Optical Company.

Figure 1.5 illustrates how the glass absorbs heat emitted by a flood-light located at the upper right of the photograph. The thermometer placed before the glass registers 220°F., whereas the temperature behind the heat-absorbing glass registers only 80°F.

Figure 1.6 is a reproduction of a scene projected in color by means of a motion-picture projector. The new glass is employed as a heat screen to protect the film. The left half of the scene was projected through the

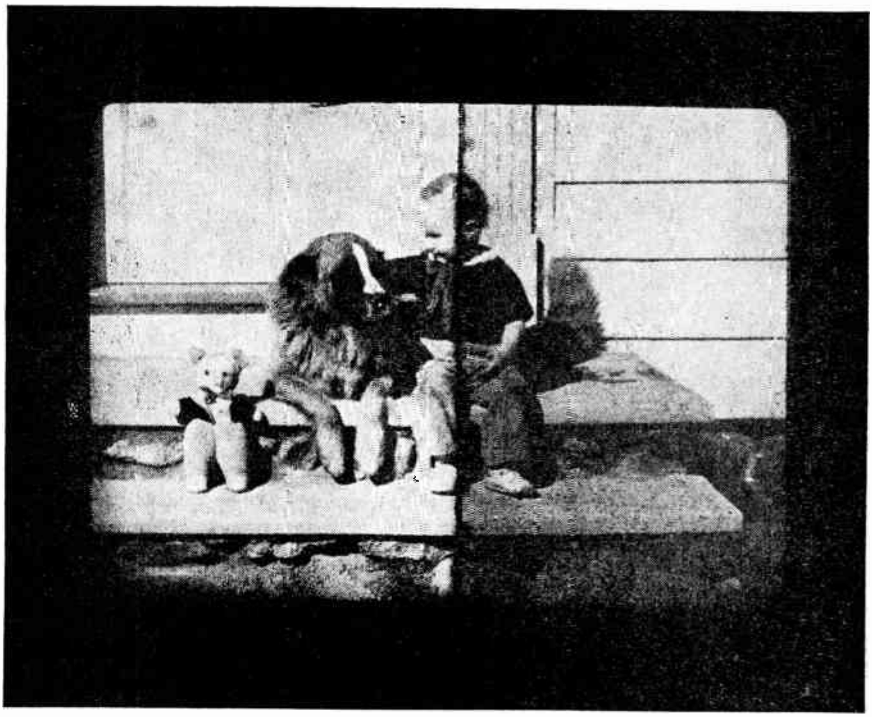


FIG. 1.6 (Courtesy of American Optical Company.)

new heat-absorbing glass, the right half through a less efficient glass. This demonstrates the improved color transmission characteristic of the new glass.

Studio Lighting Fixtures. The lighting fixtures for stage lighting in the television studio are many and varied. Because of the type of operations peculiar to the television studio, it is essential that all fixtures be light in weight yet durable in construction. Each fixture must be capable of operation by a single stage technician or electrician and must also be capable of quick and safe adjustment and movement.

Since the type 1850–A Iconoscope tube is rapidly being replaced with the type 2P23 Image Orthicon and type 5655 Studio Orthicon, it is useful to discuss only lighting-fixture requirements for studios equipped with the latter two tubes. As explained before, a combination of cold mercury-vapor and fluorescent lighting is recommended, with a minimum of incandescent lighting being employed for highlighting and special-effects lighting.

A recent industry survey indicates the need of a fixture to accommodate the 40-w. T–12 fluorescent or Slimline light source. This fixture must have a specially designed reflector to most efficiently "put the light where it is needed." A two-tube unit or fixture is most desirable for use as a portable light source. On permanently installed fixtures (overhead lighting, and the like), a three-tube unit is more desirable in order to eliminate any stroboscopic effect. The ballasts for these lamps must be remote from the stage. The fixture should be equipped with a universal-joint mount in order to provide quick directional control in both a horizontal or a vertical plane. Such a unit should be so designed as to be capable of suspension from an iron pipe grid above the stage or of being suitably mounted on a portable vertical floor stand.

Incandescent floodlighting can be obtained through use of a fixture making use of a 2,000-w. general-service motion-picture floor lamp or a special Kliegl 2,500-w. studio flood lamp. Such fixtures should be equipped with a heat screen, such as that developed by the American Optical Company previously described. A reflector of maximum efficiency is highly desirable in such a fixture so as to obtain necessary lighting effects together with even distribution of the light. A matte-finish Alzak aluminum reflector of ellipsoidal design will provide all the desirable features. The fixture must also be readily interchangeable for suspension from an overhead iron pipe grid or for mounting on a rubber-tired studio-type floor stand. It must be adjustable to the following elevations:

Low	30 in. to 4 ft. (for footlighting)
Medium	5 ft. to 8 ft. (for floodlighting)
High	6 ft. to 10 ft. (overhead angular lighting)

Strip incandescent floodlighting suspended overhead has also been used in connection with studio stage lighting where type 2P23 or 5655 Orthicon tubes have been employed in television cameras. A strip fixture to accommodate six type R–40 300-w. photoflood lamps is made approximately 4 ft. long and the lamps wired in two circuits with No. 10 asbestos wire. Male load feeders are used at one end of the fixture and female load fixtures at the other end. The reflector associated with the fixture is finished in flat white, and the unit is supported by a universal joint so that it may be controlled as to vertical or horizontal movement. In this manner the maximum reflected light may be directed toward any desired section of the stage to be illuminated.

Many television studios are equipped with 1,000-w. spotlights to provide either spot lighting or high lighting where either one is desired for artistic effect. Such spotlights, of necessity, must be completely adjustable, well ventilated, durable, sturdy, easily controlled, and equipped with a Fresnel lens. They should be provided either for mounting on rubber-tired floor stands or for suspension from an iron-pipe grid work or light bridge above the stage.

Another spotlight, which has been extensively used, incorporates a 2,000-w. lamp and makes use of much the same features as described above. It is mounted on a studio-type roller-base stand and is adjustable to an elevation of 10 ft. This unit may be quickly removed from the floor stand for suspension from an overhead iron-pipe grid.

Incandescent spotlights in the television studio should provide a beam spread through suitable mechanical adjustment of 5 to 45 deg. for maximum utility. The focusing control must be external to the lamp housing, and a polished Alzak aluminum reflector has been found most efficient. A studio-type safety switch is usually mounted on the lamp hood itself, and 25 ft. of rubber cable has been found to be a convenient length to use. The rubber cable is usually provided with Kliegl No. 056 stage-type pin connectors located on pigtails situated 18 in. from the safety switch on the hood. This arrangement permits rapid removal of the complete spotlight from the floor stand for overhead suspension. Thus, the 25 ft. cable is an accessory to the spotlight assembly.

Television studios almost universally make use of Kliegl stage-type pin connectors (wall and portable type) and Kliegl plugs. The Kliegl type 301½ has proved to be the most popular plug. It is of the half-plug variety, occupies a minimum of space, and is rated at 30 amp. Almost all connection of plugs in the studio is effected with the full lamp load connected because of the minimum time element involved in connecting and disconnecting fixtures when in production.

Almost all portable floor-lighting equipment is mounted on rubber-tired wheels for greater utility, and no protection is offered the lighting technician or stage electrician in the event of a short circuit in the fixture. However, there will shortly be made available a plug with a ground leg to eliminate this hazard. The new plug will provide a safety catch at each pin connector of the plug, with the result that the plug will hold under normal strain on the cable but will disengage if the cables should become fouled on the studio floor, and more than normal strain thereby be applied to the plug. Because of the hazard of fouled cables on the studio floor, twist-lock plugs are not to be depended upon, as excessive strain on the cable leads will result in their being pulled out of the plug terminals.

1.3 Light Measurement. It is essential that the amount of light energy falling upon the subject before the television camera be definitely known. Therefore, we must have some means for measuring the light energy. Light measurement is just as important to the television engineer as are the electrical measurements with which he is very much concerned. It enables him to determine precisely whether enough light is being employed, whether it is evenly distributed over the subject, and whether it is being used to the best advantage.

Originally, the basic unit of light measurement was a candle of specified construction, having definite dimensions universally agreed upon. Improvements in light measurement and the development of more stable and dependable sources of light have resulted in a lamp of specified dimensions and characteristics being adopted as a standard. This standard lamp employs amyl acetate as fuel. A carefully calibrated tungsten-filament lamp is employed in the practical measurement of light, it being calibrated against the standard lamp fueled with amyl acetate. The light meter, the practical device used in the television studio for light measurement, is usually calibrated in units termed "foot-candles."

The unit "foot-candle" describes the intensity of light on a white surface one foot square illuminated by a standard candle at a distance of one foot from the surface. Under this condition, the amount of light that falls upon each square foot of the surface per second is termed a "lumen." These are the two basic units for light measurement. The foot-candle, as a unit of measurement for comparing intensity of illumination, is very small indeed. In bright sunlight at the beach it is common to measure at least 500 c. per sq. ft., and at higher altitudes—particularly in mountainous areas, where the air is free of moisture and dust—it is possible to measure 800 c. per sq. ft. In the early afternoon on a clear September day, the intensity of illumination may vary from 70 to 100 c. per sq. ft.

It should be noted that the intensity of illumination is subject to considerable variation, and this is particularly true of outdoor illumination, where man has no control over the quality or quantity of light available at the source. The brightness of light outdoors is a function of weather conditions as well as of the hour of the day and the season of the year. This proved to be a considerable disadvantage in televising outdoor scenes with early available types of camera pickup tubes, since they lacked sensitivity. However, the advent of the highly sensitive R.C.A. Image Orthicon has made possible the televising of outdoor scenes even under conditions of quite poor general illumination. This type of pickup tube for the camera is under continuous development by R.C.A., and even more improved types of Image Orthicon tubes are certain to evolve.

If a certain amount of light of given intensity is spread over an increased area, the intensity of illumination will decrease in proportion to the area. Conversely, if the same light is concentrated over a smaller surface, the light intensity will be greater. In the television camera, the photosensitized surface of the target in the pickup tube is of constant area. It is therefore necessary to vary the amount of light falling upon the target by either increasing or decreasing the intensity of the light source, by varying the angle through which the source light must fall upon the subject, or by controlling the amount of light admitted through the lens system of the television camera. To some extent the amount of reflected light can be controlled by using flats or stage backdrops which provide a greater or lesser amount of light reflection.

With a constant source of light, the intensity of light falling upon a surface varies inversely as the square of the distance between the surface and the light source. Therefore, if the distance between the source of light and the surface upon which it falls is increased from 1 to 2 ft., the light will be only one fourth as intense. This law is important when considering the placement of semifixed television studio lighting, particularly overhead lighting. In one instance twenty 900-w. banks of PAR–38 lamps, mounted on a grid structure suspended just below a 15-ft. ceiling, provided adequate studio illumination for cameras employing Iconoscope pickup tubes. When these same light banks were employed at another studio location, with the banks suspended from a grid elevated about 25 ft. above the floor, the available light was far from satisfactory. It was necessary to increase the capacity per bank from 900 to 1,800 w. and to employ reflector spots instead of flood lamps. This arrangement, with additional border lighting, provided adequate illumination. However, the highly concentrated infrared radiation from the incandescent spots made life for the actors below practically unendurable. As a matter of fact, they were unable to work under the hot lights except for short intervals, and even then only with extreme discomfort, which seriously hampered production.

The illumination at a surface upon which light is falling may be determined by dividing the candlepower at the source by the square of the distance (in feet) to that surface. For instance, suppose it is desired to illuminate a test pattern 1.5 by 2 ft. (3 sq. ft.) at a distance of 3 ft. with a 1,000-c. source.

$$\text{Intensity of illumination} = \frac{1{,}000}{3^2} = 111.1 \text{ ft.-c.}$$

In the calculation above, it is assumed that the light arrives at the surface of the test pattern from a direction normal to the plane of the surface of the illuminated area. This, of course, would not be true in the case of the test pattern, since the television camera would be placed directly before the test pattern, the test pattern supported on an easel, and the light source placed to one side of the camera. The method of calculation above would hold true in the case of a motion picture projected directly upon a viewing screen.

The inverse square law must be modified when the light falls at an angle upon the subject, and this modified law is termed the "cosine law." This law dictates that the illumination received by an element of surface varies as the cosine of the angle of incidence. The angle of incidence is equivalent to the angle of reflection. The face of a subject being scanned by the television camera is usually in the vertical plane. In most instances the studio lights have been placed predominantly overhead and have been suspended from a metal grid structure. Each fixture is made adjustable; i.e., each bank of lamps may be so adjusted as to project light at any desired angle in order to make optimum use of the available light for any particular scene. Also, upright vertical supports on floor stands, equipped with rubber-tired wheels, have been used to support banks of lights, one bank above the other. These may be moved in and out across the studio floor for close-in lighting. In any case, the light is seen to fall at an angle upon the subject. This is almost universally true in the television studio of today. The inverse square law and the cosine law are both expressed by the following equation:

$$\text{Intensity of illumination in foot-candles} = \frac{I \cos A}{d^2}$$

The intensity of illumination is expressed in foot-candles. I is employed to express the brightness of the light source in candlepower; A is the angle of incidence of light falling upon the illuminated area; d describes the distance in feet between the light source and the area upon which the light falls.

To illustrate the application of the cosine law, we may again consider the problem of illuminating the test pattern referred to above. We shall assume that the light falls upon the surface of the test pattern at an angle of 45 deg. cos 45 deg. = 0.707. Thus, the intensity of illumination at the surface of the test pattern is equivalent to

$$\frac{I \cos A}{3^2} = \frac{1{,}000 \times 0.707}{9} = 78.55 \text{ ft.-c.}$$

Thus, only about 70 per cent as much light is received at the surface of the test pattern when the angle of incidence is 45 deg. as compared with the illumination should the light arrive from a direction normal to the plane of the test pattern surface.

To convert the foot-candles arriving at the test pattern to lumens, it is necessary to determine the product of the area of the test pattern in square feet and the intensity of illumination in foot-candles. Therefore, $3 \times 111.1 = 333.3$ lm. Therefore, the light per second falling upon the surface of the test pattern in this particular case is 333.3 lm.

It is important that the television engineer should not confuse the terms "intensity of illumination" and "brightness." These terms do not describe the same thing. If we project 300 ft.-c. of light upon a test pattern card in the studio, these units describe the "intensity of illumination," and the light will be more or less uniformly distributed over the entire area of the test pattern. However, this does not mean or imply that "brightness" over each unit area of the surface will be strictly uniform. The test pattern is usually printed upon a white card, the characters and numerals being imprinted with black India ink. Thus, the inked portions will absorb some of the light, while the white background will reflect considerable light. There may be areas printed in gray.

"Brightness" is measured by the flux emitted per unit of emissive area as projected on a plane normal to line of sight. The unit of brightness is termed the "lambert" and refers to a perfectly diffusing surface which emits 1 lm. per sq. cm. of projected surface. Another way of expressing brightness is in units of candles per square centimeter, though the term is not yet in general use among television engineers. The units of conversion are as follows:

$$\text{Candles per square centimeter} = \frac{\text{lamberts}}{\pi}$$

$$N \text{ lamberts} = N \text{ lumens per square centimeter}$$

$$\text{Lambert} = \pi \text{ candles per square centimeter}$$

Because we do not use the metric system to any great extent in the United States for purposes of practical measurement, the term "foot-lambert" is commonly employed to describe brightness measurement. Thus,

$$\text{Foot-lambert} = \frac{1}{\pi} \text{ candles per square foot}$$

From the above discussion it should be clear that the intensity of illumination is the amount of light striking a surface area and is expressed in units of foot-candles. The quantity of light flux leaving the surface of the source of illumination or reflected from the subject being illuminated is expressed in units of candles per square foot. Also, it will be seen that brightness is not the same as intensity of illumination.

The television engineer is concerned not only with the laws of radiation as applied to light energy but with the wavelength of light. Actually, as we have said, light energy occupies a small portion of the total frequency spectrum. Visible light extends from violet through red, and the wavelength of light is expressed in Angstrom units. In referring to the wavelength of light, the Angstrom unit is more convenient than the meter which is common in radio communication. Both radio waves and light waves travel through space at like velocity, i.e., 3×10^8 m. per sec. Visible light has wavelengths about 0.000038 to 0.00008 cm. depending upon color. The Angstrom unit is equivalent to one hundred-millionth (10^{-8}) centimeter and is a more convenient expression than the centimeter, since the latter is too large for practical application. The visible portion of the light spectrum extends from 4,000 to about 8,000 A. This range refers to the light visible to the human eye, though some television pickup tubes have spectral response exceeding the wavelengths included in the visible spectrum.

Of less importance in expressing the wavelength of light is the millimicron. It is equivalent to a billionth of a meter. One millimicron is equal to 10 Angstrom units. Thus, we may say that the visible wavelength of light extends from 400 to 800 millimicrons ($m\mu$.).

Of all the units of light measurement discussed above, only a few are in practical use insofar as television engineering is concerned. These are the foot-candle, the lambert, the lumen, and the Angstrom unit. The student or engineer must be able to use these in the everyday practical problems encountered in the study or application of television. Table 2 indicates the relationship of wavelength to frequency as related to light.

1.4 Lenses. A study of the principles of television transmission and reception must be undertaken step by step. We have first obtained some knowledge of that form of energy recognized as light, for it is the subject that we must acquaint ourselves with before we undertake the more intricate electronic principles of the system. We must next discover how the reflected light from the television-studio stage enters the camera to be imaged upon the photosensitized target or mosaic of the camera's electron pickup tube. The medium by which this reflected light enters the camera is termed the "camera lens." The camera lens, therefore, is the first link in the chain of equipment which ultimately results in the transmission and reproduction of the televised image. A knowledge of lens construction and its operation and maintenance is of the greatest importance to anyone concerned with the art. Any optical error occurring at the lens cannot be later compensated for electronically.

TABLE 2

PORTION OF THE ELECTROMAGNETIC SPECTRUM DEVOTED TO LIGHT TRANSMISSION

Region	Wavelength limits, cm.		Frequency limits, kmc.		Remarks
	Max.	Min.	Min.	Max.	
Infrared	0.1	0.00008	300	375,000	Heat and black light
Light (visible)	0.00008	0.000038	375,000	790,000	Red, through orange, yellow, green, blue, and violet
Ultraviolet	0.000038	0.0000012	790,000	22,500,000	Chemical and invisible

Light is most commonly measured in Angstrom units. The equivalents of the Angstrom unit in more familiar units of measurement are as follows:

1.0 Angstrom = 0.1 millimicron (mμ.)
= 0.0001 micron (μ)
= 0.0000001 millimeter (mm.)
= 0.00000001 centimeter (cm.)

Fundamentally, a lens can be described as a transparent body which is employed in creating a true image of an object by the principle of refraction. The use to which the lens is put determines its optical design and construction. It may consist of a single element or a number of simple refractive elements all united to form a common assembly. To be properly described as a lens, the transparent body must possess opposite sides, which are not parallel, for all lenses are thicker either at the periphery or at the center, with the possible exception of certain lenses employed in some television projection-type receivers. Some degree of curvature is present at one or both sides of each element in most lenses.

Hardly ever is a simple single element employed in the construction of any camera lens. Actually, two or more simple lenses are used in combination, their individual characteristics being combined to obtain the desired characteristics. Figure 1.7 illustrates lens elements that are typical of those used to construct the conventional lens system. These lens elements are classified according to their effect upon a ray or beam of light and may be divided into two principal groups. In one group are included lenses of the diverging type, and in the other group, lenses of the converging type.

A converging lens, as the term implies, represents an element that causes the light ray admitted to converge at a point. It will be noted that a converging (or convex) lens is thicker at the center than at the edges. It may always be identified by its shape.

Those lenses which result in the diverging, or spreading, of the light rays passing through are termed "negative lenses." The negative, or diverging, lens is always thick about the periphery and thin through the center. All lenses are made as nearly transparent as possible, and the surfaces are very highly polished. This results in their admitting and transmitting light most effectively, i.e., with little attenuation. The lens

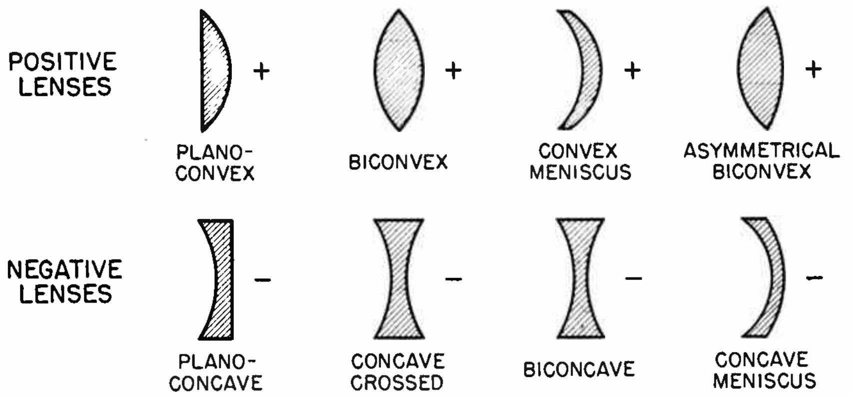


FIG. 1.7 The eight typical lens elements used in various combinations to construct the television camera lens.

surfaces are made spherical or semispherical in shape, and all lenses are classified as to shape and form. This is clearly illustrated in Fig. 1.7.

The complete lens for the television camera is made up of a number of elements, one element being employed to correct for errors and distortion of another element. The result is usually a rather complex

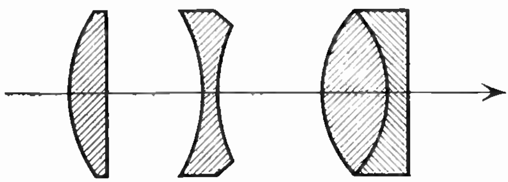


FIG. 1.8 The camera lens for one type of Eastman Ektar (f/3.5, 10.7 cm.). The television camera lens is constructed of a number of lens elements.

optical structure. Lenses for the television camera must, of necessity, be of the highest quality.

There are three general types of positive convergent lenses. These are termed the "plano-convex" lens; the "biconvex," or "double-convex," lens; and the "unsymmetrical biconvex" lens. A *plano-convex* lens possesses both a spherical convex face and a flat face. The *biconvex*, or *double-convex*, lens is distinguished by its two spherical convex faces. The *unsymmetrical biconvex* lens may be recognized by its two spherical convex faces, which possess curves of dissimilar radii. All three types are positive. It will be noted, as mentioned before (page 27), that lenses of this type are thicker through the center of the transparent body than at the periphery, a characteristic that results in uneven light distribution and dissimilar angles of refraction at different points on the lens. For this reason, any image formed by one of these lenses will be distorted. Other lenses must be used in combination to obtain an undistorted image of the object, although the positive convergent lens will in itself form a real image of any object.

Fig. 1.9 A 20-in. (508-mm.) f/5.6 Telephoto lens employed on the lens turret of a Du Mont Mark II Image Orthicon television field camera. (Courtesy of Allen B. Du Mont Labs., Inc.)

The second major group of lenses are termed "negative divergent." Such lenses diverge or spread the light rays entering the transparent body of the lens and result in a virtual image—not a real image. The effective focal length of either a plano-concave or a biconcave lens has been defined as the virtual focal length measured to the virtual focal point. The virtual image is an imaginary image, and the virtual focal point locates the plane in which it is assumed to exist. It will be noted that a diverging (negative) or concave lens is thinner through the center than at its outer edge. Negative lenses possess no actual focal point, and this imaginary focal point—termed the "virtual focus"—is used for purposes of measurement. The virtual focal point is determined by projecting the diverging rays back where they finally intersect the optical axis. The point establishes the plane of the virtual image.

Included among negative divergent lenses are plano-concave, biconcave, and unsymmetrical biconcave lenses.

The plano-concave lens is one in which one side is found to be concave, the other surface flat. The biconcave lens can always be positively identified by its two spherical concave surfaces. The unsymmetrical biconcave lens is recognized by its two spherical concave faces with curves of different radii.

As opposed to the lenses in the positive convergent category, negative divergent lenses are always thicker at the outer extremities than at the center. The negative lens always possesses at least one concave side. This concave side is responsible for a ray of light entering to diverge. Thus, the light is made to spread out instead of converging, or bunching, to a point, as is true of the positive lens. Since the negative divergent lens is the opposite of a convex lens, it is employed to correct the action of a positive lens, thus correcting for distortion and aberration (faults). By suitable and appropriate combinations of spherical and plane surfaces, any of six different kinds of lens may be constructed.

If the two surfaces of a lens are made spherical, then the centers of the complementary spheres are termed the "centers of curvature." An axis penetrating the two centers is called the "principal axis of the lens." The principal axis of a plano-convex or plano-concave lens is the perpendicular from the exact center of the spherical surface to the plane face. The center of curvature is not to be confused with the optical center of the lens. Measurement of the focal length and other distances from the lens are made from the exact optical center, assuming that the center is the point of greatest light concentration. The optical center of a biconvex lens is taken as the point half the distance between the two surfaces and along the optical axis. The focal length L is measured from O to the focal point F. Point O is found by drawing two parallel lines from the centers of curvature C until they intersect the surfaces at MM and connecting these intersections by the line MM. The intersection of this line with the principal axis at O yields the optical center.

The optical center of a lens of the plano-convex type lies at the exact intersection of the convex surface with the optical center line, and measurements L to the focal point F are made from this point as indicated in Fig. 1.10.

In the case of an unsymmetrical lens, the center is determined in the same manner as is the center for the biconvex type. The centers of curvature C are used, the diagonal MM being drawn so that it intersects the optical center at O. It is seen that the optical center always lies near the surface having the greatest curve in the case of a positive lens, resting on the curve itself in the instance of the plano-convex type.

Some lenses have one concave and one convex surface. If the concavity is predominant, the lens is described as a "concave" or "negative meniscus." If the convexity is such that it appears predominant, then the lens is described as a "convex" or "positive meniscus." The word

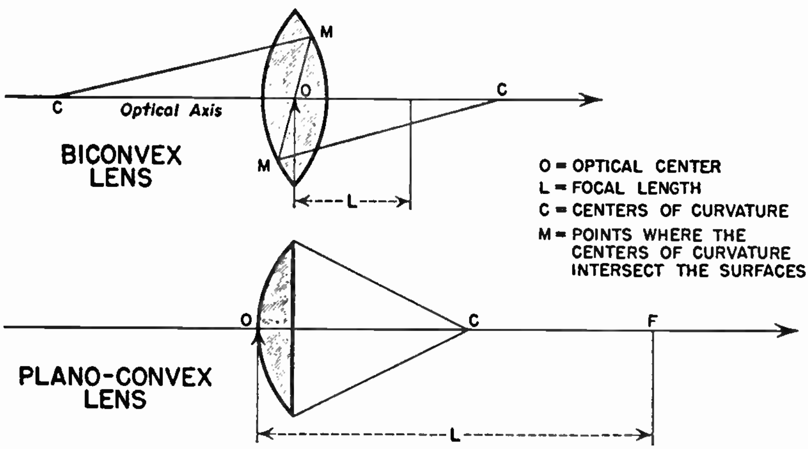


FIG. 1.10

"meniscus" means "crescent-shaped." The angle of field of the lens is that angle formed at the lens by the rays of a beam of light from the extreme boundaries of the field (or stage in the television studio) being covered by the lens.

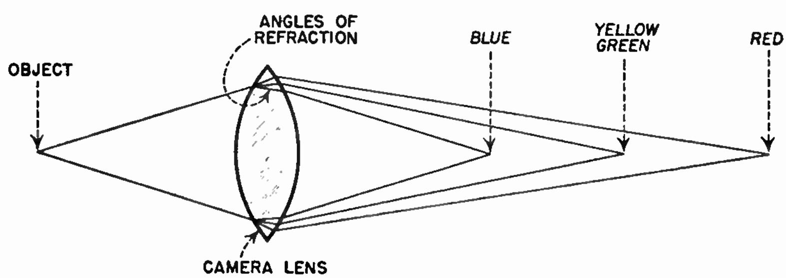


FIG. 1.11 Angles of refraction of different colors of light. Since each color of light has a different wavelength, each results in a different angle of refraction when passing through an uncorrected camera lens. The result is that not all colors focus in the same plane to form a sharp image.

Because each color in the light spectrum possesses a different wavelength, each will demonstrate a different angle of refraction in passing through the camera lens. The result is that all the colors do not focus on an identical plane to form a sharp image (see Fig. 1.11). Owing to inequalities of refraction of the component light rays, the blue rays will focus in front of the less actinic but more conspicuous visible rays. Lens systems may be corrected for color. Lenses in which chromatic aberration has been eliminated (color-corrected) are termed "achromatic lenses."

To accomplish such correction, positive and negative lens elements having different refraction but the same dispersion are combined. The result is that separation of the component wavelengths of light is prevented, and the entire bundle of rays of various wavelength is bent as a unit. Usually, the correction is made for the two principal spectral

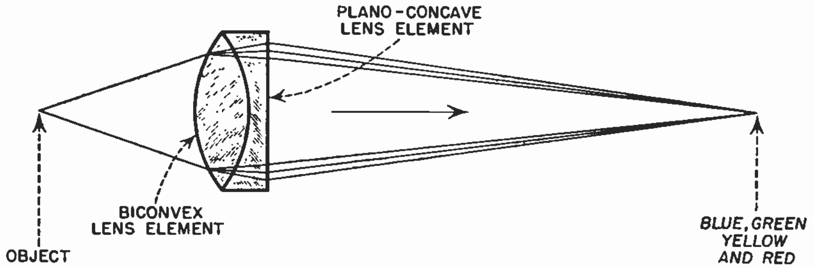


FIG. 1.12 Overcoming chromatic aberration by means of a doublet, in which the glass of the convex lens element is of a dissimilar refractive index from that of the concave lens element. In color correction all the rays of different wavelength (color) are brought into focus on an identical focal plane.

bands. Lenses corrected for three colors are known as "apochromatic lenses." When light rays of unequal wavelength focus at varying distances back of an uncorrected lens, the effect is termed "chromatic aberration."

Chromatic aberration is quite often overcome by a doublet, or system of doublets, the glass of the concave and convex elements having a different refractive index. A common type of doublet is made up of two elements cemented together, combining a biconvex and a biconcave lens. This results in the rays formed by the different wavelengths of color in the object being focused on the same focal plane. The result is a sharply defined and correct image. One type of doublet is illustrated in Fig. 1.12.

The depth of field is the distance between the nearest object to the lens in focus and the farthest object from the lens in focus when the lens is focused on a given point. The depth of field will vary with the distance of the object in critically sharp focus, the focal length of the lens, and the aperture used. (The aperture is the diameter of the lens or the width of the iris opening.) (See Fig. 1.13.)

It is a relatively simple matter to calculate the depth of field for a given lens by means of the following equations:

$$N = \frac{H \times D}{H + D} \quad \text{and} \quad F = \frac{H \times D}{H - D}$$

where D = distance to the object focused on
H = hyperfocal distance of the lens
N = near depth plane
F = far depth plane

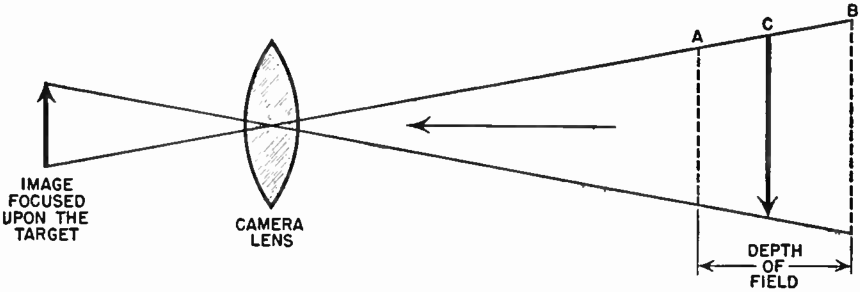


FIG. 1.13 Depth of field. The depth of field is the distance between the nearest object to the lens, focus A, and the most distant object from the lens, focus B, when the camera lens is focused on point C.

To determine the hyperfocal distance of any lens, or the nearest point at which objects are in approximately sharp focus with the lens set at infinity, the following equation is employed:

$$H = \frac{F^2 \times C}{f \times 12}$$

where F = focal length of the lens in inches
H = hyperfocal distance in feet
f = diaphragm opening or f number
C = reciprocal of the diameter of the circle of confusion in inches

Some explanation of the expression "circle of confusion" should be given. When a lens is focused on an object at a predetermined distance, the light rays from various other distances are not all brought into focus precisely on the focal plane, the focal plane being the plane upon which the image of the object is formed. (The focal plane may be considered as existing at the mosaic of an Iconoscope television camera pickup tube.) Some of the light rays are brought into focus in the plane and some ahead of the plane, and some would fall behind the plane were it translucent. All the rays that would be brought into focus in front of or behind the focal plane do not result in a point of light, but show up as a small circle. This is termed the "circle of confusion." It adversely affects the definition of the image, reducing sharpness of focus.

Depth of focus (see Fig. 1.14) is the distance between the nearest image to the lens that is in focus and the farthest image when the lens is focused on a given point. The student must not confuse depth of field with depth of focus. Depth of field describes an area in front of and behind the main object plane, whereas depth of focus describes the small range of positions that the focal or image plane may occupy without having any deleterious effect upon the sharpness of the image.

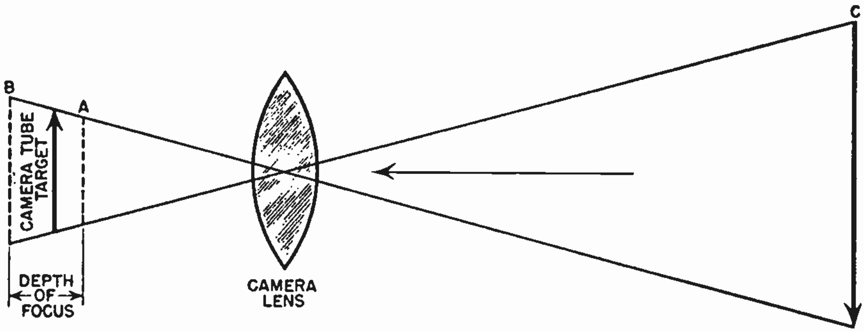


FIG. 1.14 Depth of focus. The depth of focus is the distance between the nearest image to the lens, focus *A*, and the most distant image from the lens, focus *B*, when the camera lens is focused on a given point *C*.

The *focal* length of a lens is indicated by *F* and for all practical purposes represents the distance separating the optical center of the lens and the image when the lens is focused on infinity. As a practical consideration, all objects at distances greater than 100 ft. are said to be at infinity. The greater the curvature of the lens is made, the shorter the focal length that obtains. This is because the refractive power is greater, which, with a specific medium, is a function of the curvature of the surface.

The *index of refraction*, or the refraction index, of a given transparent material, such as a lens, is a measure of the bending that a ray of light will experience in going from air into this medium. Quantitatively, it is defined as the ratio of the velocity of light in air to the velocity of light in a given transparent material. The index of refraction of air is taken as unity (see Fig. 1.15).

As noted above, an object located 100 ft. or more from the lens is said to be at infinity. Theoretically, it is impossible to focus upon an object whose distance from the lens is infinite. For any lens, approximate infinity may be considered as the focal length squared multiplied by the reciprocal of the desired circle of confusion.

When the lens of the camera is appropriately focused on an object at a definitely predetermined distance, the light rays arriving from objects at various other distances are not brought to focus on the focal plane. It will be found that some are focused on the plane, some behind the plane, and some ahead of the plane. Each ray of light that is brought to focus in front of or behind the focal plane is not a *point* of light. Instead, each such ray of light shows up as a tiny *circle*, termed the "circle of confusion." The circle of confusion reduces the sharpness of the image. A

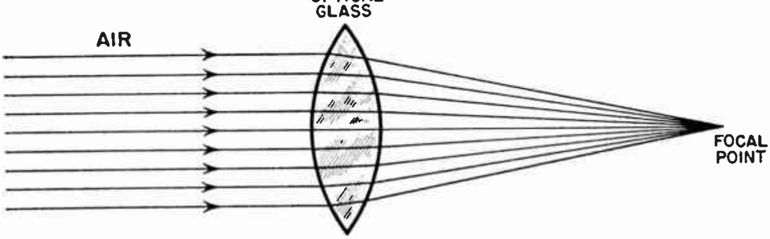


FIG. 1.15 Diagram of the way in which light rays are bent or refracted in passing through a medium of greater density than the density of air.

tiny circle will appear as a point to the average eye if smaller than $\frac{1}{100}$ in. in diameter. It is desirable, therefore, that the circle of confusion be made smaller than $\frac{1}{100}$ in. in diameter if a sharp image is to be obtained.

The term "image" defines the optical reproduction at the pickup tube mosaic or target of the camera of the object upon which the television camera lens is focused. The image is always inverted with respect to the object (see Fig. 1.16).

The *iris* is any stop or diaphragm that serves to limit the size of the beam of light passing through a lens system from a given point. The iris of the camera lens may be compared to the iris of the human eye. The aperture, stop, iris, or diaphragm of the lens is a very simple mechanical device, its location with respect to the lens elements depending upon the type or variety of lens employed. In most cases, it is placed in front of the optical lens elements. In other cases it is placed within or behind the lens mount. In a simple meniscus lens it is always placed in front of the element. In a symmetrical doublet, it is placed within the mounting and between the front and rear elements of the lens.

The diaphragms found in lens systems seen in television cameras are of the adjustable iris type. The iris type of diaphragm allows the cameraman to select a large number of openings by means of a simple adjustment and permits precise regulation of the size or diameter of the bundle of light rays passing through the lens system.

The diaphragm actually serves as a light-volume control and serves to reduce or remove residual aberration (aberrations or faults existing in the lens). It improves the depth of field, making it possible to control the zone of sharpness in near and distant objects in a scene. Thus, in the television studio, the diaphragm may be stopped down if sufficient light is available to result in an acceptable picture. Stopping the lens down is employed particularly when stages of great depth are being televised.

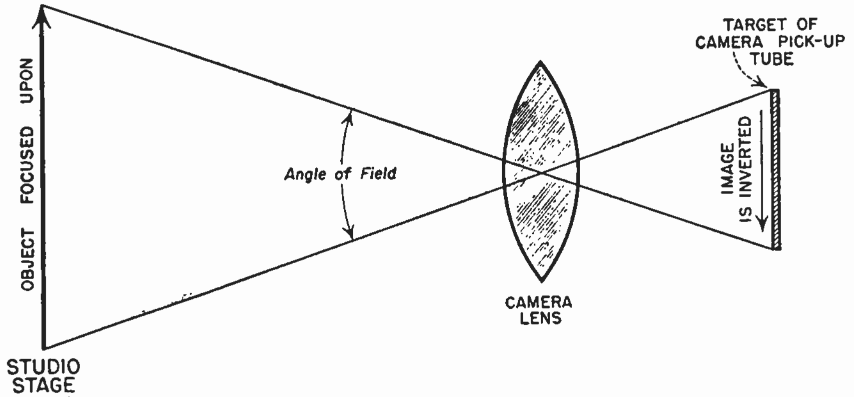


Fig. 1.16 Diagram of the way in which light reflected from the studio stage is imaged upon the target of the pickup tube in the television camera. The angle of field is that angle formed at the camera lens by the beams of light from the outer boundaries of the studio stage.

Lenses of two principal types are employed in television. One type, known as a "projection lens," is employed at the motion-picture projector associated with the film-scanning apparatus. It projects all the light from the lamp source in the projector into a highly concentrated beam. The second type is that employed at the studio or field television camera. It projects an illuminated object upon a distant surface; i.e., the reflected light from the studio stage is imaged upon the mosaic or target of the electron pickup tube in the television camera. A virtual image of the object therefore results.

A projection lens is sometimes used in certain types of projection television receiver. It is employed to project a large image upon a screen in the home, the image originating at the fluorescent screen of a small-diameter cathode-ray tube. Some manufacturers have demonstrated experimental receivers of this type which develop an image of dimensions 3 by 5 ft. The difficulty with such systems lies in the inability to obtain enough light at the source, i.e., at the screen of the small-diameter cathode-ray tube, the source light resulting from electron bombardment of the chemical phosphor with which the screen is coated.

A knowledge of the optical center of the lens is important in the measurement of focal length and other distances from the lens. It is assumed that the *optical center* is the point of light concentration, although this is not strictly true. Nevertheless, it establishes a definite point from which comparative measurements can be taken. In the instance of the plano-convex lens, the optical center lies at the intersection of the convex surface with the center line. The optical center of a biconvex lens is also the geometrical center and is one half the distance between the two surfaces and along the optical axis (see Fig. 1.17).

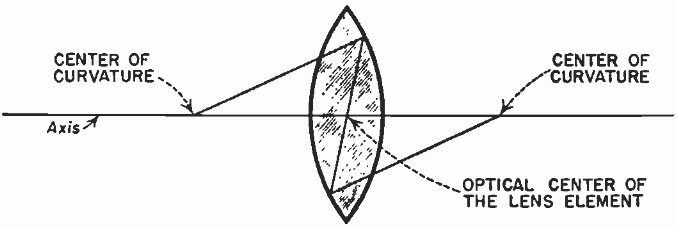


FIG. 1.17 Optical center. Parallel lines are drawn through the centers of curvature of the lens to meet the lens surfaces. The line joining these intersections crosses the lens axis at a point termed the "optical center."

Refraction has been defined as the bending of a light ray resulting from its passage through a transparent medium such as glass. No refraction occurs at the center of the lens because the beam of light does not strike the curvature of the lens at an angle at this point, but does at all other points.

Spherical aberration in a lens results in a general blur of the image. It is due to the curvature of the glass in the case of a biconvex lens element. The rays of light being transmitted through the center of the lens are brought to focus farther off than the rays penetrating through the edge because of the lesser angle at which they strike the lens surface at the center. The result is distortion of the image. Spherical aberration, therefore, is due to a difference in focus that occurs between the edge and center light rays. The convex lens is so constructed that the marginal rays are brought to shorter focus than are the axial rays, resulting in spherical aberration. The opposite condition obtains in the concave lens and is termed "spherical overcorrection." The defect may be compensated for in lens production by so combining positive and negative lenses as to neutralize the effect. Such a corrected lens is termed an Aplanat.

Another type of distortion that occurs in lenses is known as "astigmatism." It is an aberration of the oblique light rays and does not affect the axial light rays in any particular. The distortion appears as small crosses, one of which is out of focus, while the other is sharply in focus.

Lenses corrected for this condition are termed Astigmats. All lenses employed with television cameras must, of necessity, be highly corrected.

1.5 The Television Camera Lens. The most important lens with which the television engineer must work is the television camera lens. A typical lens, as employed with a television field Orthicon camera, is shown in Fig. 1.18. The mechanical gear box, by means of which the iris is adjusted remotely from the turret (upon which the camera lenses are mounted), is also shown.

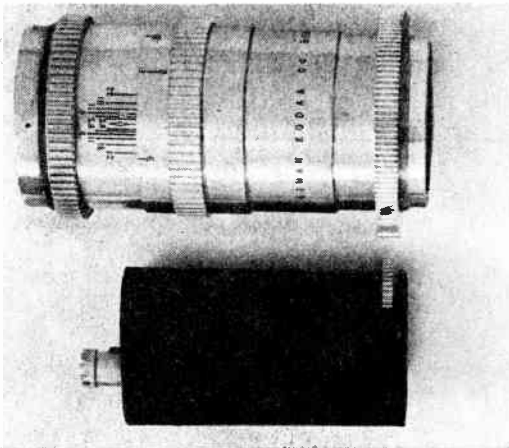


FIG. 1.18 A camera lens associated with the Du Mont Mark II Image Orthicon camera. The gear box permits remote adjustment of the iris by means of a hand control at the rear of the camera. (Courtesy of Allen B. Du Mont Labs., Inc.)

The television camera is similar in many respects to the motion-picture camera. In motion-picture photography, a series of exposures are made on the sensitive surface of a chemically prepared film, and the camera shutter is adjusted to record a definite number of frames per second. The television camera employs an electron tube for image pickup. This device contains a light-sensitive mosaic or target upon which the reflected light from the object is focused through the lens to form an image on the target. The stationary mosaic or target thus replaces the intermittently moving film surface that we find in the motion-picture camera.

The light shutter of the motion-picture camera is replaced by a cathode-ray scanning device in the pickup tube of the television camera in most instances. This portion of the tube is known as the deflection or sweep system, and is coordinated with external electronic sweep circuits, etc. The reflected image of the object before the camera lens appears on the mosaic or target and is wiped off the surface at a given number of times per second, the surface being prepared each time for a new exposure. In this manner, a definite frame frequency is established in television. The frame frequency involved in television may be compared with the frame frequency established in motion-picture photography, though they are not equivalent with respect to the number of frames resulting per second of time.

An image before the television camera lens is sharply brought to focus upon the mosaic or target of the electron pickup tube in the camera, with the result that there is a great increase in the amount of light reaching this photosensitive surface. This is comparable to the increase in the amount of light reaching the film surface in a motion-picture camera owing to the presence of a high-quality lens between the object and the image. The television camera lens, like that of the motion-picture camera, is usually of the double convex type and has been suitably corrected for both chromatic and spherical aberration.

A lens with long focal length has proved more desirable in the past for use in the television studio camera than one with short focus. A short-focus lens of large diameter will collect more reflected light from an object before the lens, but it has no depth of focus and possesses a flat field. A lens with longer focal length will collect less light from the object before the television camera, but will yield considerably greater depth of focus. This feature is important when an Iconoscope pickup tube is used in the camera, and the cameraman is called upon to shoot scenes on stages of considerable physical depth. To obtain greater depth of focus, as much light as is possible under the circumstances is employed, thereby permitting the use of a lens with moderately great focal length. If enough light is available to permit the iris of the lens to be stopped down, a considerable depth of focus can be achieved. This will depend upon the sensitivity of the camera pickup tube, i.e., upon whether the amount of light reaching the target can be reduced and still result in a suitable or acceptable picture.

With the development of more sensitive electron tubes for image pickup, such as the R.C.A. types 2P23 and 5655 Orthicon tubes, less light is required in the studio, and the use of lenses with greater focal length is possible. The R.C.A. type 2P23 Image Orthicon tube possesses a sensitivity about 100 times greater than that demonstrated by the R.C.A. type 1850–A Iconoscope tube.

As can be determined from our general discussion on lenses, the speed of the television camera lens refers to the intensity and amount of light permitted to pass from an object through the lens to form an image upon the mosaic or target of the pickup tube in the camera. The greater the diameter of the lens, the more light is permitted to pass through it. The shorter the focal length, the less distant the lens must be from the image, resulting in greater light intensity. The measure of the relative speed of the television camera lens is indicated by the letter f, which will be found inscribed on the lens. The f will be followed by a digit. The speed f is the ratio of the principal focus of the particular lens to its effective diaphragm opening. The *principal focal point* of a positive lens is defined as the point at which a sharp image is formed when the object is at a great or infinite distance from the lens, so that the incident light rays reflected from the object are parallel.

A lens speed is rated at its widest stop, f/1.4 or f/2.7 indicating very fast lenses, f/4.5 for medium speed, and f/6.8, f/16 or f/22 indicating slow lenses. Lenses of television cameras have a built-in iris, and only a lens with a variable iris can have more than a single stop. The stop (f value) is determined through the following equation:

$$f = \frac{F}{D}$$

where f = stop value
F = focal length
D = diameter of the lens with iris open (I.D.)

An f/2.7 lens may have stops at f/2.7, f/3, f/3.5, f/4.5, f/5.5, f/6.8, f/8, f/11, and f/16. An f/4.5 lens may have stops at f/4.5, f/5.6, f/8, f/11, f/16, f/22, and f/32.

Each diminishing stop reduces the amount or quantity of light energy passing through the lens by one half.

The faster lens, one having large diameter, will prove more difficult to correct for spherical aberration and thus will be an expensive optical unit to acquire. In practice, a television camera lens rarely exceeds f/1.9. An f/4.5 lens with focal length of 8 in. is the most widely used lens in television cameras equipped with Iconoscope pickup tubes. This lens has a diameter of 1.33 in.

The R.C.A. type 1850-A Iconoscope tube is so constructed that the distance between the photosensitized mosaic (upon which the image is formed) and the optical window of the glass bulb (through which the light collected and transmitted by the lens must pass) is approximately 4⅛ in. The separation can be noted by referring to Fig. 4.2. This fixed separation between the mosaic or target and the optical window of the glass bulb imposes a limitation on the minimum focal length of a lens which may be used with this pickup tube. It is seen that 4⅛ in. is the minimum possible focal length permitted. In practice, lenses with focal lengths from 4½ in. up to and including 8 in. are customarily chosen.

The motion-picture camera is focused by moving the lens nearer to or farther from the film within the camera. In a similar manner, the television camera employing an Iconoscope tube may be focused by increasing or decreasing the separation between the lens and the sensitive surface of the mosaic within the pickup tube. In the Iconoscope camera the lens is mounted in a hollow brass tube called a "lens mount," and the entire assembly is moved closer to or away from the fixed position of the Iconoscope by means of a mechanical system controlled by a handle, knob, or lever.

In the Image Orthicon camera, the lens is fixed in position, and the Orthicon tube is moved close to or away from the rear of the lens, the latter being rigidly mounted on a rotatable camera lens turret. The optical principle of focus is the same in either case.

At least two television cameras, and often three, are employed in the typical television studio. One camera is equipped with a close-up lens, i.e., a narrow-angle lens of relatively long focal length. The second camera is equipped with a lens of relatively short focal length. This second wide-angle lens is used to take longer or more distant shots of a complete stage or set. The camera with the close-up lens is used to obtain interesting shots of the faces of performers on the set or of action incidental to the main performance, such as miniature sets, effects, illusions, or other secondary action. The third camera may serve as a general-utility unit, a boom camera, or a stand-by.

It should be pointed out here that the shorter the focal length of the lens, the wider the angle of field that obtains. However, the lens of short focal length, such as is used to obtain a wide angle of field in television, is not strictly a wide-angle lens, although it is erroneously described as such. Fast f/1.9 or f/2.5 lenses with short focal lengths of 5½, 6, or 6¼ in. may have fields of 50 to 70 deg., whereas a strictly wide-angle lens may have a field as great as 75 to 140 deg. The true wide-angle lens has extremely slow speed, the average speed being f/8, f/16, or f/32, notwithstanding the fact that they have short focal lengths. The slow speed of the strictly wide-angle lens prohibits its use in television, particularly where Iconoscope camera tubes are employed.

The selection of lenses for the television field cameras employing type 2P23 Image Orthicon tubes has led to an expensive investment on the part of the television station, since quite a wide variety must be obtained. In choosing a lens for a particular remote pickup, the principal problem is that of determining the distance between the cameras and the subjects or field to be televised. With turret-head Image Orthicon cameras, a complete complement of lenses is instantly available. The camera turret of a Du Mont Mark II Image Orthicon field camera will mount four lenses, any one of which may be instantly brought into use (see Fig. 1.19).

Ordinarily, a 3½- or 5¼-in. lens will cover close-up action 50 to 150 ft. from the cameras. A 6-in. lens will cover double plays on the baseball field, while a 14-, 16-, or 20-in. telephoto lens will adequately provide coverage of individual plays on the football or baseball field and action in the outfield. For boxing or wrestling, a 5¼-in. lens at 50 ft. will effectively cover the ring. In football, a 9-in. telephoto lens will cover a considerable portion of the playing field, and the 20-in. lens will bring in individual play for close-ups. A 6-in. lens will cover practically the entire field of play in football. Most of the telephoto lenses will have

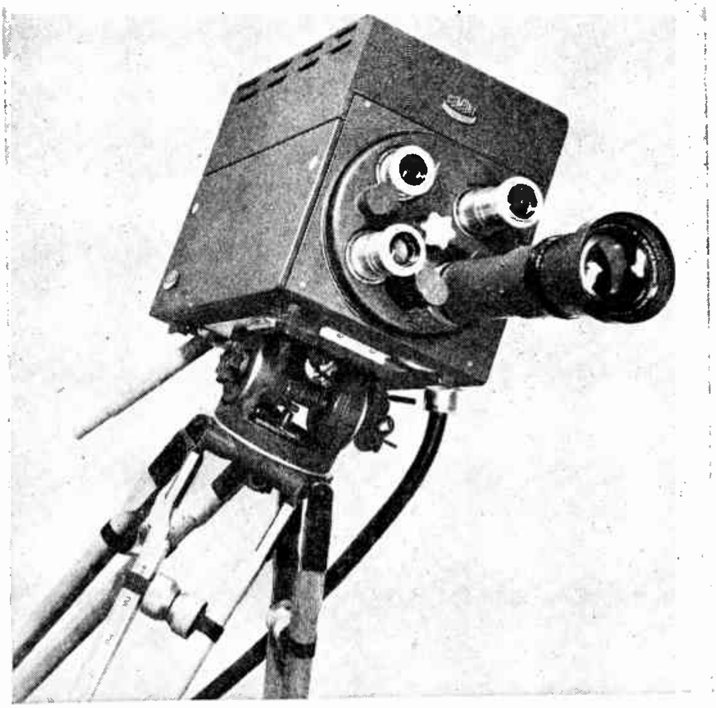


FIG. 1.19 Du Mont Mark II Image Orthicon field camera. Four lenses are mounted on a turret which may be rotated to select any lens desired. (Courtesy of Allen B. Du Mont Labs., Inc.)

speeds ranging from f/4.5 to f/5.6. The 2-, 3½-, 5¼-, and 6-in. lenses should have speeds of not less than f/3.5.

Where the types 2P23 or 5655 Orthicon tubes are used in studio television cameras, at least two lenses are required. One should certainly be a 2-in. lens for wide-angle or wide-field shots where it is desired to include a complete stage or studio set in the resulting picture. The other lens should be a 3½- or 5¼-in. lens, depending upon the physical area of the studio. The latter lens will be used for close-up shots. If a dual Image Orthicon camera chain is employed in the studio, then one camera should be fitted with the 2-in. lens, while the other should be equipped with the

3½- or 5¼-in. lens. With turret-head cameras, i.e., cameras employing turrets which mount several lenses, each camera can be equipped with both a "wide-field" and a "close-up" lens, thus making possible faster action and more interesting camera shots.

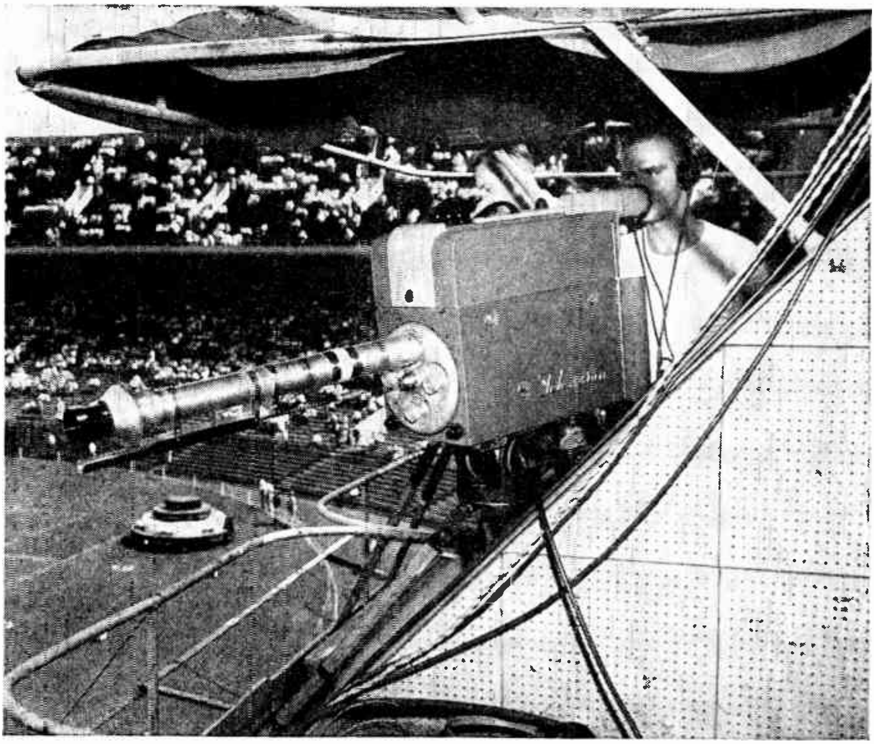


FIG. 1.20 Zoomar lens as mounted on the turret of an R.C.A. Image Orthicon field camera and as first used in televising a football game. (Courtesy of Station WFIL-TV, Philadelphia.)

Recently, Dr. Frank G. Back has introduced a new lens described as the "Zoomar lens." The principle of the lens is variable focus, permitting zoom shots that are maintained approximately in true focus throughout the zoom. One application would be in following a baseball player completely around the bases of the baseball diamond while he makes a home run, the lens holding the player in approximate focus throughout the play. A view of the lens, as mounted on the turret of an R.C.A. Orthicon field camera, is shown in Fig. 1.20. It will be noted that it simply replaces one of the regularly employed lenses on the turret, yet it does the work of three, i.e., close-up, wide angle, and telephoto.

Many zoom lenses have been employed in the motion-picture industry, Bell and Howell having imported a zoom lens from Taylor-Hobson in

England. The main difficulty experienced with all lenses of this type has been their inability to hold objects continuously in *true* focus from close-up to infinity. Another difficulty in applying the zoom lens to television cameras has been due to the weight of the lens and its physical size, though the problem is not without solution. If the lens is mounted directly on the camera turret, as shown in Fig. 1.20, the balance of the

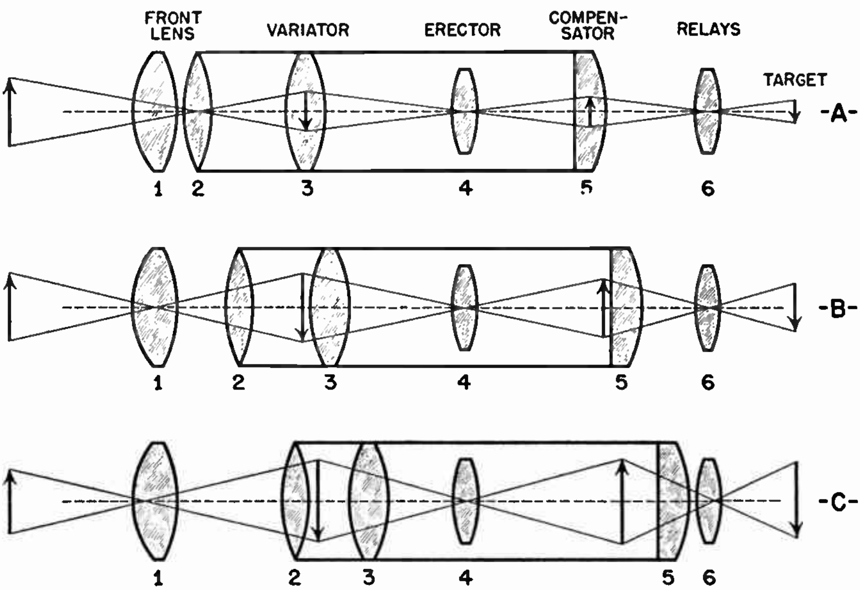


FIG. 1.21 Simplified schematic of the Zoomar lens in three operating positions: wide angle, medium, and telephoto.

camera upon its tripod is disturbed, and a counterweight must be used at the rear of the camera to maintain balance, or the mounting of the camera upon the tripod must be modified to prevent the camera from tilting forward.

The Zoomar lens, as developed by Dr. Frank G. Back, has eliminated many of the mechanical difficulties inherent in earlier lenses of this type, particularly with reference to the manner in which approximately "true" focus is maintained. The Zoomar lens incorporates only one movable barrel, and the compensation for the image movement is accomplished through optical, rather than mechanical, means.

Dr. Back's lens makes use of two groups of lens elements, one stationary and the other group comprising a system of coupled movable elements. The static elements are mechanically connected by means of the lens housing, whereas the coupled movable elements are mounted in a common lens barrel. Therefore, movement of the barrel to any position within the housing results in a stationary image of varying size. This is really a unique approach toward solution of the principal problem.

Figure 1.21 shows an arrangement of the lens in three operating positions. Position *A* indicates the wide-angle position, *B* the medium position, and *C* the telephoto position. It will be noted that lens elements 1, 4, and 6 comprise the stationary group and lens elements 2, 3, and 5 comprise the movable group. The stationary elements (1, 4, and 6) do not alter position within the lens housing. Elements 2, 3, and 5 move along the principal axis of the lens system simultaneously. Operation of the lens in practice yields a picture of variable size though stationary insofar as displacement along the principal lens axis is concerned. Each lens element making up the entire lens system is carefully corrected for chromatic and spherical aberration as well as for astigmatism.

The normal aperture range of the Zoomar lens is f/4.5 to f/30, and telephoto from f/5.6. The range of the lens extends from approximately 5 ft. to infinity. For telephoto use the range is from approximately 15 ft. to infinity. The zoom range is from 3 to 9 in. (normal), or 7 to 18 in. for telephoto. The lens is capable of 600-line resolution in the center of a picture to 400 lines at the corner of the image.

1.6 Care of the Camera Lens. The television engineer or cameraman can obtain good results with the lenses at his disposal if he sees that they are kept scrupulously clean. In time, a lens will accumulate dust and dirt which will blanket the exposed surfaces, thereby reducing its speed. Intervals between cleaning should be as long as practicable, since each cleaning will remove a portion of the lens surface. A new and highly polished lens is practically invisible except for reflections at its surface. It is recommended that lens caps be kept over exposed surfaces of the lens as much of the time as practicable. These lens caps should be kept over both ends of the lens when it is removed from the camera. One lens cap may be used when the lens is fixed in position on the camera turret, but inactive.

High-quality lenses are both expensive and easily damaged, and the use of a lens cap will both protect the lens as well as prevent direct light from reaching the surface of the mosaic or target of the camera pickup tube. Severe burning of the targets of some electron tubes for image pickup will occur if direct (not reflected) light is permitted to strike the target over an extended period of time.

It is recommended that a soft camel's-hair brush be used to eliminate accumulated dust and dirt from the exposed lens surface. The rear end as well as the front end of the lens must be so cleaned. Only after the camel's-hair brush is first applied is it permissible to apply the special lens tissues available for removing any residual dust or dirt. These tissues must be applied gently, and with a minimum of pressure, so as not to scratch or mar the lens surface. It is not good practice to breathe upon the lens surface before applying the tissue. This may force vapor back into the lens mount, which will cool into droplets within the lens.

Two recommended lens tissues are the Kodak (Eastman Kodak Co., Rochester, N.Y.) and the Thomas No. 6325 (Arthur H. Thomas Co., Philadelphia, Pa.). The selection of a lens tissue is important, particularly if a coated lens is to be cleaned; otherwise, some of the coating may be removed. Such a coating consists of a layer of magnesium fluoride approximately one quarter wavelength in thickness, or 0.000004 in. thick. A coated lens can be recognized by its bluish or pale tint. The purpose of the coating is to reduce the amount of light reflected from the surface of the lens, thus increasing the amount of light transmitted through the lens and minimizing ghosts or reflected images. When the thickness of the layer or coating is taken into consideration, it can be seen how abrasion—due to the use of a poor lens tissue—can soon remove it.

When camera lenses are carried into the field in mobile or remote operations, they should be stored in a felt-lined lens case. The case should be of such dimensions as to house the complete complement of lenses. The case should be moisture- and dustproof, and a carrying handle should prove convenient.

1.7 Scanning. Once the reflected light from an object upon the studio stage is focused by means of the camera optical system upon the photosensitized target of the camera pickup tube, an inverted image of that object appears upon that target. The light and shade of the image result in what is known as a "picture." The camera pickup tube (to be discussed later) is employed to convert the light values in the picture into finite electrical potentials. It follows that the resulting electrical potentials must vary in amplitude because of the variation in light and shade in the picture.

The photosensitized target, or mosaic, of one electron tube for image pickup is so constructed that its surface (perpendicular to the light source and lens system of the camera) is coated with myriad light-sensitive globules. These globules are one layer deep and are affixed to a sheet of mica. On the opposite (or rear) side of this plate is affixed a conductive coating of silver or colloidal graphite. We may now consider each tiny photosensitive silver globule and the coating of silver (to the rear of the target) as constituting a tiny capacitor, with the intervening mica serving as the dielectric material. The silver coating on the reverse side of the dielectric material is, of course, common to all the globules of silver, while each globule is insulated from every other globule.

The thousands of light-sensitive silver globules on the face of the target lose electrons when subjected to light. Since the image focused upon the face of the target is made up of light and shade, more electrons are lost by some of the silver globules than by others. The brighter the incident light falling upon a certain area of the target, the more electrons are lost from the globules in that particular area. Thus, the globules assume a positive charge (owing to loss of electrons) and with respect to the silver coating on the reverse side of the sheet of mica. Since a picture imaged upon the target by means of reflected light is made up of a wide range of light values, the target, or mosaic, will assume a charge proportional to the amount of light falling upon any given element of its surface.

Let us then visualize the target as constituting a mosaic of many thousands of tiny capacitors, each assuming a charge proportional to the light falling upon its individual globule of silver. Each one of these capacitors will hold or retain that charge until discharged by some means. The fact that an electrical potential is stored by each capacitor has led to a phenomenon known as the "storage" effect possessed by some electron tubes employed for image pickup. It is then possible to discharge these capacitors one by one and in a controlled sequence, so that sequential electrical potentials may be taken off the mosaic which are in all respects equivalent to the amount of incident light originally striking each picture element.

The globules are discharged in proper and controlled sequence by the scanning effect of a tiny beam of electrons. This beam is produced by the electron gun of the camera tube, the movement of the beam both horizontally and vertically across the mosaic being under control of the deflection system of the television transmitting system. The electrons displaced by the electron beam of the gun of the pickup tube, i.e., those removed from the mosaic, are attracted to a collector ring about the inner circumference of the pickup tube. This collector ring has a high positive potential and is connected to the cathode of the input tube of the camera video preamplifier. A lead from the rear plate of the mosaic connects to the control grid of this pickup tube, and a load resistor is connected across these two points. The action that occurs at the electron tube for image pickup will be described in greater detail in a later section of the text (see pages 172–175).

In the above discussion, the action that takes place in the Iconoscope has been explained, since this is the most simple type of camera pickup tube in which scanning takes place. Another tube, which is rapidly replacing it, is known as the Image Orthicon. This new tube is basically similar to the Iconoscope insofar as scanning is concerned, except for its physical size and construction. The mosaic, or target, is of smaller area and is essentially transparent, and the silver coating of the insulating plate is very thin compared to that of the Iconoscope. The tube is shown in Fig. 1.22. The scene in the television studio is imaged upon the front side of the target, and the target is scanned on the rear, or back, side. Such an arrangement makes possible the use of a low-velocity rather than a high-velocity scanning beam, and secondary emission at the target and spurious shading signals are eliminated. The increase in sensitivity makes possible the televising of scenes under conditions of extremely low level lighting.

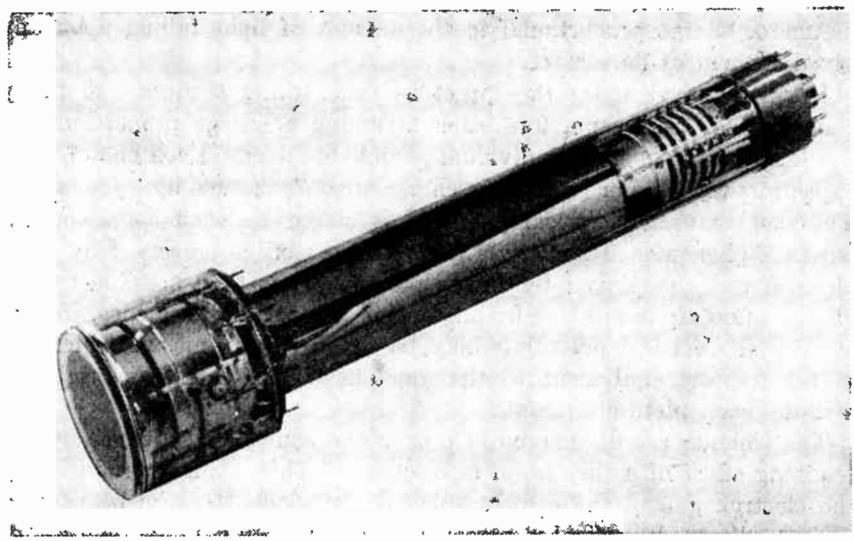


FIG. 1.22 R.C.A. type 2P23 Image Orthicon pickup tube.

The electron beam of the pickup tube in the television camera scans the target from left to right, top to bottom, much as you now visually scan this page in reading. The electron beam which accomplishes the scanning is controlled and directed by means of a magnetic yoke about the glass neck of the camera pickup tube, through which the electron beam must pass before striking the target. The magnetic yoke is made up of pairs of horizontal and vertical deflection coils, one set of coils acting upon (or directing) the beam in the horizontal plane, the other pair exercising control over the beam in the vertical plane. Thus, by suitable control of the current amplitudes and wave shape in the coils, the beam may be moved across the target from left to right, or it can be made to move vertically across the target.

The target of the pickup tube is not scanned directly across from left to right, but slantwise. This is shown in Fig. 1.23. In actual practice, the beam may start at (1) at the upper left corner of the target, then drop slantwise across to conclude the scanning of line (1). The electron beam is then extinguished, or blanked out, after which the beam is returned to the left side of the target to scan another line of picture information. Before the end of the blanking interval but with no picture, the beam begins scanning line three; i.e., the odd lines are scanned first, then the even numbered lines are scanned. Since each television frame is theoretically made up of 525 horizontal lines, 262.5 odd lines of the picture are first scanned, then 262.5 even lines are scanned. At the same time that the electron beam in the pickup tube moves from left to right and top to bottom of the picture, a similar beam moves simultaneously at the television receiver, reproducing the

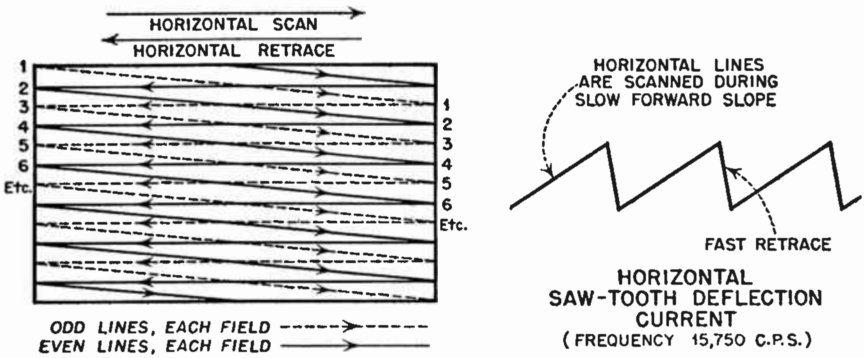


FIG. 1.23 Interlaced scanning as employed in a modern high-definition all-electronic television system (262.5 horizontal lines are scanned for each field. Two fields interlaced are required to make one frame, and 30 frames of 525 lines each are transmitted each second).

picture upon the screen of the cathode-ray tube at the receiving point. We have stated that 525 lines are horizontally scanned in completing the scanning of one frame. Since, owing to vertical blanking, approximately 6 per cent of the horizontal lines are blanked out, only about 94 per cent of the 525 lines supply picture information. There are, therefore, approximately 493.5 *active* horizontal lines per frame.

When 262.5 odd lines at the camera pickup tube have been scanned, one field is said to have been completed. When the 262.5 even lines have been scanned, another field is said to have been completed. The two fields, of 262.5 lines each (neglecting vertically blanked portions) combine to make up one picture frame. Thirty frames are transmitted each second; and each frame, therefore, is constructed of 525 horizontal lines, or approximately 493.5 active lines of picture information. The system whereby odd lines are scanned first, then the even lines, the two fields produced being combined to form one frame, is termed "interlaced scanning." Such a system is used to reduce flicker and is the basis of our modern system.

As will be seen in Fig. 1.23, when one field is completed, the electron beam is moved from the bottom of the picture to the top center of the picture, after which the scanning of a new field is begun. Therefore, 60 fields per second are scanned to result in 30 frames for the same period of time. Sound motion pictures are projected at a speed of 24 frames per second without appreciable flicker. Owing to the presence of the shutter, there are effectively 48 frames per second.

The student may wonder why a frame frequency of 30 has been chosen in television. It must be remembered that the frequency of the alternating current available in most sections of the United States has been standardized at 60 c.p.s. Too, both television transmitter and receiver must be supplied by alternating current at an identical frequency. Since the electron beam in the camera pickup tube must be synchronized with the electron beam of the cathode-ray tube of the television receiver if both are to move together in reproducing the picture, the selection of a frame frequency of 30 per second has proved a practical standard. This frame rate is a submultiple, numerically, of the power-line frequency. Since the frame frequency in television bears a subharmonic relationship to the power-line frequency, observable interference in the picture is reduced to the minimum. Since the interference is recurring at the power-line frequency, the frame-recurrence rate being a submultiple of the frequency of the power-line current, the distortion due to observable interference remains virtually stationary and does not become apparent to the eye unless it becomes very serious. Were the frame frequency 24 instead of 30, the interference would slowly move across the picture vertically and interfere with viewing.

The currents used to develop horizontal and vertical deflection in the magnetic yoke are termed saw-toothed currents (see Fig. 1.23). A saw-toothed current increases in amplitude gradually to some predetermined amplitude and then drops to zero, the process to be repeated over and over again. Since the magnetic fields of the deflection coils produced by these currents are responsible for displacement and movement of the electron beam of the pickup tube, it can now be seen how scanning is actuated. On the forward slope of the saw-toothed current wave the beam is moved slantwise from left to right across the target (horizontal deflection). The beam is extinguished during the return trace, at which time the magnetic fields set up in the coils collapse and reverse to a maximum field at the left side of the frame. Since there are 525 lines in each frame and 30 frames per second has been standardized, 15,750 horizontal lines of picture information are scanned each second. The frequency of the horizontal scanning current (sweep) is, therefore, established as 15,750 c.p.s. Since the beam must be moved from the lower edge of the picture to the top 60 times per second and also from the top to the bottom at the same rate (there are 60 fields), the frequency of the vertical saw-toothed current is standardized at 60 c.p.s.

It follows that two saw-toothed deflecting or sweep currents are required, one produced by a saw-toothed current of 60 c.p.s., the other being standardized at 15,750 c.p.s. If the cathode-ray picture tube incorporates electrostatic deflection (one pair of deflection plates being arranged to deflect the beam horizontally, another arranged to deflect the beam vertically), then the scanning generator must produce saw-toothed waves of *voltage*. If the cathode-ray picture tube incorporates electromagnetic deflection, the saw-toothed generator must produce saw-toothed waves of *current*. Since most cathode-ray picture tubes (although not all) employ electromagnetic deflection, saw-toothed waveforms used in television scanning will be referred to as "current saw-toothed waveforms" throughout the text. This does not mean, however, that voltage saw-toothed waveforms are not used for purposes of electrostatic deflection. Saw-toothed generators, voltages and currents will be discussed in greater detail later in the text.

1.8 Aspect Ratio. In its Standards of Good Engineering Practice concerning Television Broadcast Stations, the F.C.C. states that the term "aspect ratio" means "the numerical ratio of frame width to frame height, as transmitted." In the transmission standards promulgated by that authority, it is seen that "the aspect ratio of the transmitted television picture shall be 4.0 units horizontally to 3.0 units vertically" (see Fig. 1.24). This ratio was recommended to the F.C.C. by the National Television System Committee, which suggested 22 specific standards for television during a public hearing before the F.C.C. on Mar. 20, 1941.

In early experimental work in television, the pictures were made square, i.e., with aspect ratio of 1 : 1. The reason for this was to make the greatest use of the circular luminescent screen of the cathode-ray tube. The screen of the tube is circular in shape, and a square image occupies a greater portion of the total screen area. Subsequent studies and observations by interested engineers and physicists revealed that there were other far more important considerations involved. It was the result of a rather thorough investigation that the present standard was chosen.

Biophysically, there are logical reasons why the rectangular frame shape chosen has been selected because the horizontal dimension is greater than the vertical. It has long been well known to medical science that the horizontal muscles of the human eye possess greater strength than the vertical muscles. There results, in consequence, less eye strain in viewing an image with a greater horizontal plane. Also, it is known that the fovea, the region of sharpest vision of the eye, is 10 per cent greater horizontally than vertically. The visual acuity of the retina is also found to be much greater in the horizontal meridian. All these factors are important.

Since the beginnings of art, painters have in most cases chosen a greater horizontal than vertical dimension for their canvases, for the effect of such a proportion proved more pleasing to the eye. Psychologically, it has been known for a long time that any objects with a greater horizontal than vertical dimension provide greater appeal. The most pleasing ratios of vertical to horizontal dimension of rectangles have been known to mathematicians for many centuries. Pythagoras

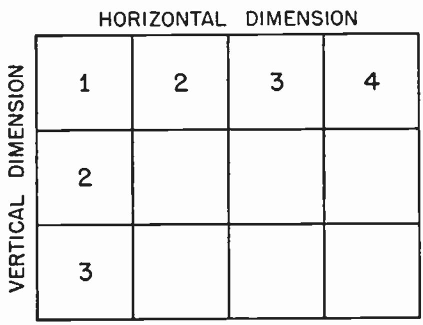


FIG. 1.24 Aspect ratio. The aspect ratio of the television frame must be 4:3; four units horizontally to three units vertically.

adhered to the "root square rectangle" ($1:\sqrt{2}$), and early manuscripts have been found which refer to "the rule of three to five" as the divine proportion. Mention is also found in many early mathematical treatises of the "five foot rectangle" as the basis of dynamic symmetry ($1:\sqrt{5}$). The principles of dynamic symmetry have long been adhered to by the manufacturers of radio cabinets, since it has been proved that units having certain dimensions were more acceptable to the public and enjoyed greater salability. There is little doubt that in any case certain very definite ratios of width to height are more desirable to use.

Engineers concerned with problems of standardization in television sought to adopt an aspect ratio which would approach that found in the motion-picture industry. The purpose was to make available the vast storehouse of suitable film subjects for transmission into the home. Film subjects will undoubtedly provide a large proportion of television programs for many years to come, due to the great expense involved in producing extravagant live-talent studio shows comparable in scope with feature-length films. Television engineers sought to make it easier for existing motion-picture films to be employed in television programing.

In choosing standards for frame size, the motion-picture industry was confronted with a similar problem, that of choosing the most generally satisfactory standards, long before the birth of present-day television. It was obviously expedient to take advantage of the experience already gained in the field of visual entertainment, and certainly there was no valid reason for setting up standards that would be in controversy with those established in motion-picture production.

It is interesting to note that while the standard aspect ratio in television is 4 : 3, this ratio does not coincide precisely with the standards adopted by the motion-picture industry, although the two ratios approach an equality. In television, the quotient of width over height is 1.333. The standard size of a 35-mm. motion-picture frame is 0.825 in., or 20.96 mm., horizontally and 0.6 in., or 15.24 mm., vertically. Thus, the quotient of width over height is 1.375. The standard frame size of 16-mm. film is 0.380 in., or 9.65 mm., horizontally and 0.284 in., or 7.21 mm., vertically. Therefore, the quotient of width over height for standard 16-mm. motion-picture film is 1.334.

The R.C.A. type 1850–A Iconoscope, a principal television-film pickup tube, has a mosaic or target area of approximately 16.922 sq. in. The quotient of horizontal dimension ($4\frac{3}{4}$ in. $\pm \frac{3}{32}$ in.) over the vertical dimension ($3\frac{9}{16}$ in. $\pm \frac{3}{32}$ in.) is 1.333. Thus, it is seen that the aspect ratio of neither standard 35-mm. nor standard 16-mm. motion-picture film frames precisely satisfies the standard aspect ratio employed in television.

No serious error occurs in televising motion-picture film, however, since the amplitude of the horizontal sweep voltage in the television system need be only slightly altered to compensate for the slight error, and without serious geometrical distortion of the image. Also, it is entirely possible to mask off some of the edge of the film frame when focusing it upon the mosaic of the pickup tube without losing an important part of the film-frame area. In the vernacular, this is known as allowing the edges of the film frame to "slop over" when focusing it upon the mosaic of the pickup tube.

Since the standard aspect ratio is 4 : 3, the video scanning system is so developed that the quotient of picture width over height is always 1.333. Thus, when picture size is adjusted to a vertical dimension of 6 in., the horizontal dimension becomes 8 in. A picture adjusted to a horizontal dimension of 20 in. will have a vertical dimension of 15 in. One Du Mont experimental projection receiver will provide a picture measuring 4 ft. horizontally. Thus, the height is made 3 ft. so as to satisfy the standard aspect ratio requirement, and the deflection potentials are adjusted until the desired aspect ratio is obtained.

The aspect ratio of an image reproduced upon the fluorescent screen of a receiver cathode-ray tube is a function of the ratio of deflection potentials applied to the deflection plates of the tube if electrostatic deflection is made use of; or it is a function of the ampere-turns ratio at the deflection coils if a magnetic deflection system is employed. Therefore, with an image of given horizontal dimension, it is possible to obtain the desired aspect ratio at the receiver viewing tube by adjusting the current amplitude in the vertical deflection coils until the desired vertical dimension is obtained. The horizontal dimension of the image may likewise be controlled.

In commercial receiver design it is very desirable that the horizontal and vertical deflection potentials be fixed, so that they will not be subject to adjustment by an inexperienced person from the front of the panel. If they are made adjustable, the necessary controls customarily are not placed on the front panel of the receiver, accessible to the user, but are located at the rear of the set. The potentiometers providing deflection control may employ slotted shafts in many cases which are subject only to screw-driver adjustment. The slotted heads of the potentiometer shafts are recessed back of the chassis so as not to be readily accessible, and the units themselves are suitably mounted under the receiver chassis and accessible from the rear of the set. Sometimes receiver deflection circuits are so developed that a single control adjusts both horizontal and vertical deflection potentials by the same amount. With this arrangement, it is impossible to increase picture size along one dimension without increasing the size along the other. Thus, the image aspect ratio is closely maintained in the proportion 4 : 3. Such circuits have not come into widespread use.

In adjusting the amplitude of both horizontal and vertical deflection voltages for a given image area, at the same time preserving the standard aspect ratio, it is customary to cut out a rectangular pattern of stiff paper or cardboard to the desired proportions. Thus, if a 6- by 8-in. image upon the fluorescent screen is desired of a cathode-ray tube 12 in. in diameter, the proper pattern is cut to an area of 48 sq. in., 6 in. vertically and 8 in. horizontally. This pattern is held firmly against the fluorescent screen and is properly centered. The horizontal and vertical deflection voltages are adjusted until the raster just reaches the outer extremities of the pattern. The desired image area is thus obtained together with satisfaction of the standard aspect ratio requirement.

It is very important that the receiver or monitor raster be adjusted as explained above; otherwise, serious distortion of the image may result. For a picture of given vertical dimension as viewed at the cathode-ray tube screen, the voltage impressed across the horizontal deflection coils or plates may be so maladjusted that the ratio of horizontal width to vertical height does not satisfy the standard aspect ratio and images appearing on the screen will not be in proper proportion.

A reduction in horizontal deflection voltage below the required amplitude will compress the picture elements, with the result that all objects or persons appear thin. Increasing the deflection potential applied across the horizontal deflection coils, or plates, and above the required amplitude will result in an opposite effect. All persons or objects appearing on the screen will seem "stretched" and all out of proper proportion. Of course, the same distortion will occur along the vertical plane of the image should the vertical deflection be improperly adjusted. It is seen that deflection potentials must always be adjusted to such amplitude that the proportion of vertical deflection to horizontal deflection satisfies the standard aspect ratio.

It is the usual practice at the television station first of all to adjust rasters at all monitoring screens to the proper aspect ratio before the beginning of a period of operation, and the experienced television serviceman in the field exercises the proper care to ascertain that the raster of the viewer's receiver is properly adjusted to the standard aspect ratio each time the set is serviced.

1.9 Brightness. A very important consideration is that of brightness of the reproduced image at the television receiver. It is obvious that the image, as reproduced upon the fluorescent screen of the cathode-ray viewing tube, must demonstrate a degree of brightness greater than the ambient illumination in the room in which the receiver is placed. It has been shown that if the picture brightness can be made at least 100 times greater than that produced by the ambient illumination in the room, the latter would have little or no effect upon the just perceptible differences in the highlights nor the just perceptible differences in the shadows which go to make up the picture.

Factors other than ambient illumination in the room dictate the degree of brightness that must be achieved. Some of these are psychological factors, but none the less important. The retinal dark-light adaptation of the human eye is most important, since the presence of surrounding light in the room has an effect upon it. The size of the picture is also important, since the pupil of the eye must vary as the picture size is changed, and control of the pupil is a function of the macular region of the eye's retina. A great deal has been learned from the experience of the motion-picture industry. Biophysically, it has been shown that the visual resolving power of the eye varies approximately with the logarithm of the brightness over most of the range of visibility, but reaches a maximum at about 50 milli-lamberts. Below this maximum value, increased picture brightness results in a higher resolving power. Since the maximum resolution is known to be limited by the height of the scanning line (one line) in relation to the separation of the observer from the screen of the viewing tube, there is no necessity for an increase in screen brightness above that which would result in a visual resolution represented by this limit.

Practically speaking, the fluorescent screen of the cathode-ray tube in the television receiver must be capable (when under bombardment of the electron gun) of producing sufficient brightness to provide a satisfactory image under conditions of normal ambient illumination in the room. Brightness of the cathode-ray tube screen is usually expressed in terms of foot-lamberts, 1 ft.-L. being equivalent to an illumination of $1/\pi$ c. per sq. ft. The highlight brilliance of a television picture, as reproduced on the face of a 12-in. cathode-ray viewing tube, was measured accurately as 19.8 ft.-L. Tests have indicated that screen brightness should be greater than 10 ft.-L. to provide a satisfactory image under conditions of average ambient illumination in the room. Such a brightness level is easily obtained with the use of modern commercially available cathode-ray tubes.

Screen brightness will be discussed in greater detail in the section describing cathode-ray tubes. It suffices to state here that current density in the electron beam which scans the fluorescent screen of the viewing tube, as well as the amplitude of second-anode potential applied to the tube, influences the brightness of the screen. With the use of a P-4 (white) phosphor on the screen of the viewing tube, screen brightness is quite a linear function of beam current density. This proves to be a highly desirable characteristic, as the density of the beam current is a function of the cathode-ray tube control grid voltage, this voltage being equivalent at any instant to the sum of the bias and signal voltages applied to the grid. Hence, picture brightness will change as the signal voltage varies, resulting in a reproduction of the highlights and shadows contained in the original scene before the studio cameras.

1.10 Contrast. The term "contrast" in television refers to the ratio between points of maximum to minimum brightness on the viewing screen of the cathode-ray tube of the receiver. Under conditions of total outdoor darkness the contrast ratio will be 1 : 1, and it will increase to a ratio of 10,000 : 1 in bright sunlight. At the screen of a picture tube, contrast ratios of 50 : 1 to 100 : 1 prove entirely adequate for effortless viewing.

The picture contrast actually achieved is a function of several factors. Of primary importance is the nature of the chemical phosphor employed to coat the screen of the viewing tube. The contrast obtaining throughout two different areas of the picture itself is a function of the nature of the scene being televised and reproduced. Greater contrast is obtained if a small white object is televised against a dark background than if a dark object is televised against a very bright background. The reason for this is that internal reflections from the bright area (background) have a tendency to illuminate the small dark object, serving to reduce the contrast ratio. Other factors which affect contrast are screen curvature at the picture tube, scattered electrons within the tube, and reflections from the glass wall of the tube. Of great importance in the reduction of contrast ratio in the picture is the amount of ambient light in the room which is permitted to fall upon the fluorescent screen of the viewing tube.

Ordinarily, the over-all brightness contrast ratio can be made greater than 50 : 1 with present tubes, and the detail contrast ratio will be better than 10 : 1. There is a difference between brightness contrast ratio and detail contrast ratio. The first refers to the contrast ratio existing between bright areas in the picture and the usually dark background. The latter refers to contrast ratio of fine detail in the bright area as compared with the degree of brightness of the remainder of the generally bright area. The contrast range in the picture is defined as the ratio of brightness of the brightest highlight in the picture to the deepest shadow. Under ordinary conditions the brightness range should be at least 25 : 1 to 40 : 1, depending to some extent upon the nature of the scene being televised. The gamma of the scene is commonly referred to and is used to describe the gradation of the picture. It must be remembered that a modern television system is a monochromatic system, black through shades of gray, to white, being transmitted and reproduced. If the original shades throughout the scale were televised and reproduced in exact gradation, the gamma of the system would be said to equal 1, or unity. A low gamma can be tolerated in scenes where contrasts are high.

The means by which picture contrast is electronically controlled in the system will be discussed later.

1.11 Resolution. The resolving power of a television system, or any part of that system, has been defined as "a measure of its ability to delineate picture detail." Resolution is commonly expressed in terms of the number of lines resolved on a test chart or pattern. Such a test pattern, as transmitted by Station WNBT of N.B.C., is shown in Fig. 1.25. It will be noted that the horizontal resolution is indicated by white dots arranged along the vertical wedges of the test pattern, the resulting horizontal resolution of the system being indicated in terms of horizontal lines along the upper wedge; and by the upper frequency, in megacycles, being passed by the system along the lower vertical wedge. The vertical resolution is expressed by white dots along the horizontal wedges of the test pattern. Such a test pattern or resolution chart is almost always transmitted by the television broadcasting station prior to its regularly scheduled transmission of programs. This practice is followed to permit listeners and servicemen to check and adjust receivers properly before the regular broadcast of program material.

The test pattern has other purposes, including that of determining the ability of the transmitter or receiver to reproduce faithfully the gradation of black to white, through intermediate shades of gray. It will be noted that the circle in the center of the pattern is made black;

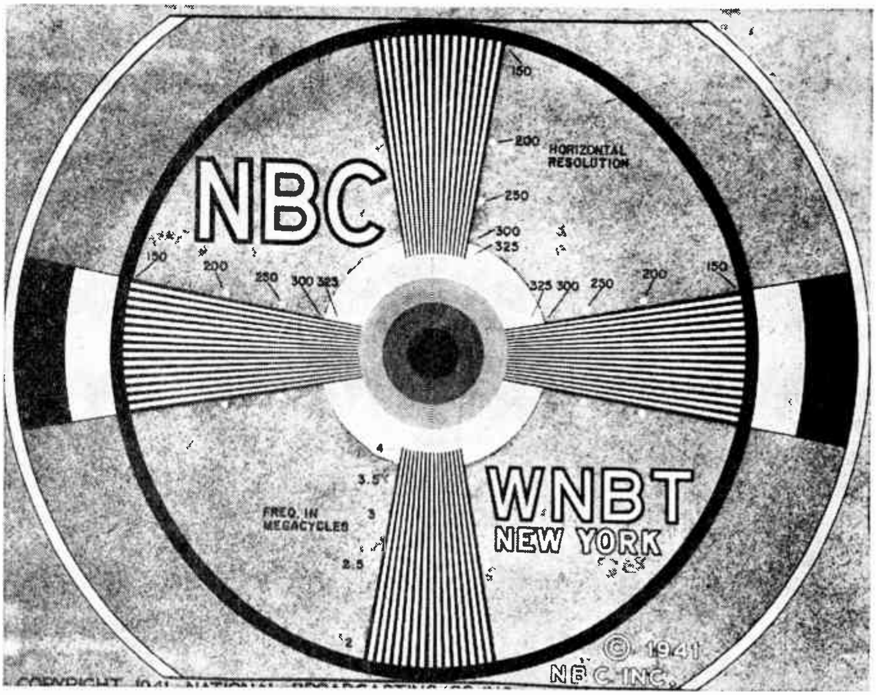


FIG. 1.25 Test pattern of Station WNBT, New York. (Courtesy of National Broadcasting Company.)

and this circle is inscribed in additional circles of shades of gray to an outer circle of white. The "gamma" of the system should be such that black is transmitted and reproduced at the receiver as true black, that white is transmitted and reproduced by the system as true white. The shades of gray between these extremes must also be transmitted and reproduced in proper gradation. The test pattern is further employed to determine the horizontal and vertical linearity of the system, much of which will be discussed later in the text. Geometric distortion adequately describes the lack of proper linearity.

Vertical and horizontal resolution of the system must be considered separately. The vertical resolution is essentially a function of the number of lines comprising the scanning pattern, as well as upon the size or diameter of the scanning spots at the camera pickup tube and the cathode-ray tube at the receiver. Horizontal resolution is principally a function of the width of the picture channel as well as of the shape and size of the two scanning spots. It is quite easy to understand how the size of the spots produced by the electron beams of the camera pickup tube and the viewing tube can affect the detail resolution of which the system is capable. In the system of scanning that is employed, which has already been discussed, each globule at the target of the pickup tube (Iconoscope) must be discharged in order to produce an electrical current of an amplitude coincident with the amplitude of reflected light which first caused the globule to store a charge. Hence, the finer the spot developed by the scanning beam, the greater the fidelity of detail of the reproduced picture and the greater the resulting resolution.

In order to transmit the shading of the picture in the vertical direction, the television system must be capable of passing very low frequencies, and it has been shown that in order to faithfully reproduce the vertical background in the picture, the complete system (transmitter and receiver) must be capable of transmitting frequencies equal at least to that of the frame frequency (30 c.p.s.). This capacity is necessary in order to reproduce through the system information about the background of an image, the average illumination of which is constantly changing. The lower limit of the system's pass band will, therefore, approximate 30 c.p.s.

The system bandwidth required to produce excellent horizontal resolution can be easily calculated for all practical purposes. We will recall that the modern all-electronic television system is such that one standard frame theoretically contains 525 horizontal lines. However, about 6 per cent of the horizontal lines are blanked out because of the vertical blanking interval. Therefore, only approximately 94 per cent of the theoretical 525 horizontal lines per frame are active in supplying picture information. Thus, we shall consider 493.5 active horizontal lines in calculating the approximate required bandwidth of the transmission system.

The standard aspect ratio of the image is expressed numerically as 4 : 3. The video signal due to the picture is expressed in terms of alternating current, in which the frequency is constantly changing. One line of picture information may be considered as one element wide. Thus, with 493.5 active horizontal lines making up one frame, we may assume that there are 493.5 elements vertically throughout the image. The width of the picture will be $\frac{4}{3}$ by 493.5, or 658.0, picture elements wide, since the aspect ratio is 4 : 3. Now, one complete frame is scanned in approximately $\frac{1}{30}$ sec., and one cycle equals two picture elements, since in interlaced scanning the odd lines are first scanned and then the even lines. Simple arithmetic may then be used to determine the approximately maximum frequency that must be passed by the transmission system to result in optimum resolution: 493.5 elements (vertically) $\times$ 658.0 elements (horizontally) = 324,723 elements per frame. $\frac{324{,}723}{2} = 162{,}361.5$ (because of interlaced scanning). 162,361.5 (elements per cycle) $\times$ 30 (frames per second) = 4,870,845.0 elements to be reproduced per second.

For optimum resolution, it appears that the bandwidth should be 4.87 mc. per sec. Actually, the F.C.C. has specified the video channel bandwidth as 4.25 mc. per sec. If we take into consideration the fact that only about 75 per cent of the active horizontal lines of picture information are correctly reproduced, we may lower the bandwidth requirement by 25 per cent. The required bandwidth then becomes approximately 3.64 mc. per sec. It will be seen that the 4.25 mc. per sec. bandwidth specified by the F.C.C. is entirely adequate to afford good resolution of the picture. The above deductions are based upon resolution expressed in detail equivalent to somewhat less than 493.5 active horizontal lines of picture information being reproduced by the system.

The R.M.A. Committee on Television Transmitters has proposed (Standards Proposal 217) that the over-all resolving power of the television studio facility be at least 350 lines in the vertical direction and 400 lines in the horizontal direction, both measurements to be made near the center of the picture. The measurements should be made through use of an R.M.A. Resolution Chart. This chart is shown in Fig. 1.26. Before discussing the use of this chart in determining resolving power, it is felt that we should further investigate the N.B.C. test pattern in Fig. 1.25.

To put the station test pattern to practical use in checking the resolution of a studio facility, transmitter, or receiver, the following procedure is used:

1. Adjust the equipment under test for optimum operation.
2. Observe the image of the test pattern as reproduced upon the fluorescent screen of the cathode-ray tube, making sure that not too much ambient light is striking the screen.

If you are able to see clearly defined white and black lines along the upper vertical wedge of the pattern and as far as the first white dot (almost midway the top wedge), the system is demonstrating resolving power down to 200 horizontal lines. If the black and the white lines are clearly defined along this wedge as far down as the second white dot, the horizontal resolution is equivalent to 250 lines. The vertical calibrations are at 150, 200, 250, 300, and 325 lines.

Observing the calibrations along the lower wedge, you will see that ability to "see" all the way down the wedge to the outer circumference of the light-gray circle indicates that the system is passing 4 mc. of picture signal. In other words, the resolving power of the system indicates that the system is passing a band of frequencies, the upper limit of which is 4 mc. or better.

The same interpretation may be made of vertical resolving power, this time using the horizontal wedges.

The R.M.A. Test Chart is employed in much the same manner. In making use of the chart to determine the over-all resolving power of the studio facility, it is recommended that the chart be televised by the studio facility and reproduced on the screen of a suitable studio picture monitor. To study the resolving power of the entire studio facility, this monitor would accept a picture signal from the output of the line amplifier. The following procedure would be undertaken:

1. Focus the chart on the mosaic or target of the camera pickup tube, so that its area (boundaries determined by arrowheads) exactly covers the usual area scanned by the camera.
2. Adjust circuits for minimum geometric distortion.
3. With uniform illumination of the chart, adjust the picture signal to occupy the normal picture range on a waveform monitor.
4. Adjust shading (if employed) for uniform background brightness.
5. Set the monitor bias and gain for delineation of maximum number of gray steps without blooming.
6. Read maximum resolution of horizontal and vertical wedges near the center of the picture.
7. A measure of maximum resolution should be accompanied by a statement of the number of distinguishable gray steps (for example, 400 lines, steps 2, 3, 4, 5, 6).

The following information is taken from Standards Proposal No. 217 and is repeated for the convenience of the engineer:

Instructions for Use of R.M.A. Resolution Chart

This chart should be televised by the studio facility and reproduced on a suitable picture monitor.

Resolution is to be read only after equipment has been adjusted to have a minimum of distortion: (1) scanning; (2) shading, if system employs shading; (3) low-frequency phase shift; (4) focus.

After these adjustments, note the maximum gray-scale reading (for perfect adjustments reading should be same on all four scales) and then take maximum resolution (horizontal and vertical) readings on large wedges in central portion of picture; also on small wedges in circles in corners. For example, read the horizontal resolution from the wedges located vertically on the chart, the vertical resolution from the wedges located horizontally on the chart. A measure of

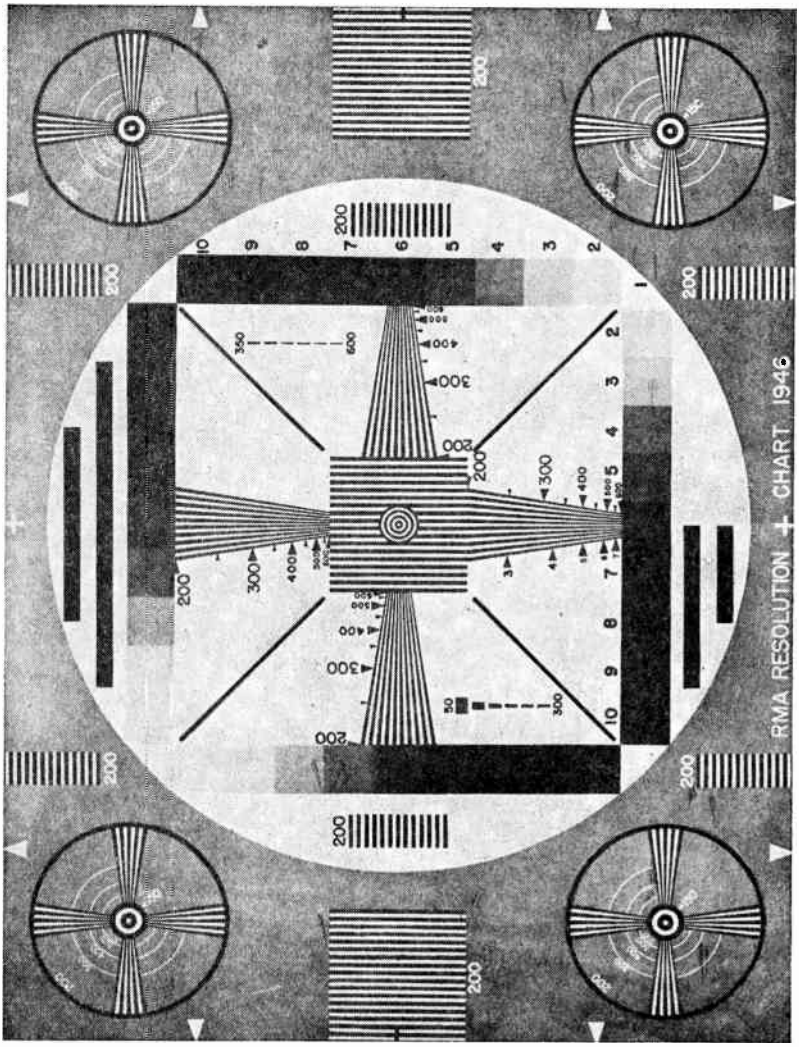


FIG. 1.26 R.M.A. resolution chart (1946).

maximum resolution should be accompanied by a statement of the number of the distinguishable gray steps (for example, 400 lines, steps 2, 3, 4, 5, 6).

The maximum resolution reading will indicate system performance. The least of the maximum resolution readings (usually found in picture corner) will indicate the system degradation due to failure in achieving optimum results for one or more of above adjustments or inherent CR tube distortion.

1. *To check scanning*

The scanning adjustment involves: size, linearity, and aspect ratio.

Focus the chart on the camera tube so that its area (boundaries determined by arrowheads) exactly covers the usable area scanned by the camera.

Check the vertical sweep linearity by comparing the spacing of the short horizontal bars at both top and bottom of picture with that of the bars midway between.

Check horizontal sweep linearity in similar manner by comparing the spacing of the vertical bars in the square at each side of picture with that of the bars in the center square.

Check aspect ratio by measuring the large pattern formed by the gray scales to see if it is a square. If the horizontal and vertical scanning is linear and the above pattern is square, the aspect ratio is correct.

2. *To check shading*

If the camera employs shading, two methods of checking are suggested: (*a*) visual inspection of the picture monitor to determine if the background is an even gray; and (*b*) use the waveform monitor and note if the average picture signal axis is parallel to the black level line both at line and field frequencies. As an additional aid in correcting the shading adjust same until the gray-scale reading is the same (and a maximum) for all four scales.

3. *To check low frequency phase shift*

Streaking following either one of the two horizontal black bars at the top or bottom of the large circle is an indication of low-frequency phase shift.

4. *To check focus*

Two checks are required: camera lens focus and cathode-ray beam focus (camera tube and receiving tube). Cathode-ray beam focus adjustments are made for a maximum resolution reading first of the horizontal scanning and then of the vertical. Due to beam characteristics a maximum adjustment for one may not be the maximum adjustment for the other; in this event a compromise adjustment is indicated.

5. *Miscellaneous chart information*

a. All bars for checking sweep linearity are spaced for 200 lines resolution.

b. One of the wedges for checking horizontal resolution is calibrated in both lines and megacycles to facilitate equipment checking.

c. The gray scale is composed of 10 steps varying in an approximate logarithmic manner from maximum white brightness to approximately 1/30 of this value. This scale may be used in connection with a waveform monitor to check the transfer characteristic of the system.

d. The four diagonal lines in the square may be used to check quality of interlacing. A jagged line indicates pairing of the interlaced lines. (Not effective when interlace failure is 100 per cent.)

e. The circumference of each of the four small circles is tangent to an imaginary circumference at the point nearest the corner of the chart. The radius of this imaginary circle is 4½ in. and located along a line bisecting the corner angle of the chart. (This is to indicate the part of the corner masked off by some television receivers.) Hence, the corner circles should be visible on a receiver whose picture corners are masked.

f. The resolution circles in the center of the pattern and in the center of the corner resolution wedges are for testing spot ellipticity on cathode-ray picture tubes (useful to tube manufacturers). The resolution of the circles in the corners (150) was made less than the resolution in the center (300) because of added deflection defocusing in these areas.

g. The four crosses (+), positioned one at the center of each side of the chart, are used for alignment of projection kinescopes and the optical system of television-projection receivers.

h. The gray background of the chart provides a satisfactory balance with the whites so that a studio system correctly set up by the use of this chart will operate satisfactorily on an average scene without additional adjustments.

i. The two sections of single-line widths, 50–300 (50–100–150–200–250–300) and 350–600 (350–400–450–500–550–600) provide an accurate means of checking "ringing" in equipment. (The multiple lines in the wedge are confusing in checks of this type.)

LINE CALIBRATION* OF RESOLUTION WEDGE

No. of lines	Width per line, in.	Width, in.	
		of 9 lines	of 19 lines
200	0.090	0.810	1.71
250	0.072		1.37
300	0.060	0.540	1.14
350	0.051		0.97
400	0.045	0.405	0.85
450	0.040		0.76
500	0.036	0.324	0.68
550	0.033		0.62
600	0.030	0.270	0.57

EXAMPLE: The 300-line point is located on the large wedge where its total width is 1.14 in. and on the small wedge where its width is 0.54 in.

* Calibration is based on a chart having a height of 18 in.

FREQUENCY CALIBRATION* OF RESOLUTION WEDGE

Formula and constants employed:

$$f_n = A_r n \frac{10^6}{H_a \times 2}$$

f_n = fundamental frequency for n number of lines
A_r = aspect ratio = 4/3
n = number of lines
H_a = active time of horizontal trace. (Horizontal time less blanking time. Blanking time is 0.16 H—the average between maximum and minimum allowable time.) Horizontal time = 63.5 μsec. and

$$H_a = 63.5 \times 0.84 = 53.3 \ \mu\text{sec.}$$

Substituting given values in the above formula:

$$f_n = \frac{4}{3} \frac{10^6}{53.3 \times 2} n = .0125\, N \text{ mc.}$$

or

$$n = \frac{f_n}{0.0125} \text{ lines}$$

when f_n = 3 mc., 4, 5, 6, 7
n = 240 lines, 320, 400, 480, 560, respectively

f_n	No. of lines	Width per line, in.	Width of 19 lines, in.
3	240	0.0750	1.42
4	320	0.0562	1.07
5	400	0.0450	0.85
6	480	0.0375	0.71
7	560	0.0325	0.62

Locate frequency calibration along wedge by same method employed to locate line calibration (see example above). An alternate method is suggested for locating the line calibrations along the wedge by the following formula:

$$L_n = L\left(\frac{300}{N} - \frac{1}{2}\right)$$

L_n = distance from end of wedge indicating maximum lines resolution (in this case 600)
L = length of entire wedge (shortest distance between ends)
n = number of lines per picture height

1.12 Flicker. It has long been known that the human eye is unaware of discontinuity of motion at frequencies above approximately 15 c.p.s.; i.e., if pictures of an object are projected upon a motion-picture screen,

* Calibration is based on a chart having a height of 18 in.

for instance, at a rate of more than fifteen pictures per second, and if each picture shows the object in a different position, an illusion of continuous motion is achieved. This effect is due to "persistence of vision" of the eye. This phenomenon is responsible for motion pictures as we know them today. The greater the frequency at which the pictures are projected, the less flicker becomes apparent. The frequency of repetition at which flicker becomes apparent is a function, in television, of (*a*) the frame frequency of the system, (*b*) the brightness of the object, (*c*) the color of the light reaching the eye, (*d*) the length of time dark and light areas in the picture are transmitted, and (*e*) the position on the retina where the light energy falls. The frame frequency of the system is by far the most important factor influencing the flicker observed at the viewing screen of the television receiver.

The F.C.C. has established the frame frequency in television at 30 per second, each frame being made up of two fields interlaced. Interlaced scanning does much to reduce apparent flicker, since the field frequency is twice the repetition frequency of the picture. Interlacing must be perfect, however, for if individual horizontal lines of the raster are resolved, a very perceptible interline flicker, or weave, can be noted. Since sound motion pictures are transmitted at a frame frequency of 24 per second, the modern all-electronic television system should theoretically result in less flicker, because there are six additional frames, or pictures, transmitted each second. But for flicker-free reproduction the full interlacing capabilities of the television system must be utilized.

Flicker is also a function of picture brightness. The critical fusion frequency of flicker varies with the logarithm of the brightness, as does visual acuity; that is to say, as the reproduced picture is made brighter the possible resolution becomes greater, but the necessary frame frequency must theoretically be made greater to avoid flicker. Since visual resolving power becomes maximum at a brightness level of approximately 50 millilamberts, there is no point in increasing brightness beyond this level since flicker then becomes more noticeable.

Because the present television system is a monochromatic one, approximately "white" light being emitted by the fluorescent screen of the viewing cathode-ray tube, and the reproduced pictures being made up of a gradation of white through shades of gray to black, the effect of color upon the apparent flicker at the viewing screen may be dismissed for the present time. The F.C.C. has not as yet promulgated standards covering the transmission of color in television.

The time during which dark and light areas of the picture are reproduced upon the screen of the viewing tube has a definite influence upon apparent flicker. The explanation is that there is a definite rate by which the eyes of each individual adapt themselves to darkness and light. The ability of the eye to adapt itself to changes in brightness, therefore, will determine whether one individual observes flicker while another individual does not. To some extent the distance of the viewer from the fluorescent screen of the television receiver will determine how much flicker is apparent, and the conclusion has been reached that less flicker is observed the farther away the viewer is from the screen.

There can be no control, of course, upon the position on the retina of the eye where the light energy from the viewing screen falls.

BIBLIOGRAPHY

1. ENGSTROM, E. W., "A Study of Television Image Characteristics," *Proc. I.R.E.*, December, 1933.
2. WOOD, R. W., *Physical Optics*, The Macmillan Company, New York, 1934.
3. LOCKETT, A., *Camera Lenses*, Pitman, New York, 1937.
4. WILSON, J. C., *Television Engineering*, Sir Isaac Pitman & Sons, Ltd., London, 1937.
5. WHEELER, H. A., and A. V. LONGREN, "The Line Structure of Television Images," *Proc. I.R.E.*, May, 1938.
6. WILSON, J. C., "Channel Width and Resolving Power in Television Systems," *J. Television Soc.*, June, 1938.
7. MALOFF, I. G., "Gamma and Range in Television," *R.C.A. Review*, April, 1939.
8. LAW, R. R., "Contrast in Kinescopes," *Proc. I.R.E.*, August, 1939.
9. MILHOLLAND, H. C., *Optical Notes for the Television Cameraman*, Allen B. Du Mont Laboratories, Inc., Passaic, N.J.
10. FINK, D. G., *Principles of Television Engineering*, McGraw-Hill Book Company, Inc., New York, 1940.
11. ST. CLAIR, R. W., *Photographic Lenses and Shutters*, Ziff-Davis Publishing Co., New York–Chicago, 1940.
12. ZWORYKIN, V. K., and G. A. MORTON, *Television*, John Wiley and Sons, New York, 1940.
13. JACOBS, D. H., *Fundamentals of Optical Engineering*, McGraw-Hill Book Company, Inc., New York, 1943.
14. "The Zoomar Lens," *Television Magazine*, May, 1947.

REVIEW QUESTIONS

1–1. Describe the principal light sources used in the television studio, and state the purpose of each.

1–2. Why is the television camera sometimes referred to as an "optical-video transducer"?

1–3. (a) Define "aspect ratio." (b) What is the standard aspect ratio in television? (c) Explain how the standard aspect ratio was selected in television and the reasons for the choice.

1-4. What is meant by the following: (a) contrast? (b) flicker? (c) scanning? Define (a) frame; (b) field.

1-5. How is operation of a modern television system related to the utility power-line frequency?

1-6. (a) Why are several camera lenses required in television broadcasting field operations? Describe the following lens types: (1) biconvex; (2) plano-convex; (3) meniscus; (4) unsymmetrical biconvex. (b) Compare negative and positive lenses, and explain how several lens elements are employed to make up a typical television camera lens.

1-7. (a) Compare the following studio lighting sources both as to utility and as to cost: (1) mercury; (2) fluorescent; (3) incandescent. (b) Define (1) foot-candle; (2) lumen; (3) refraction.

1-8. How is the test pattern utilized in television?

1-9. Explain in simple terms how the reflected light energy from a subject before the cameras in a television studio may be converted into electrical energy.

1-10. (a) What is meant by brightness? (b) Compare the terms brightness and contrast.

CHAPTER 2

THE CATHODE-RAY TUBE

2.1 General. The cathode-ray tube is a special type of vacuum tube which has proved itself indispensable in the development and operation of electronic television apparatus. Not only is the cathode-ray tube important as a test instrument (incorporated into an oscillograph), whereby all types of electrical waveforms may be examined and measured. Special forms of the tube, however, such as the pickup tube in the television camera (i.e., Iconoscope, Orthicon, and Image Dissector), and the viewing tube in the TV picture monitor and television receiver (Teletron, Kinescope, etc.), are thus far irreplaceable in any high-definition electronic television system.* In truth, the cathode-ray tube is the most important single tool at the disposal of the television engineer. A thorough knowledge of its operation and practical application is essential to the proper understanding of any phase of the art.

In this vacuum tube, electrons from a cathode heated to the point of emissivity are caused to move in a narrow beam at very high velocity and to bombard a chemically prepared screen which fluoresces, or glows, at the point of impact. The multitudinous electrons, light in weight and traveling in vacuums, are accelerated and deflected by suitable means and are made to trace out on the fluorescent screen a pattern that provides a visual means of investigating and measuring currents and voltages. The oscillograph is capable of recording an action occurring as slowly as once each 2 sec. or a transient of 1/300,000,000 part of 1 sec. duration. One modern tube permits recording at writing rates in excess of 2,500 km. per sec. (using a 35-mm. camera with f/1.9 lens) corresponding to sine-wave transients of 10,000 mc. per sec.

As a measuring device the cathode-ray tube operates at high impedance and thus does not materially alter the waveform under investigation. It is practically free of inertia in operation, which cannot be said of other electrical measuring instruments incorporating mechanical or electromechanical systems. The cathode-ray tube also permits the investigation of much higher frequencies than are possible by other means. It is the only measuring instrument capable of accurately plotting a visual curve of one electrical quantity as the function of another electrical quantity. Its many applications in every branch of science are too numerous to mention within the scope of this specialized text.

* Du Mont, A. B., "Practical Operation of a Complete Television System," *Radio Eng.*, Vol. II, No. 7 (July, 1931).

2.2 Operation of the Cathode-Ray Tube. In order that the reader may better understand the operation of the cathode-ray tube, and before a detailed description of the device is undertaken, part by part, a general summary of the most important functions of the tube will follow.

The physical arrangement of the electrodes in a high-vacuum cathode-ray tube incorporating electrostatic deflection is illustrated schematically in Fig. 2.1. The tube is seen to be made up of the following parts: a containing envelope of properly shaped glass for the purpose of maintaining the necessary vacuum in the assembled tube; a specially prepared cathode *K* for the generation of free electrons which are finally formed into the necessary beam; an electrode *H* for the purpose of

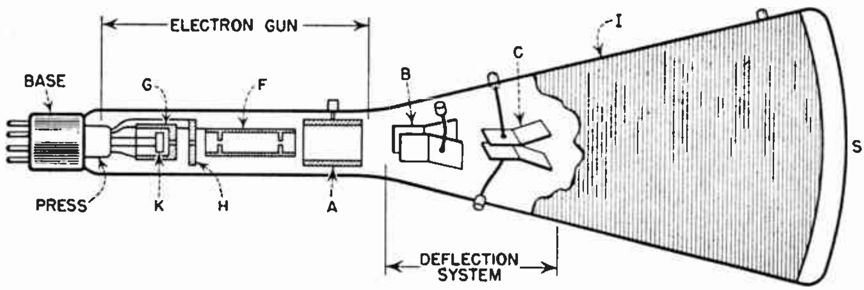


FIG. 2.1 Cathode-ray tube employing electrostatic deflection system.

accelerating the free electrons; a focusing electrode *F* which is also termed anode 1, for concentrating the electrons into a cathode-ray, or clearly defined, beam; a high voltage anode *A*, termed anode 2, for further accelerating the electrons constituting the beam; a control electrode *G*, referred to as grid 1, or the control grid, for controlling the beam current; two sets of electrostatic deflection plates *B* and *C*, for suitably deflecting the electron beam once it is generated, and focused, and accelerated; and a screen *S* which is suitably coated on the inner surface of the enlarged end of the bulb with a chemical phosphor which displays a fluorescent glow at the impact point of the electron beam.

The electron gun is made up of electrodes *K*, *G*, *H*, *F*, and *A*. It is termed the "electron gun," since its function is to generate a well-defined beam of free electrons, directing them toward the prepared fluorescent screen *S*. The particular tube illustrated schematically is used principally in oscillographic applications, i.e., in the cathode-ray oscillograph, although some electrostatic-type tubes are still employed in inexpensive television receivers as a picture tube.

Because the concentrated electron beam is made up of rapidly moving electrons, it constitutes an electric current possessing both electromagnetic and electrostatic properties. Since no material conductor is required

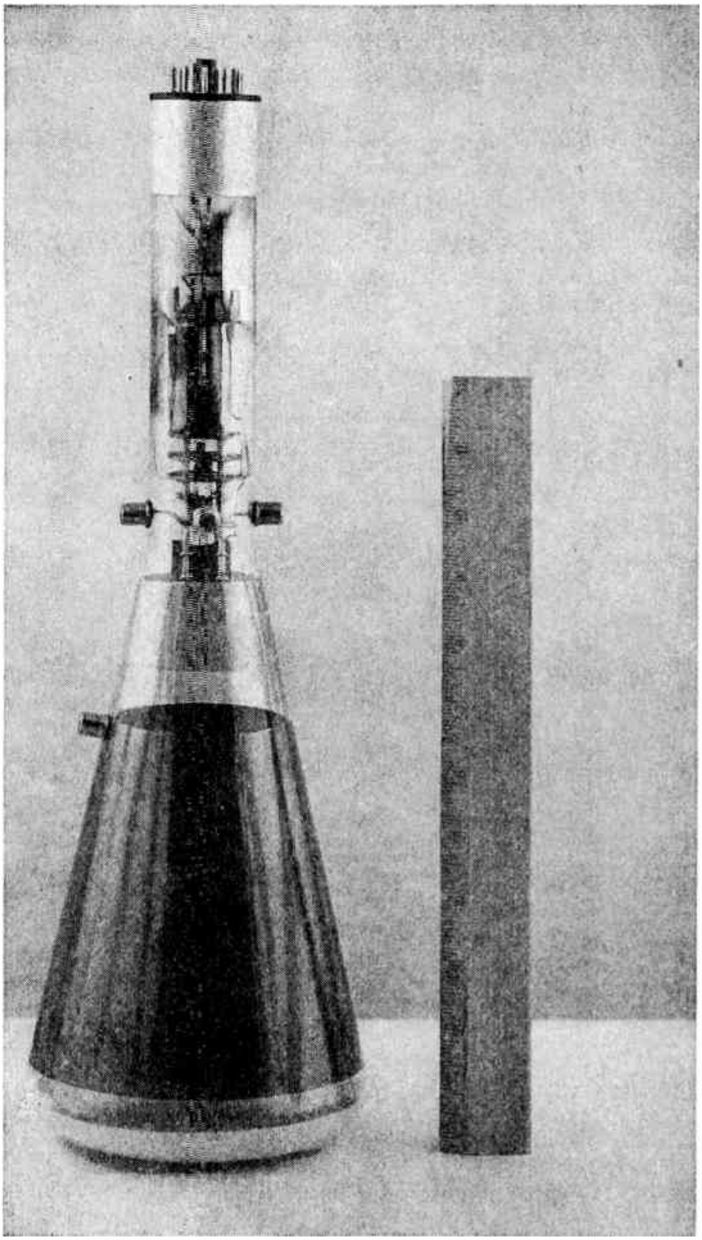


FIG. 2.2 Norelco type 5JP1 5-in. cathode-ray tube. This tube employs an electrostatic deflection system. Typical operating characteristics are: E_f: 6.3 v., 0.6 amp.; E_b, or E_{g2}: 1,000 v. maximum; E_{b2}: 2,000 v maximum; E_{b3}: 4,000 v. maximum; grid cutoff volts: -56 ± 25. (Courtesy of North American Philips Company, Inc.)

to carry the electrons, the generated, focused, and accelerated beam possesses negligible mass and inertia. Due to the fact that the beam is practically inertialess, it may be quite easily deflected by either electrostatic or electromagnetic fields. The term "magnetostatic field" is sometimes employed synonymously with the term "electromagnetic field." In the conventional electrostatic type cathode-ray tube, the deflecting force produced by the particular phenomenon under investigation (through use of the oscillograph) takes the form of an electrostatic field produced by

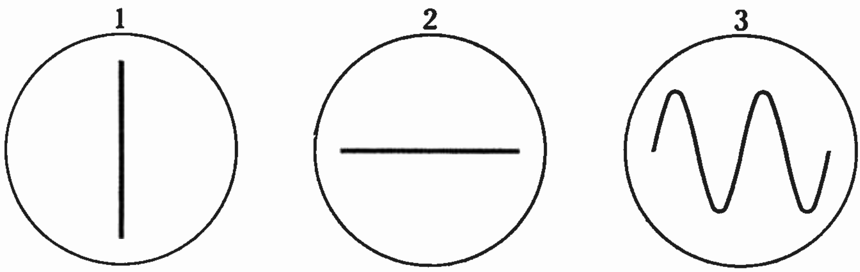


FIG. 2.3

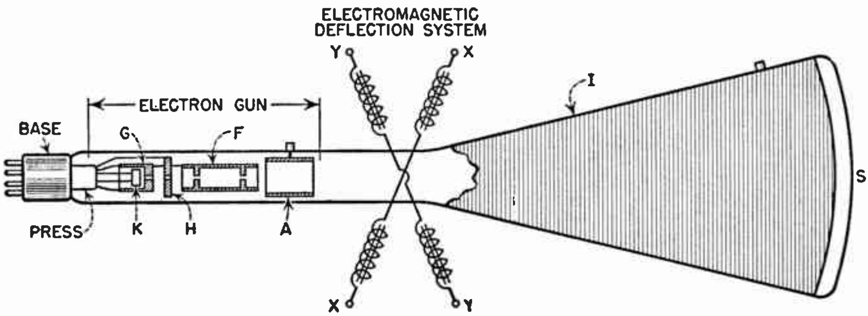
a potential applied across the vertical deflecting plates *B*. Should the applied potential constitute an a-c voltage, the produced electrostatic field results in the fluorescent spot moving up and down across the screen (when viewed at the face or front of the tube). This movement will result in the spot tracing out a vertical line as shown in (1) in Fig. 2.3.

A "time sweep" potential of suitable waveform and amplitude is applied across the horizontal deflecting plates *C*, resulting in the beam moving back and forth horizontally, as in (2) of Fig. 2.3. The fluorescent pattern may be easily viewed in a well-lighted room. The combined deflecting forces of both the horizontal and vertical electrostatic fields will result in a pattern such as that shown in (3) in Fig. 2.3. The resulting image, displayed on the fluorescent screen of the cathode-ray tube, may be viewed, measured, and photographed.

A second type of cathode-ray tube is shown schematically in Fig. 2.4 and is termed an electromagnetic cathode-ray tube. Here, electromagnetic deflection of the beam is employed. This type of cathode-ray tube has found widespread application as a picture tube in modern television receivers and for reasons that will be discussed later in the text. Deflection of the electron beam generated by the "gun," both horizontally and vertically, is effected by two electromagnetic fields at right angles to one another, which are produced by two sets of magnetic deflecting coils *X* and *Y*. Except for the method of deflection, both types of cathode-ray tubes are identical in practically every respect. Magnetic focusing is sometimes used and will be described later.

Thus, a general description of the design, construction, and operation of the cathode-ray tube has been undertaken for the reader. It is well that this introductory description be fully understood before proceeding further with the text, for each element of the tube will be discussed in detail so as to impart a more precise understanding of the device.

2.3 The Electron Beam. The electron beam in cathode-ray tubes may best be visualized as a narrow stream of negatively charged particles. Each particle—an electron—has a mass of 9.0×10^{-28} g. and a charge of -1.59×10^{-19} coulomb. The radius of each electron has been calculated to be 1.9×10^{-13} cm., and the particle is assumed to be spherical in nature. There are billions of these electrons leaving the emissive



•Fig. 2.4 Cathode-ray tube employing electromagnetic deflection system.

cathode and moving toward the fluorescent screen with velocities estimated at 30,000 m.p.s. At the point of impact with the screen they result in a clearly defined spot, the diameter of which may be as low as 0.2 mm. or less. The spot size is regulated and its intensity adjusted by suitable choice of electrode voltages and, to some extent, by the geometry of the gun construction, a subject for later discussion. Typical gun construction of an electrostatic-type cathode-ray tube is shown in Fig. 2.5.

The indirectly heated cathode, from whence the electrons forming the beam are emitted, is of tubular form with a flat emitting surface. This specially prepared surface is parallel with the chemically treated fluorescent screen at the far end of the envelope. The flat end of this cathode, usually of pure nickel, is coated with a preparation of strontium and barium oxides, the cathode cylinder being electrolytically cleaned and fired in hydrogen at about 700°C. before the coating is applied. The heater element within the cylindrical cathode is formed of pure nonsag tungsten. It is coated, in one typical manufacturing operation, to about three or four times its original diameter with the purest aluminum oxide, which is later sintered at 1600°C. to provide adequate insulation. So that the tungsten wire heater coil will be noninductive in character and have minimum effect on the electron beam, the coil is usually formed, physically, in a double spiral. Thus, the magnetic field of one half

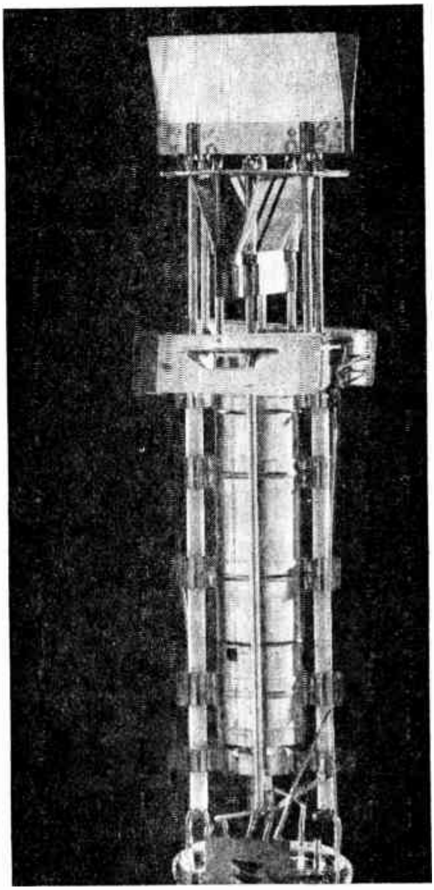


FIG. 2.5 Modern electron gun of a Du Mont electrostatic type cathode-ray tube. Above the press, through which leads from the elements pass to the tube base, is located the cathode support. The first cylindrical electrode above it is the control grid (modulating electrode). The thin cylindrical electrode directly above it is termed the "preaccelerator electrode." The third cylindrical electrode from the lower end is the first-anode focusing electrode. The final cylindrical electrode at the upper end of the gun is the second accelerating electrode. The horizontal and vertical plates of the deflection system are electrically welded to supports at the end of the gun assembly. (Courtesy of Allen B. Du Mont Labs., Inc.)

the winding is phase-opposed to the magnetic field produced by the second half of the winding, and the fields cancel for all practical purposes.

As stated, the heater coil is suitably insulated from the inner surface of the cathode cylinder by means of the coating imparted to the surface of the tungsten. However, the heater coil is physically close to the inner cathode surface, so that the thermal circuit is closed for all practical purposes; hence, heat is effectively transferred to the cathode proper.

It is from the outer surface of the cap enclosing the screen end of the cathode cylinder that the billions of electrons are emitted. They are then accelerated, focused, and sped on their way toward the screen of the tube. An electron gun is illustrated in Fig. 2.6.

2.4 Cathode Emission. To properly understand the electron emission that takes place from the coated surface of the capped end of the cathode cylinder, one must know something of the electron theory as applied to metals. Fundamentally, it has been shown that any metal

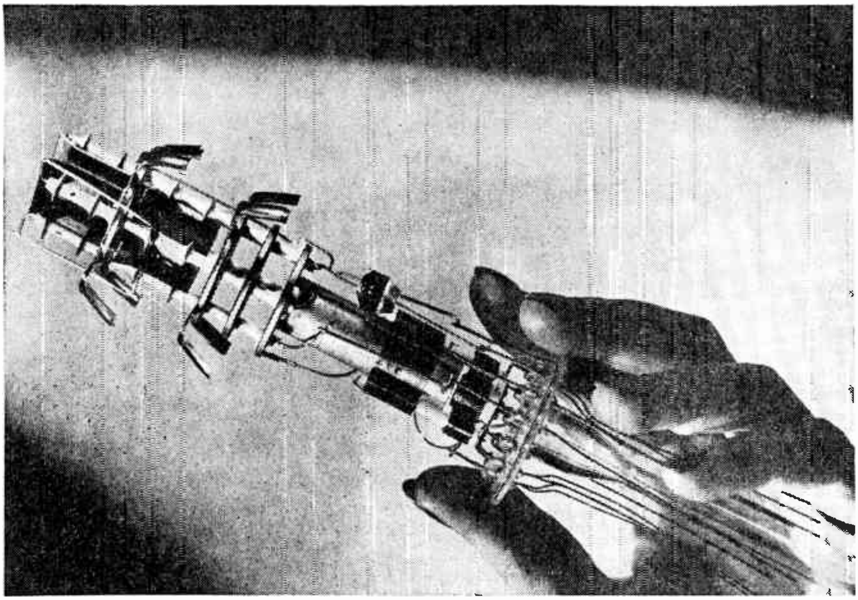


Fig. 2.6 Electron gun of a Norelco cathode-ray tube employing electrostatic deflection. (Courtesy of North American Philips Company, Inc.)

comprises a three-dimensional lattice of positively charged ions. These ions are assumed to be fixed within the structure of the metal. Electrons move about among the fixed ions, since the attraction of the positive ions for the negative electrons is almost nullified because of the repulsion some electrons receive from other electrons. In fact, there are approximately 1 or 2 free electrons per atom of metal and, although the same electrons within the atomic structure of the metal are not free for any given length of time, because some of them come under the influence of other ions, it is the consistently large number of free electrons which, in the end, result in the well-known thermal and electrical conductivity evidenced by all metals.

The kinetic energies of the free electrons within an atom of a given metal are not the same but are distributed according to a law. The distribution is known as the Fermi-Dirac distribution. This distribution does not conform with the distribution of molecules within a gas, as described by Maxwell. While the molecules of a gas have zero kinetic energy at 0° abs., the free electrons inside the structure of a metal have been proved to possess kinetic energies at 0° abs.

In pure nickel, of which the cathode of the cathode-ray tube is constructed, there are approximately 2 free electrons per atom of the metal and a cubic centimeter of the metal has been shown to possess approximately 18×10^{22} free electrons. The total kinetic energy in a cubic centimeter of nickel is calculated to be 20×10^{11} ergs. This tremendous kinetic energy, demonstrated by these free electrons upon the walls of a cubic centimeter of pure nickel, results in a pressure of about 13×10^5 atm. and the electrons literally tend to explode out of the metal.

However, the potential energy of a free electron within the metal is less than that outside the metal. The difference lies in the work (transfer of kinetic energy into potential energy) that a free electron has to exert against the surface forces in order to make its escape from the nickel. The potential barrier at the surface of the metal is present, since the atoms within the metal are arranged in a lattice-type structure. It has been shown that all metals are of crystalline formation, the molecules (and their contained atoms) being arranged in crystals. The atoms that make up the metal lattice do not retain their rather loosely bound electrons which are associated with them in their free state. The electrons released when a metal crystal is formed do not retain precise positions in the lattice, but exist as an electron gas that is free to move about through the structure. Therefore, in order that electrons may stay within the metal, a potential barrier must be assumed to be present at the outer boundaries of the metal.

An electron must attain sufficient momentum and velocity to break through this surface barrier in order to be liberated. The energy of an electron is

$$E = V_0 + \frac{P^2}{2m}$$

where V_0 = potential energy
P = momentum
m = mass

Electrons must be given sufficient kinetic energy to escape through the normal potential barrier. This energy is usually supplied in the form of thermal (heat) energy taken from the lattice of a heated metal crystal. The electron emission from the metal in this case is termed thermionic emission.

Thus, it is possible to cause electrons to be emitted from the metal cathode of a cathode-ray tube by heating the metal surface to such a high temperature that the surface potential barrier can be pierced by electrons seeking to escape. Thus, the potential barrier is lowered. The emission current obtained is dependent upon the height of the potential barrier above the Fermi distribution of free electrons, upon the shape of the barrier, as well as upon the energy distribution of the free electrons.

It is conventional practice to coat the exposed metal surface of the cathode with barium and strontium oxides in order to improve the electron emission characteristic. Tungsten, alone, will emit about 13 ma. per sq. cm. of surface when the metal is heated to 2200°K. The oxide-coated cathode results in a considerable improvement in the electron-emission capability of the cathode. The presence of the barium and strontium oxides lowers the surface potential of the metal, resulting in more copious emission.

The cathode comprises a thin layer of barium and strontium on a nickel base. Best results are to be had when the base metal includes a small quantity of reducing agent (Si, Ti, Al, etc.). The cathode material is customarily prepared by coprecipitation of strontium car-

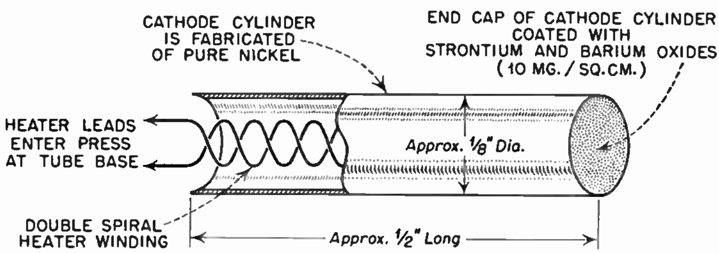


Fig. 2.7 Modern cathode-ray tube heater and cathode design.

bonate and barium carbonate. The two form a mixture that contains about equal parts by weight of the two components, although the ratio of one to the other varies with different cathode-ray tube manufacturers. The mixture, suspended in a suitable organic binder, is applied to the cathode in the form of a spray. The tungsten-wire heater coil within the cathode is wound in a double spiral so that the magnetic field of half the winding is canceled by the equal but opposite magnetic field of the other half. The heater coil is insulated from the cathode, but the insulation touches the cathode to afford good conduction of heat.

As has been stated, the mixture of barium and strontium oxides is applied to the exposed end of the cathode in a spray. After the mixture is carefully applied, the cathode is still inactive as an emitter and must go through an activation process. The temperature of the cathode is raised in vacuums until it is much higher than the normal operating temperature. The cathode draws a large electron current at this increased temperature. The cathode temperature, the electron current produced, the thickness of the coating, and the type and quantity of residual gas in the envelope of the tube determine the activation process necessary for various cathodes. Different manufacturers employ various methods toward the same end. Typical cathode-ray tube heater and cathode construction is illustrated in Fig. 2.7.

The actual purpose of the activation process is to produce a thin layer

FIG. 2.8 Operator using a spray gun to coat the cathodes of cathode-ray tubes at the Dobbs Ferry, N.Y., plant of the North American Philips Company, Inc. Held in a special platen, 165 of the tiny cylinders have their emissive tips coated simultaneously with the chemicals.

of free barium on the exposed surface of the cathode. The heat causes the barium and strontium carbonates to be broken down to oxides of these materials, and enough barium oxide is reduced to barium to produce the thin surface coating necessary. The emission of a BaO-SrO coated cathode is at maximum when the coating has a ratio of 60 per cent SrO and 40 per cent BaO. For a reasonable cathode life expectancy it has been shown that not more than 2 ma. per sq. mm. may be drawn from the conventional oxide-coated surface.

In the manufacturing process followed by one large cathode-ray tube manufacturer, the ratio of 60 per cent $BaCO_3$ and 40 per cent $SRCO_3$ is used in preparing the mixture to be sprayed on (see Fig. 2.8). It is suspended in amyl acetate, a small quantity of nitrocellulose being added as a binding agent. Great care is exercised in spraying the emissive surface. The air admitted to the spray gun must be absolutely clean and filtered. No impurities may be admitted to the solution. About

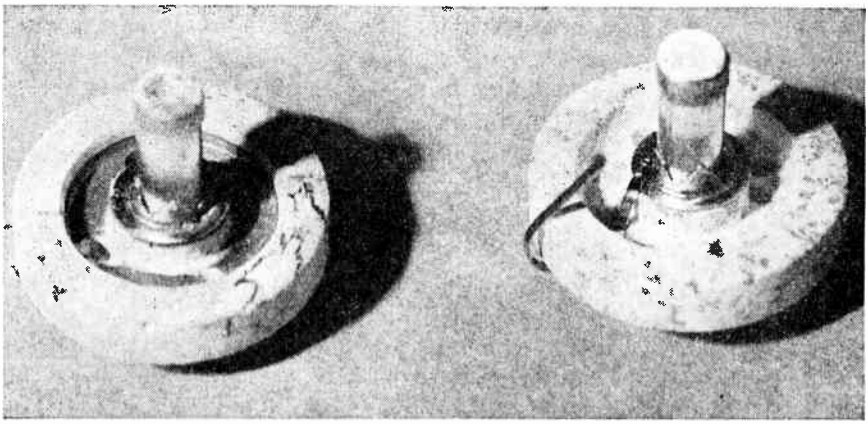


FIG. 2.9 Enlarged photograph of typical cathode construction. The cathode is fixed upon a ceramic support which ensures mechanical rigidity when mounted in the gun assembly. The flat cylindrical end of the cathode is coated with strontium and barium oxides. It is from this surface that the electrons are copiously emitted. (Courtesy of North American Philips Company, Inc.)

10 mg. per sq. cm. of solution is usually the amount of coating applied. Figure 2.9 shows the finished cathode and heater assembly mounted on its ceramic support.

In processing the filament, it is first formed into the double spiral coil previously described. The winding is accomplished by taking the length of pure tungsten wire necessary to form one heater coil and placing its center into the notched end of a suitable cylindrical rod. The rod is then moved with a screw motion to form the required double spiral. The tungsten wire used is less than 0.010 in. in diameter and must be carefully handled by the operator. After it is formed into the desired shape, it is thoroughly cleaned and placed in a suspension of aluminum oxide in amyl acetate. Enough nitrocellulose is added to the solution to act as a binding agent. One manufacturer then dries the heater in air and fires it in either hydrogen or a vacuum at approximately

2,000° abs. for a short period of time. The method of drying and firing is not the same with each manufacturer. After the heater is fired, it possesses a ceramic coating of about 0.02 in. in thickness, which serves to insulate it from the cathode once the structure is assembled.

After processing, the cathode and heater must be assembled into the final shape as a part of the electron gun. The heater is carefully inserted into the cathode by applying pressure at many points in a direction toward the emitting cap. This pressure must be light so as not to inflict any mechanical damage to the structure. The fit is made so tight that both a good thermal connection and the necessary electrical insulation—heater to cathode—is provided. For all practical purposes, the insulation should be greater than 10^7 ohms, as tested by means of a high internal-resistance instrument. The operating temperature of the filament is about 500°C. above that of the cathode, and it usually operates at 2.5 v., 2.2 amp., or at 6.3 v., 0.6 amp. in modern tubes.

The cathode must pass through yet another process called "activation." This process is carried out with the tube still sealed to the vacuum pump and after evacuation and outgassing of the electrodes and the glass envelope has taken place. The amount of activation required is a function of both the thickness of the oxide coating already applied to the cathode-emitting surface and the method used in applying it. These vary among the different tube manufacturers. However, the process is kept under control by ascertaining the amount of current drawn from the cathode. The heater voltage is first raised to approximately 2 v. (for a 2.5-v. heater) to facilitate outgassing of the metal. A potential of approximately 50 v. positive is then applied to the gun elements, and the heater potential is slowly increased until the heater current is measured at about 3 amp., 2.2 amp. being the normal operating-current rating. The heater current is maintained constant at 3 amp. until the emission current, as drawn by the gun elements, and measured with an ammeter in series with the lead supplying the 50 v. positive potential to these elements, demonstrates no further increase. The filament current is then reduced to 2.2 amp. (normal), and the 50 v. potential applied to the gun elements is removed for 1 min. Emission readings are then taken with 5 and 10 v. positive potential applied to all gun elements. If the cathode is acceptable, the emission should be greater than 3 ma. for 5 v. electrode potential and greater than 7 ma. for 10 v. positive potential applied to the elements.

Before assembly, parts must not be handled with bare hands. Operators wearing gloves and working with clean tweezers eliminate the possibility of unclean components, and air conditioning of the room in which filament and cathode construction is performed obviates the possibility of too many rejects. Chemical analysis before application of the carbonates and other chemicals used also serves to reduce the number of rejects. In addition, it must be ascertained that the metals used are of the highest possible quality.

2.5 The Control Grid. In the early types of cathode-ray tubes there was negligible control of either the quantity or direction of electrons emitted by the heated cathode. This lack resulted in the development of bulky high current external power supplies to obtain a spot at the screen of useful size. Large transformer design added to the size of the cumbersome apparatus. In modern tube design, however, improvements in the cathode and the addition of a control grid have overcome these disadvantages to a large degree.

The modern high-vacuum, hot-cathode tube consists of a source of electrons, i.e., indirectly heated cathode, a control electrode, a focusing system, a deflecting system, and a chemically prepared viewing screen. All these parts are enclosed in a highly evacuated glass envelope of special design. The cathode is surrounded by a Wehnelt cylinder, or control grid, designated by the letter G in Fig. 2.1, and is sometimes referred to as grid No. 1 or as the modulating electrode. It is called a Wehnelt cylinder after its inventor. It is to this cylinder in the modern television receiver that incoming signals are conducted. These signals vary the potential difference of this element with respect to the cathode, serving to alter the intensity of the beam reaching the screen in conformity to the picture-signal potentials originally generated at the transmitter.

The direction in which electrons are emitted is controlled by a circular metal disk, usually of nickel, fixed to the end of the Wehnelt cylinder nearest the screen. Electrons are permitted to pass only through a small circular aperture in the exact physical center of the disk. Figure 2.10 illustrates how the control grid is located coaxially about the previously described cathode assembly and indicates the lines of force of the electrostatic field between these elements. We may consider an electrostatic field present, since the two metal cylinders are fixed coaxially in the assembly, with a dielectric intervening, across which there is a potential gradient. When the cathode is heated to the point of emissivity, and if an electron is propagated in the direction of the arrow KA, it will be subject to the influence of the electrostatic field. The force upon the electron will be in the direction of the arrows along the lines of force it traverses, and the result is that the electron moves in the direction KA, being curved along a path KCP. Thus, the electron has been forced to change its path from that of a straight line to that of a curve, owing to the electrostatic force that is being applied along its route. Likewise, a second emitted electron traveling along a course KB will be forced to follow the route KDP. Now, the path of the two liberated electrons will be seen to cross at P, and this holds true for any emitted electron which passes through aperture X.

By increasing the aperture, it is possible to increase the current density at the hot core of the electron beam. However, there is a practical limit to which this can be carried, since an aperture of too large diameter at the end of the Wehnelt cylinder will increase both the amount of the masked current and the crossover diameter. This crossover point, rather than the heated cathode surface, is finally imaged on the fluorescent screen of the tube. So, as the aperture is increased in diameter, the spot size, as projected upon the screen, will be larger. In addition, as the bias applied to the control grid is raised, the diameter of the aperture is effectively reduced, resulting in smaller spot size at lower operating current. The geometry of the grid element can be controlled,

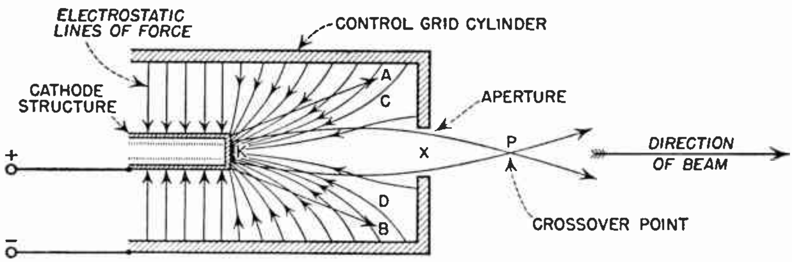


FIG. 2.10 Electron optics at control-grid lens, where electrons are first concentrated into a small beam.

so that for high-definition television images a small intense spot can be achieved or a bright large spot for high-speed traces.

The potential applied to the control grid is usually more negative than that applied to the cathode, and a difference of potential exists between the two elements. As a result, a smaller number of electrons are enabled to follow paths which will permit them to pass through the circular aperture at X. Some of the electrons are masked and not projected through the aperture. Also, the attraction of the first and second anodes, beyond the grid structure, will be decreased by the increased negative voltage on the grid. This permits the quantity of electrons making up the beam to be controlled as well as allowing control of the brightness of the spot at the point of impact with the chemically treated fluorescent screen. Consequently, there are two major functions ascribed to the control grid. First, it acts to permit control of emission from the heated cathode. Second, it acts as an electron lens to concentrate the electrons into a small, sharply defined beam before entering the deflecting system of the tube. It must not be misconstrued as a focusing anode, however, since it is not intended for this purpose.

The control grid has been referred to as a modulating electrode because a fixed bias may be applied to the grid and a varying bias or signal may be superimposed to vary the instantaneous brilliance along the trace on the screen in much the same manner as the plate current of any vacuum tube may be varied by a change of potential on the control grid. The action might be more directly compared to that taking place in grid-bias modulation of a radio transmitter.

In the manufacture of the control grid, a cylinder is formed, usually of nickel or copper-nickel alloy, with one end closed by a disk having a small hole or aperture in its exact center. Any metal used in the construction of the grid must be nonmagnetic in character. If stainless steel is used in the fabrication of any of the gun parts, these components must be treated in an inert or reducing atmosphere at temperatures greater than 1000°C. and precautions taken to prevent oxidation of the metal, since a bright, clean surface is absolutely essential for welding.

The control-grid cylinder must be coaxial and concentric within ± 0.002 in. with respect to the other cylinders and apertures of the electron gun, and all apertures throughout the gun assembly must be precisely parallel and at exactly 90 deg. with reference to the axis through the tube.

The spacing between the inner surface of the disk enclosing the end of the cylinder and the coated end of the cathode proper is very critical. It must be maintained within ± 0.001 in. of the value dictated by a particular design.

External connection to the control grid is made through the base of the cathode-ray tube, as are connections to the heater and cathode.

2.6 The Screen Grid. The element situated between the control grid and the first anode in typical gun construction is known as the "screen grid," designated by the letter *H* in Fig. 2.1. This electrode consists of a metallic disk of nickel or copper-nickel alloy, with a circular aperture in its center. It is located very close, physically, to the control grid. A potential is usually applied to it of a lower value than that applied to the first anode, just as the potential applied to the screen grid of any vacuum tube is usually maintained at a lower value than that applied to the plate.

The characteristic of the screen grid is such that the total current drawn by the cathode is independent of the potential applied to the first anode of the cathode-ray tube. This condition is much more likely when the screen grid is operated at a slightly lower potential than that applied to the first anode. (Not all cathode-ray tubes employ the screen grid, as described.) This element is externally connected through the base of the tube, as are the elements previously described.

2.7 Electron Optics. There is a close analogy between the path of an electron moving through the electrostatic or electromagnetic fields inherent in the cathode-ray tube and the path of a ray of light passing through refractive mediums. The analogy was formulated by Sir William Hamilton in the early part of the nineteenth century and has since been used by physicists to describe the action that takes place within the cathode-ray tube. The science of electron optics deals with the geometrical relations of the propagation of electrons as compared with light rays and not at all with physical optics. Therefore, electron optics involves the laws incident to the rectilinear propagation of the electron as compared with light, the reflection and refraction of the electron as it follows its course from cathode to screen, and the independence of the electrons making up the beam, just as the rays of light making up a beam are independent one of the other. From the study of electron optics has come the axially symmetric focusing systems found in the cathode-ray tubes of today.

As shown by Fermat's principle and expressed mathematically for geometrical optics by the equation

$$\int dt = \int \frac{n}{c}\, ds = \frac{1}{c}\int n\, ds = \text{minimum}$$

where n = the refractive index of medium
c = the speed of light in vacuums
t = time

In the instance of a beam of electrons, such as pass from control grid to screen in the cathode-ray tube, the conditions for a minimum are given by the equation

$$\int p\, ds = m\int v\, ds = \text{minimum}$$

where m = mass
v = velocity
$p = mv$ (impulse)

If the equations are compared, it is seen that the velocity of electrons in the field of electron optics corresponds to the refractive index in geometric light optics. It has been pointed out that while the refractive indices for rays of light have a range of 1 to 2, the ratio of velocities of electrons at their source and at their ultimate destination (corresponding to optical refractive index) may be varied at will.

In optical systems developed for the transmission of light we find a series of spherical refracting surfaces having a common axis of symmetry which is called the "optical axis" of the system. The index of refraction changes abruptly as light rays pass from one medium to the other. In the study of electron optics, the index of refraction is found to be a continuous function of position. In an electron optical system, the large number of coaxial refracting surfaces must be considered.

The speed of electrons traveling through the gun of the cathode-ray tube may be easily computed. When the potential applied to the first anode is not in excess of 4,500 v., the velocity of an electron is given through solution of the equation:

$$v = 5.95 \times 10^7 \sqrt{V}$$

where v = velocity in centimeters per second
V = final anode voltage

In light optics, the relation of image to object is shown by the equation

$$A_1 \Omega_1 n_1^2 = A \Omega n^2$$

where A = image area
Ω = angle of beam
n = refractive index

In the field of electron optics the velocity V is substituted for the refractive index n. Because the object in the cathode-ray tube is a very small spot, it has been pointed out by J. R. Beers that, to meet the conditions of the above formula, the velocity of the electrons in the image area must be several hundred times that of electrons in the gun area.

Just as the focusing of light rays results from their passing through refracting mediums, as shown by the laws of geometric optics, so are electrons focused by passing them through rotational and axially symmetric electric fields of varying strength. The number of electrons admitted to the system is a function of the amount of negative potential applied to the control grid of the cathode-ray tube. Through the use of stopping and limiting apertures mounted within the first anode of the tube, the electrons traveling parallel to the axis of the system are selected as the most satisfactory for making up the fixed electron beam.

To cover the entire field of electron optics is beyond the scope of this text, but numerous works have been published that will enable the student or engineer to follow this subject in great detail. Most notable is *Electron Optics in Television*, by I. G. Maloff and D. W. Epstein (McGraw-Hill Book Company, Inc.).

2.8 Focus of the Electron Beam. The first and second anodes, two cylindrical electrodes—the second sometimes made larger in diameter than the first, comprise an electronic focusing system for the beam. These two electrodes are designated F and A in Fig. 2.4. Though the control grid (already described) operates to reduce the diameter of the electron beam, it is not capable of optimum focusing action. The control grid does focus the electrons to a point close to grid No. 1, but the electron beam achieves wider diameter or diverges beyond the crossover point. It must, therefore, be reduced in size before entering the deflection system of the tube. It must be remembered that if the cathode-ray tube is to permit precise electrical measurement, or if it is to be used in a high-definition television system, the spot size must be kept to a minimum. Therefore, the multitudinous electrons emitted by the hot cathode are focused and accelerated by the action of the grids and anodes, 1 and 2. Because of the circular apertures in the several tube elements and the characteristics of the electric field at the two anodes,

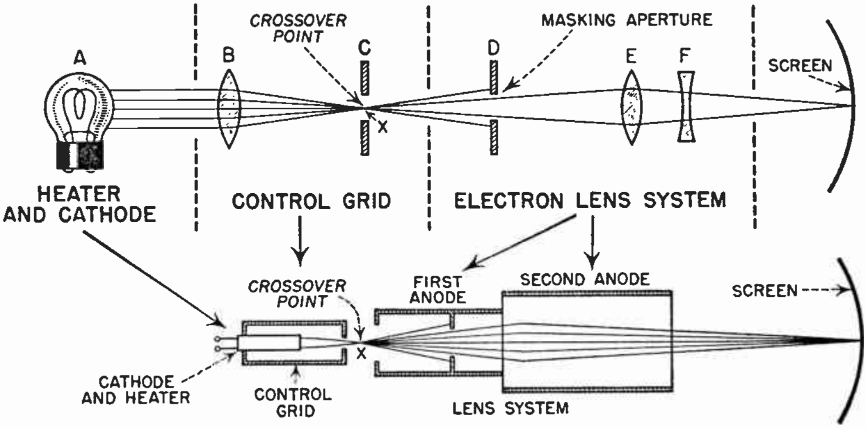


FIG. 2.11 Comparison of optical and electron focusing systems.

the stream of electrons is constricted into a very small diameter beam which passes through the deflecting system before bombarding the screen.

The focusing of the beam of electrons within the tube is analogous to the focusing of light rays by means of an optical lens system. The electron optical system operates similarly to the system of lenses and the source of light (Fig. 2.11).

In this analogy, the lamp *A* replaces the heater and cathode of the cathode-ray tube. It is the source of light, just as the indirectly heated cathode is the source of free electrons in the cathode-ray tube. The light from the lamp is passed through an optical biconvex lens *B*. This lens focuses the rays of light into an optical point *X*. The lens *B* is equivalent to the control grid of the cathode-ray tube. The lens at this point is sometimes referred to as an immersion lens, owing to the fact that the object is immersed in the lens. The immersion lens may be described as two refracting surfaces, the first convergent, with the ratio of indexes being quite large. This surface, therefore, will focus all electrons originating at the cathode surface very close to the focal point of this surface, producing the crossover.

After the light rays cross over, they converge at a single point insofar as the following lens system is concerned. Therefore, by optimum adjustment of the biconvex and biconcave lenses at *E* and *F*, the light rays passing through the optical system can be focused into a spot on the screen of like diameter as obtained at the crossover point *X*. The amount of light impinging upon the screen can be controlled by operating the shutter at *C*, i.e., varying the diameter of the aperture at that point in the system.

The rays stopped by *D* are not focused by the lens system *E* and *F*, because of their angles; so the placement of a second disk with circular aperture at *D* prevents them from passing beyond this point. This ensures that there is no scattering effect of these light rays and that the image on the screen is not distorted.

Figure 2.11 illustrates an electrostatic focusing system that is in all respects analogous to the system just described. In the optical system of Fig. 2.11, optimum focusing of the spot at the screen may be effected by changing the position of the biconvex lens *E* along the axis of the lens system, and some point along the principal axis will result in sharpest focus at the screen. However, it is mechanically impractical to focus the spot in this manner in conventional cathode-ray tubes, and other analogous means must be substituted. It is accomplished through adjusting the d-c potential applied to the first, or focusing, anode.

The spot size, when measured visually, or from a photograph, is not necessarily the true size. Thus, the qualification "apparent spot size" or "apparent spot diameter" is usually used. If the spot is not optimum with respect to size and shape, the term "defocus" is applied. This defocus is analogous to a spot of light not properly brought to focus. If only the shape of the spot is distorted, the term "spot distortion" is usually applied. The true or actual size of a round spot is termed the "spot diameter." Therefore, "spot size" is a term applied to the true dimension or dimensions of a spot and is usually measured along the greater and lesser axes of the spot.

"Line width" is another term commonly applied to describe the dynamic, luminescent spot and refers to the absolute or true width of the moving spot measured at right angles to the direction of motion.

These definitions are given so that the reader will recognize the meaning of the terms when used in the text. They all apply to the tiny spot of light obtained at the screen when the beam is focused.

2.9 First and Second Anodes. Precise focusing of the spot is largely the function of the geometry of the first and second anodes, and the d-c potentials applied to these two anodes. The second-anode potential is always made greater than the first-anode potential, both anodes being held at positive d-c potential with respect to the cathode. As a result, the electrons emitted from the cathode are attracted and accelerated toward the fluorescent screen of the tube.

The first and second lens comprise what is termed a "bipotential lens." Such a lens has different equipotential regions on its two sides and is the type generally used in television cathode-ray tubes, principally because it produces a smaller spot at the point where it impinges with the screen.

Electrostatic lines of force are present between the two anodes, since they are constructed of metal and a dielectric intervenes and a potential difference exists. The lines of force are roughly plotted in Fig. 2.12. The electrostatic field that obtains is the one which results when two

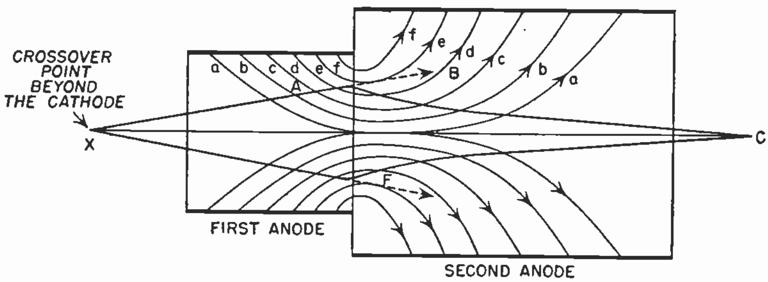


FIG. 2.12 Electrostatic field at first and second anodes.

metal cylinders, one of larger diameter than the other and both lying along an identical and common axis, are placed end to end.

It is easy to visualize the effect this electrostatic field exerts upon an electron in flight from cathode to screen, if one will investigate the angular electrostatic forces exerted. An emitted electron moving away from the crossover point beyond the control grid and along the axis *XAB* will pass across the electrostatic line of force designated *a*, and the electrostatic field will force it toward the axis *XC*. In the deflection of its flight, this electron will also pass across the electrostatic lines of force *b, c, d* and *e*, each of which, imparting an additional force, will further press it toward the axis *XC* from cathode to screen. The action of these combined electrostatic lines of force within the field will cause the electron to follow a trajectory *XAC*.

In the region of the field near the axis *XC*, the lines of force are almost perfectly parallel to this axis, and the electron will not be forced closer to the axis but will be accelerated in flight by the electrostatic lines of force designated *c* and *d*. The electron develops additional speed, and, since the electrostatic field at the right end of the second anode is relatively weak, the electron is only very slightly forced off its course by attraction along electrostatic lines *b* and *a* as it leaves the anode.

Owing to the geometry of the anodes, all the electrons entering the first anode are similarly acted upon by the electrostatic field. Those far off the axis XC have greater force applied to them than higher velocity electrons which speed through the system nearly parallel with this axis; yet all are made to converge at the point of focus on the fluorescent screen.

The aperture at the right, or screen, end of the cylindrical first anode is known as the "masking aperture" and limits the diameter of the electron beam. The beam is also limited in diameter by the presence of the second anode aperture. Both apertures ensure that the beam is of small diameter, round and well defined as it passes through either the electrostatic or electromagnetic deflection mechanism.

With proper geometry in gun construction, it is entirely possible to produce a beam of such small diameter that it will pass through the masking aperture without limiting, but the design engineer actually prefers to mask down a larger diameter beam to the desired size. Better utilization of the high-voltage current and more sensitive control of the beam result from generation of a beam of very small diameter, but lower maximum current at the fluorescent screen obtains. This is due to the fact that the beam is most intense at its core and less intense at its outer circumference and that the core density increases rapidly with increase in beam diameter.

The provision of a masking aperture at the screen end of the cylindrical first anode, a point along the gun which is field-free, results in part of the beam being masked. Hence, only the intense core is shot through to the deflection system beyond.

The cylindrical first and second anodes of the conventional cathode-ray tube used in an oscillograph for purposes of electrical measurement are usually connected to the external circuit by means of leads through the insulating base of the tube, as are all the other gun elements thus far described. This base is preferably molded of ceramic material to exclude the possibility of high-voltage breakdown between pins, since high potentials are present. For example, in a typical tube with screen diameter of $9\frac{1}{16}$ in. diameter, 7,000 v. are applied to the second anode, while 2,000 v. are applied to the first anode. These voltages are considerably higher in tubes of large screen diameter which are currently used for direct viewing of large-screen television images. A second-anode potential of 13,000 v. is used with a 19-in. tube. When very high d-c potentials are applied to intensifier electrodes, it is often necessary to make electrical connection through the glass wall of the envelope, thus minimizing the possibility of flash over when surges occur.

The *television cathode-ray tube* employs a second-anode construction that is quite different from the one used in the construction of a tube developed for use in an oscillograph or oscilloscope. The second anode is not necessarily a metal cylinder supported by the gun structure. It is, instead, a conductive coating along the inner walls of the glass envelope, extending from the fluorescent screen to well beyond the end of the gun in the direction of the cathode (see Fig. 2.13). The coating is so formed as not to make electrical contact with the fluorescent screen material and is usually applied after the screen has been coated with its active material. The second-anode coating serves to collect the secondary electrons from the screen while functioning as an accelerating electrode and is made of a matte black material. Among the substances used

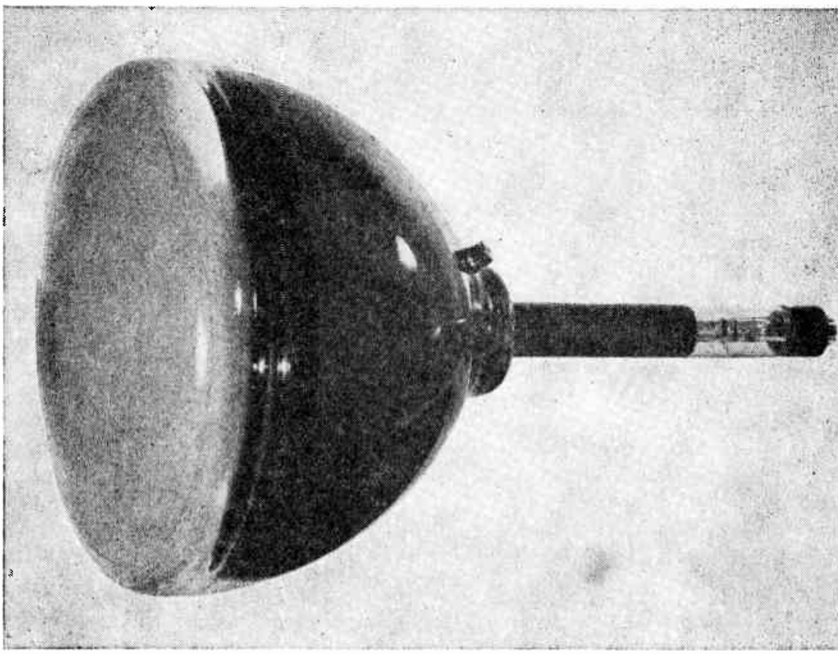


Fig. 2.13 Du Mont type 12DP4 12-in. television cathode-ray tube requiring electromagnetic deflection and focusing. The conductive electrical coating imparted to the inner walls of the envelope may be clearly seen. (Courtesy of Allen B. Du Mont Labs., Inc.)

for this purpose are Aquadag, Aquagraph, carbon black in sodium silicate, lead sulphide, and Dixonac. Aquadag is the material generally used in current manufacturing processes (see Fig. 2.14).

In mass production of cathode-ray tubes, the blackening can be obtained by spraying the inner walls of the glass blank with special sprayers and masks. The black coating may also be applied by the rolling method. In the latter process, the blank glass envelope is mounted in a machine so that the axis through the tube—cathode to screen—makes an angle with the horizontal in such a manner that it is slightly greater than the half vertex angle of the conical portion of the bulb. The Aquadag is diluted with distilled water in the ratio of about 3 : 1. This blackening suspension flows into the blank envelope until it just approaches the outer

FIG. 2.14 Method of applying a coating of electrically conductive material to a cathode-ray tube, creating an electrode upon the interior walls of the tube, which serves to accelerate the beam as well as to remove electrical charges from the walls of the tube. (Courtesy of Allen B. Du Mont Labs., Inc.)

circumference of the screen but does not come in contact with it. The bulb is then rotated about the axis—cathode to screen—untii the conductive coating flows uniformly over the inside wall of the envelope. The coating is sometimes dried until no moisture remains with a gentle air blast, the bulb having been previously drained of all blackening material in excess of the amount necessary to coat the walls. The tube is then baked in air at about 400°C. to drive off any organic materials in the suspension.

It is necessary to make good electrical contact between the conductive Aquadag coating and the external cathode-ray circuit. A short length of wire, sealed into the wall of the blank and projecting into the tube, makes the required electrical connection. The wire and glass to a radius of ½ in. about the lead is coated with silver paste which is reduced to silver by heating. As a result, the Aquadag is deposited in a layer over the silver, forming a mechanically strong connection between an external cap and the inner black coating of the envelope.

In the coating of another type of television cathode-ray tube, the envelope is not coated internally with a single layer of material extending from the screen to well beyond the end of the gun in the direction of the tube base. Instead, the coating is divided into two sections, each insulated from the other by the glass of the bulb which intervenes. This result is accomplished by masking a section of the wall between the two electrodes before the Aquadag or similar conductive coating is applied. The coating applied in the region of the gun is employed as a second anode, while the coating near the screen end of the envelope is utilized as an intensifier electrode. A higher d-c potential is applied to the intensifier coating than is supplied to the second-anode coating, resulting in improved acceleration of the beam and better deflection sensitivity. The ultimate result is an increase in screen brightness. The intensifier electrode also collects secondary electrons from the screen which result from bombardment of the fluorescent material.

There are many different *electron-gun designs* employed in the manufacture of television cathode-ray tubes, particularly in accelerating-electrode design, which varies widely. In some tubes the second anode is a nickel cylinder of the same diameter as the first anode, which is also termed the focusing electrode. In other tubes the second anode, or accelerating electrode, is of larger diameter than the first anode. The physical length of the first and second anodes, when they take the form of metal cylinders, vary widely in the tubes currently available because the electron optical design of the lens is not the same for each type of tube, although the ultimate result is essentially the same.

Some tubes employ the Aquadag, Dixonac, or other similar conductive coating on the inner surface of the tube, as the second anode. No metal cylinder is usually employed in these types as an accelerating electrode. In the new "metal" cathode-ray tubes used in television, a metal cone replaces the glass one, and it is employed as the second anode. Such tubes will be described later. Some tubes employ a very simple gun construction. There is a heater-cathode assembly; a control, or modulating, electrode; a first anode, or focusing electrode; and a second anode, or accelerating electrode, which is in the form of the conductive coating imparted to the inner walls of the tube. Such tubes employ magnetic deflection systems. A modern tube is illustrated in Fig. 2.15 and the specifications of another in Fig. 2.16.

FIG. 2.15 Type 12AP4 12-in. flat-faced R.C.A. Kinescope for television applications, an example of modern cathode-ray tube construction. (Courtesy of Radio Corporation of America.)

Another popular type of television cathode-ray tube employs a cylindrical metal second anode of the same diameter as that of the first anode. In this tube the metal cylinder comprising the second anode makes electrical contact with the conductive coating applied to the walls of the tube's large bulb. Thus, the second anode is in part a metal cylinder and in part a conductive coating along the inner walls of the envelope. Narrow metal fins extending from the upper end of the metal cylinder comprising part of the second anode extend outward in the direction of the inner walls of the glass neck surrounding the gun, making friction and electrical contact with the Aquadag or similar coating. In this type of tube the coating extends well down below the end of the gun and in the direction of the tube's base. The type of fin contact referred to can be easily seen in Fig. 2.6. In this type of construction, the metal cylinder and the second anode coating are both, of course, at the same d-c potential.

An electrostatic type of television cathode-ray tube employs a thin metallic coating upon the inner walls of the tube and surrounding the deflection-plate assembly. This coating serves to shield effectively the inner deflection assembly from extraneous electrostatic fields. Without such a metallic coating it is possible for extraneous electrostatic fields to influence the deflection of the beam, resulting in nonlinearity of the reproduced image. This treatment is quite common in the smaller tubes used in oscilloscopes or oscillographs.

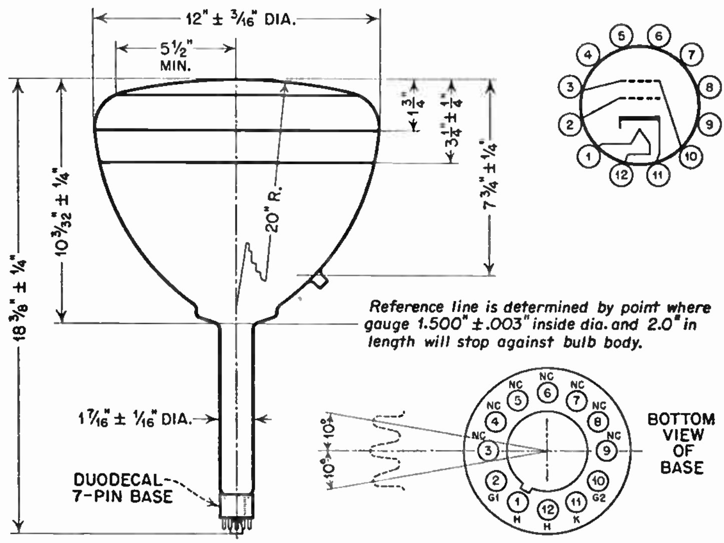


FIG. 2.16 Television cathode-ray tube specifications. (Courtesy of the Rauland Corp.)

Whatever the electron-gun construction in the television cathode-ray tube, there are certain requirements that must be met by the design engineer. First, the gun must be capable of producing several hundred microamperes of beam current. Second, the tube must possess control characteristics that allow it to be driven by the normal output of a video amplifier. This video amplifier must not require excessive power output; otherwise, its physical size and the cost of components would make it impractical. Third, the gun must be able to provide adequate focusing of the electron beam to a spot size that permits optimum scanning at the fluorescent screen. The electron-power capability of the gun must be such that satisfactory brightness at the screen is assured. The conversion efficiency of the screen is another factor influencing screen brightness. The electron optical design of the gun must be such that excessive potentials are not required at the first and second anode or at the accelerating electrode to achieve these results.

A new *high-voltage intensifier tube* has been described by Dr. P. S. Christaldi of Allen B. Du Mont Laboratories. This tube provides increased brilliance of the fluorescent trace and operates with relatively high final accelerating potentials without a reduction in deflection sensitivity which sometimes develops when increased final accelerating potential is employed. There is also more useful screen area with less spot distortion.

Postdeflection acceleration of the beam is provided by means of an intensifier electrode. Instead of a single electrode and a single intensifier to the second-anode gap, a number of electrodes and gaps are used; i.e., a number of rings of conductive coating are applied to the tube, gun to screen, with uncoated gaps separating the electrodes. The d-c potentials applied to the electrodes from an external voltage divider increase in magnitude in the direction toward the screen. Thus, there is a gradient of acceleration of the beam as it travels toward the fluorescent screen, the electrons attaining greater velocity as they pass each electrode. Distortions of spot and pattern are kept small by this method, and the final intensifier potential may be made five times that of the second anode without practical reduction of the useful area of the screen. In operation, the d-c potential applied to the second anode was 3,000 v., and the potential applied to final intensifier was 15,000 v. The potential was applied in five equal increments, the high voltage originating at a rectified radio-frequency type of power supply. There was an increase in brightness by a factor of 10 to 25 over the value obtained without the intensifier, and the deflection factor increased by 35 per cent as compared with 500 per cent had the same value of total accelerating potential been applied directly to the second anode.

Another improvement in the high-voltage intensifier tube was a decrease in spot size by 50 per cent, resulting in increased sensitivity of the tube as expressed by the beam deflection in line widths per volt. The maximum photographic writing rate of the tube increased from 35 to 1,000 km. per sec. This increase corresponds to a single trace of 16 mc. per sec. for 2-cm. peak-to-peak amplitude.

In the design of this tube suitable electrical connections between the circular conductive coatings on the inner wall of the tube are made through the glass to external contacts. The increase in brightness and the reduction in spot size are a great triumph in cathode-ray tube design, for these are two of the factors which at present seriously limit improvement in cathode-ray tube performance. This tube is employed in oscillographic applications.

2.10 Electromagnetic Focusing. Most cathode-ray tubes employed in television systems make use of electromagnetic focusing. Two anodes, such as are present in electrostatic focusing systems, are generally used in electromagnetically focused tubes, but they are employed for the sole purpose of accelerating the electron in its flight. As in the electrostatic

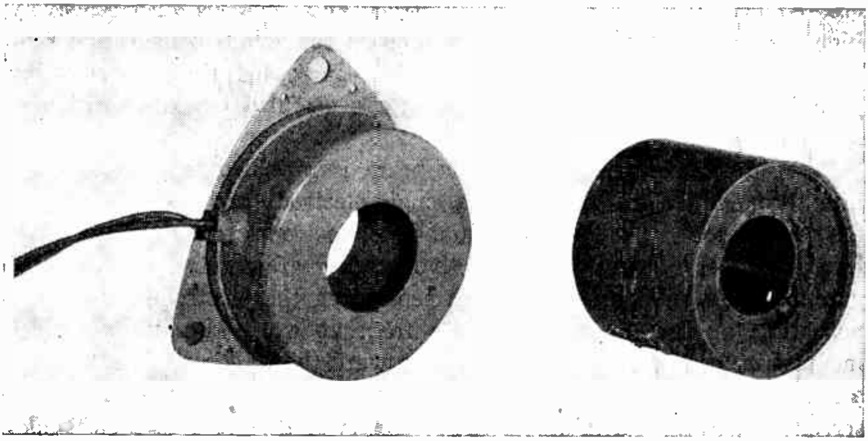


FIG. 2.17 Left, a typical electromagnetic focusing coil; right, the magnetic-deflection yoke. (Courtesy of Allen B. Du Mont Labs., Inc.)

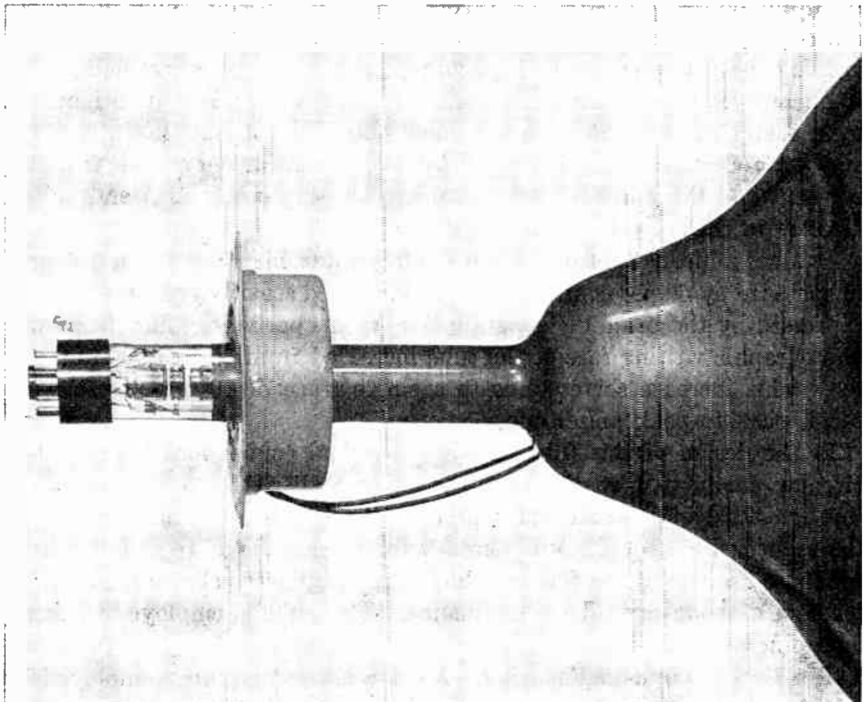


FIG. 2.18 Electromagnetic focusing coil in position along the neck of the cathode-ray tube gun. (Courtesy of Allen B. Du Mont Labs., Inc.)

type, the control grid brings the electrons to a crossover point before they enter the field of the electromagnetic focusing coil. A typical coil is shown in Figs. 2.17 and 2.18. When a d-c potential is applied across this coil, axially symmetric magnetostatic fields are created, the coil being wound to have axial symmetry.

The magnetostatic coil may be either of two types: long coils and short coils. This term refers to the end-to-end length of the coil. Each is fitted coaxially about the glass neck of the cathode-ray tube, the long coil extending over the entire length of the tube in some applications.

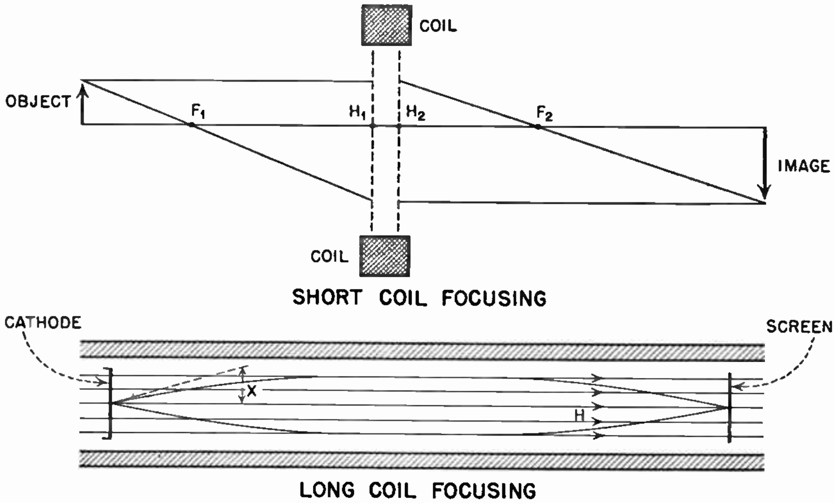


Fig. 2.19

The short coil is generally used in television and is mounted so that it may be moved along the axis of the gun assembly to provide rough focusing. The amount of d-c current actually passing through the winding is adjusted by means of a convenient potentiometer for optimum or fine focus.

The long coil was used in early versions of the Farnsworth Image Dissector, a special form of television cathode-ray tube particularly suited for televising motion-picture film. Figure 2.19 compares the electron focusing obtained through use of the long and of the short coil. Magnetostatic focusing is applied in the operation of some camera pickup tubes, as well as in the operation of viewing tubes installed in television receivers and station monitors.

Figure 2.20 illustrates the magnetostatic field set up inside the glass neck of a cathode-ray tube gun employing the short-focus coil so widely used in television. This coil encircling the tube's neck is of the multiple-layer type and has a rectangular cross section. It is formed inside a soft-iron outer housing having a similar rectangular cross section, and the housing has an annular groove cut in it next to the glass neck of the tube. The soft-iron housing referred to prevents the magnetostatic field set up by the coil from interfering with the deflection mechanism. The coil is thus magnetically shielded for all practical purposes. The air gap or annular groove next to the tube's neck results in a constricted field being set up only within the gun.

An electron traveling through the magnetostatic field will have both a radial and an axial component of velocity, and the action of the field is such as to cause an acceleration of the electron in a direction perpen-

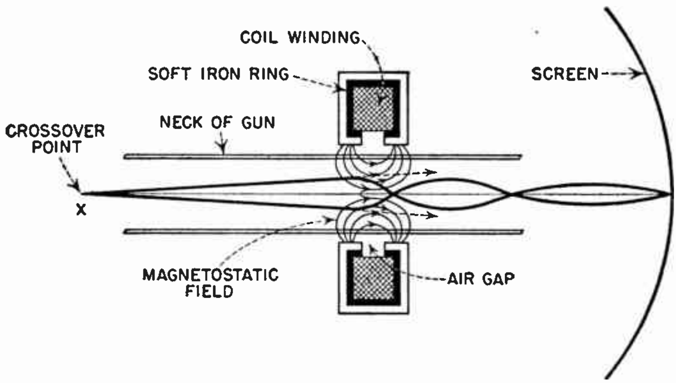


FIG. 2.20 Magnetostatic field set up in cathode-ray tube by short focus coil.

dicular to the radial component of velocity. The path of the electron, therefore, will have a circular projection on a plane perpendicular to the axis of the tube.

If the short coil is considered as a thin lens, the image will rotate through an angle; thus,

$$\theta = \frac{1}{2}\sqrt{\frac{e}{2mV}}\int_a^b H\,dz$$

$$= \frac{0.15}{\sqrt{V_{\text{volts}}}}\int H_{\text{gauss}}\,dz$$

And if the direction of d-c current flowing through the coil is reversed, the direction of rotation will be reversed.

With the constant axial component of its velocity also present, the electron will follow a helical path (or screw motion) in passing through the field.

To visualize fully just what takes place in a conventional magnetostatic focusing system, it is well to follow the path of an electron traveling from the crossover point beyond the second anode to the fluorescent screen. As stated, this electron will have two components of velocity, one component being parallel to the tube's axis and magnetostatic field. The other, or radial, component, is at an angle of 90 deg. to the first. This radial component of velocity tends to pull the electron across the field.

Electrons in motion constitute an electric current. Therefore, any electron moving at an angle across the magnetostatic field from the crossover point will move according to the left-hand rule. Thus, if the path of the electron is considered as a solid conductor grasped in the left hand with the thumb pointing in the direction of the fluorescent screen, then the fingers will form about the electron path and in the direction of the magnetic field due to the presence of the electron in motion. Since the electron is in magnetostatic field, it is constantly deflected, describing a circular path about the axis as it traverses the field. But the influence of the magnetostatic field on the motion of the electron results in its describing a helical path, or screw motion. All the electrons entering the magnetostatic field follow this screwlike path, and those entering at some distance from an axis through the field converge with electrons entering the field parallel to the axis.

Since all the electrons leaving the crossover point beyond the second anode at the same time have like velocities, they consume an equal time interval in traversing the magnetostatic field and, therefore, meet at a pin point somewhere beyond the field and toward the fluorescent screen. The amount of d-c current passing through the focusing-coil winding is adjusted and the coil is moved along the neck of the tube until this pin point of focus obtains on the fluorescent screen itself.

Let us consider an electron leaving the crossover point with velocity v and entering the magnetostatic field at an angle θ. The velocity component $v \cos \theta$ is not affected by the lines of force attributed to the field. However, the angular component $v \sin \theta$, perpendicular to the magnetostatic field, is influenced by that field as though the velocity component were not involved.

If the velocity component were not a factor, the magnetostatic field would result in the electron moving in a circular path, the plane of this circle being perpendicular to the magnetostatic field. But since the velocity component $v \cos \theta$ is present, the electron follows the helical path described above. This path is projected upon a plane perpendicular to the magnetostatic field—a true circle—resulting in the screw motion.

The radius of the circle has been given as

$$R = \frac{v \sin \theta}{\frac{l}{m} H}$$

in which H refers to the strength of the magnetostatic field. The elapsed time consumed by the electron in completing one circular motion will be

$$T = \frac{2\pi r}{v \sin \alpha} = \frac{2\pi m v \sin \alpha}{eHv \sin \alpha} = \frac{2\pi}{\frac{e}{m} H}$$

These equations indicate that the time constant is not only independent of the velocity or the angle but is entirely a function of the strength of the electromagnetic field H, which is controlled by adjustment of the d-c current flow through the focusing-coil winding.

Electrons leaving the crossover point and entering the electromagnetic field of the focusing coil enter with like velocities, but the electrons that enter at small angles with reference to an axis through the tube will have a cosine equal to 1, and $v \cos \theta$ will be constant and equal to v. The elapsed time of these electrons in describing their individual circles will be equal. Therefore, at a distance,

$$l = T_v = \frac{2\pi}{\frac{e}{m} H}$$

from the crossover point, they will focus to a common point beyond the focusing coil. However, this condition will not be true of those electrons that enter the electromagnetic field of the coil at wider angles, since $\cos \theta$ will no longer approach unity. And in this case it has been shown that

$$l = T_v \cos \theta \doteqdot \frac{2\pi v}{\frac{e}{m} H \left(1 - \frac{a^2}{2}\right)}$$

2.11 Improved Electron Gun Design. A modified electron gun of improved design has recently been described (see Fig. 2.21). In this development of the gun, an accelerating electrode that is connected electrically to the second anode has been placed close to the control electrode. The result is a spot of much smaller diameter and excellent focus appearing on the fluorescent screen, since the electron crossover is formed at higher potential. It also prevents the interaction between brightness and focus control.

Because of the higher potential placed on the accelerating electrode, it has been placed farther away from the control electrode. The increased spacing between these two electrodes has resulted in a beam of smaller diameter, an improvement of great importance to high-definition television, since line width must be kept to the minimum. Also, with the new arrangement mechanical adjustment of the apertures does not require as critical an adjustment as heretofore. This adjustment was the result of the tendency of the electrostatic fields to draw the beam through the centers of the apertures. The closer the physical spacing, the farther the beam was bent away from the axis for a given amount of misalignment.

In this new gun design, the first anode has been shortened to a disk, rather than a cylinder, and is employed solely for the purposes of focusing. The accelerating electrode, or second anode, has been considerably increased in length so that a masking aperture could be included at its

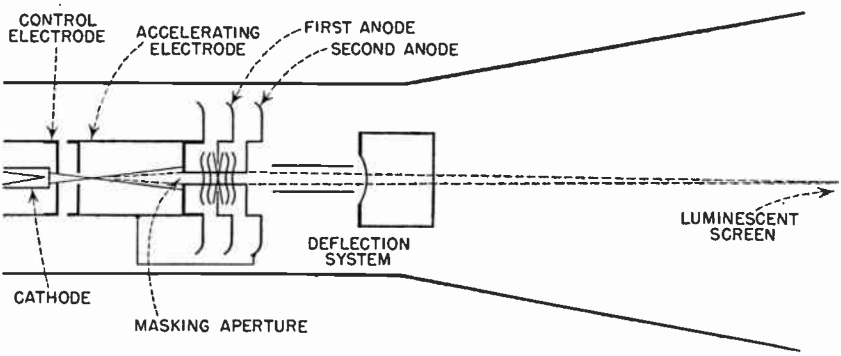


Fig. 2.21 Improved gun design based on zero first-anode current. (After L. E. Swedlund, Radio Corporation of America.)

screen end. The designer terms this new structure a "zero-current first-anode gun." It serves to obtain improved focus of the electron beam and draws zero current at the focusing connection on the power-supply voltage divider.

With the usual type of gun construction and d-c power supply, focus has to be corrected for small changes in first-anode current, but this correction is not necessary when the improved gun is used. The reason for the change in focus, which is due to irregular first-anode current in the usual gun, is that the current is usually taken from a bleeder across the power supply providing the potential to the second anode. Two power supplies, one for each anode, are not economically feasible. Thus, if the first anode demands greater current than the second anode, a larger proportion of the current must flow through the bleeder to provide good voltage regulation for the first anode. Enough current cannot be used in the bleeder to afford good regulation of the power supply; consequently, the focus must be readjusted for small changes in current demand.

The zero-current first-anode gun has the additional advantage that large changes in beam current can be obtained without refocusing, since the ratio of first-anode voltage to second-anode voltage is not influenced by first-anode current. Also, less filter capacity is required in power-supply design because of the lower bleeder current.

There are a number of structural advantages offered by the new design. Since the accelerating electrode length has been increased, it is much easier to support mechanically. The beam is also reduced to a smaller diameter before entering the final focusing field. Thus, seriously aberrated rays from the edge of the focusing field are precluded from entering the aperture of the second anode, where they would cause stray current to enter the deflection system electrodes.

The focus voltage may be varied within wide limits by varying the length and diameter of the cylinder or the diameter of the aperture. There are no reverse currents due to secondary emission from low-voltage electrodes, as they are not required to mask the beam, and aperture disks used as electrostatic shields against secondary emission in earlier designs can be eliminated.

2.12 Electron-Beam Deflection. The electron beam leaving the focusing mechanism of the tube is made up of billions of electrons traveling at high velocity toward the screen. It therefore constitutes an electric current which demonstrates both electrostatic and electromagnetic properties. These electrons are traveling in vacua, have negligible mass and inertia, and, consequently, may be easily deflected by both electrostatic and electromagnetic fields. The angle by which an electron may be deflected from its normal course toward the screen depends upon the potential difference applied across the deflecting plates in an electrostatic-deflection system or across the deflecting coils in an electromagnetic-deflection system. An electron entering the deflection system at low velocity will remain within the field of the deflection system for a relatively long period of time. Hence, the field will have a longer time in which to act upon the electron, and it will be deflected to a greater extent than will another electron possessing greater velocity. The greater the magnitude of the potential across the plates or coils of the deflection system, the greater will be the attraction for the electron, and, consequently, the greater the angle of deflection.

In the electrostatic-deflection system two sets of metallic deflecting plates are provided. The first pair of plates is mounted at an angle of 90 deg. with reference to the second pair (see Fig. 2.22). The first plates usually deflect the beam vertically and are known as "vertical deflecting plates," while the second plates deflect the beam horizontally and are termed "horizontal deflecting plates."

In a cathode-ray tube employing electrostatic deflection, the deflection plates must be accurately and firmly mounted. The physical spacing between pairs of plates must be held within a tolerance of plus or minus 0.003 in. of the spacing previously determined as proper for the particular design. The horizontal and vertical plates must be positioned at an angle of 90 deg. with reference to each other, and the angle must not vary more than ± 2 deg. The exact physical center of the assembly must be coaxial or concentric with other apertures and cylinders making up the electron gun. In fact, all such parts must be coaxial within ± 0.002 in. for precise results.

FIG. 2.22 Deflection plates from a 12-in. tube.

In considering the deflection of an electron beam passing through the vertical deflecting plates, let us assume that the upper vertical plate is made more positive than the lower vertical plate. Since the electron beam is made up of billions of negatively charged particles, the beam will be attracted upwards. Instead of eventually striking the fluorescent screen at its exact physical center, the beam will strike at some point above the center of the screen. The distance which the spot traverses in moving from the center of the screen to its new position above center will be a function of the magnitude of the d-c potential applied to the upper vertical deflecting plate, as compared to that applied to the lower vertical deflecting plate.

If the d-c potentials applied to both upper and lower vertical deflecting plates are equal in magnitude, then the beam will impinge on the screen at the exact center, as though the vertical deflecting plates were not present in the tube's geometry.

If the lower vertical plate is made more positive than the upper, the beam will move downward from the center of the fluorescent screen. Likewise, if the d-c potential applied to the lower vertical deflecting plate is equal to that at first applied to the upper plate, then the beam will move down from center by the same distance that it moved upward when the upper deflection plate potential was made positive by the same magnitude.

In the geometry of electrostatic cathode-ray tube gun construction, the horizontal pair of deflecting plates is usually located between the vertical pair of plates and the screen. The plates are rotated about the tube's axis, end to end, by 90 deg. with reference to the first pair of plates. Consequently, they result in beam deflection at right angles to the deflection that is due to the first pair of deflecting plates. Thus, if one of the horizontal deflecting plates is made more positive than the other, the electron beam will move horizontally from center and across the fluorescent screen in a direction determined by which horizontal plate is more positive. The distance through which the beam moves will be a function of the ratio and magnitude of the d-c potential applied to the horizontal plates.

Increasing the distance between the vertical deflecting plates and the fluorescent screen will result in greater deflection, just as moving a motion-picture projector farther away from its screen will result in a larger screen image. Thus, if the vertical deflecting plates are distance A from the fluorescent screen, and they are moved so that the separation from the screen is made twice as great ($2A$), then the deflection of the spot along the screen vertically will be twice as great, assuming, of course, that the d-c potential applied to the plates has not been altered.

In the conventional cathode-ray tube, the velocity of the electrons is fixed, as are the physical positions of the vertical and horizontal deflecting plates. Hence, any movement of the spot along the screen, either horizontally or vertically, is a function of the potentials applied to the deflecting plates. The electrostatic deflection sensitivity is the ratio of the distance that the electron beam moves across the fluorescent screen to the change in potential difference between deflection plates and is usually expressed in millimeters per volt. The sensitivity varies inversely with the beam voltage at the point of deflection. The beam voltage is the instantaneous voltage of the electron beam at any point along its path from cathode to screen. However, the term usually refers to the voltage of the beam at the point of deflection. At this point, in conventional cathode-ray tubes, the beam voltage is substantially the same as the second-anode voltage.

The deflection sensitivity of the vertical deflecting plates is greater than that of the horizontal plates, owing to the fact that the first set of plates is usually situated at a greater distance from the screen along the tube's axis.

In the shaping of the metal of which the plates are rectangularly formed, the plane surfaces of a pair of plates are made parallel for only a part of the total length. The remainder of the distance, end to end, is divergent or bent outward from center. Therefore, the electron beam will not strike either plate at maximum deflection for the particular tube arrangement, construction, and operation.

In the construction of the tube, the characteristics of the deflection system must be determined in order to obtain the required sensitivity. They are calculated through use of the following formula:

$$D = \frac{V_d \times L_p \times d_s}{2 \times S_p \times V_2}$$

where D = deflection
V_d = deflection voltage
L_p = length of plates
d_s = distance to the screen
S_p = spacing between plates
V_2 = final anode voltage

Although the deflection sensitivity of the tube is usually expressed in millimeters per volt, it is not unusual for some manufacturers to express this value in d-c volts per inch or in r.m.s. volts per inch. Measurement of deflection sensitivity by means of an a-c or r.m.s. voltmeter may be converted to d-c volts per inch through use of the formula

$$V \text{ per inch d-c} = \frac{\text{r.m.s. volts} \times 1.41 \times 2}{L}$$

where L is the deflection length along the screen in inches. It must be remembered that the cathode-ray tube responds to peak voltages, since it is an inertialess device.

Since the deflection sensitivity is also a function of second-anode potential, measurement of second-anode voltage must be made at the time that the deflection sensitivity is ascertained. To convert from millimeters per volt to volts per inch, divide 25.4 by the sensitivity as expressed in millimeters per volt. With various types of cathode-ray tubes, the deflection characteristic changes, but it is usually within the range 0.1 to 0.6 mm. per v. and is always expressed by the manufacturer in the descriptive literature.

As has been explained, an electromagnetic field is capable of deflecting an electron beam in a direction at right angles to both the direction of the field and the direction of motion. Thus, when magnetic deflection of the beam is employed in television cathode-ray tubes, the deflecting fields are set up by deflecting coils instead of by the internal deflecting plates, and these coils are mounted outside the tube. They are located close around the neck of the glass envelope and in the same relative position as the deflecting plates are fixed in an electrostatic-type tube.

Practically all cathode-ray tubes employed in television receivers and line monitors utilize magnetic deflection. The Iconoscope (one camera pickup tube in general use) also employs the magnetic-deflection principle. Electrostatic-type cathode-ray tubes are used mainly for purposes of measurement. One advantage of the magnetic-type tube is that the yoke assembly, comprising four deflecting coils, two for horizontal deflection and two for vertical deflection of the electron beam, may be rotated about the glass neck of the tube so that deflection may be obtained along any diameter of the face of the screen. This is not easy when electrostatic deflection is employed. In such cases the entire tube must be rotated to achieve the same result, and if the two sets of deflecting plates are misaligned in manufacture there is no recourse.

Also, through the use of magnetic deflection (as well as magnetostatic focusing) in television cathode-ray tubes, the envelope may be reduced in physical length, since the total length of a magnetic focusing system is considerably less than that in electrostatic types. Hence, a tube of short physical length is more suitable to horizontal mounting for direct viewing of the television image at the screen. Too, the maximum angle of deflection without introduction of unwanted defocusing at the screen is much smaller with magnetic deflecting systems. It is not uncommon in television cathode-ray tubes to encounter deflecting angles as great as 30 deg. away from the axis, cathode to center of fluorescent screen. The magnetic yoke may be oriented about the neck of the tube until optimum vertical and horizontal positioning is obtained at the fluorescent screen.

The four magnetic deflecting coils of the yoke assembly are so mounted and electrically connected that the fields of the two vertical deflecting coils are in series and aid. The two horizontal deflecting coils are also connected so that the fields aid. Each set of two coils is aligned along the same axis, whether horizontal or vertical, but the axis through the horizontal set of two coils is perpendicular to the axis through the vertical pair of coils. Thus, one set of coils produces horizontal deflection of the electron beam, whereas the second pair of coils produces vertical electron-beam deflection. While the electrostatic field (produced in electrostatic deflection) deflects the electrons along the lines of force, the electromagnetic field deflects them in a direction perpendicular to the lines of force.

A television cathode-ray tube employing both magnetostatic focusing and deflection is shown in Fig. 2.23. The position of the coils about the neck of the tube is clearly indicated.

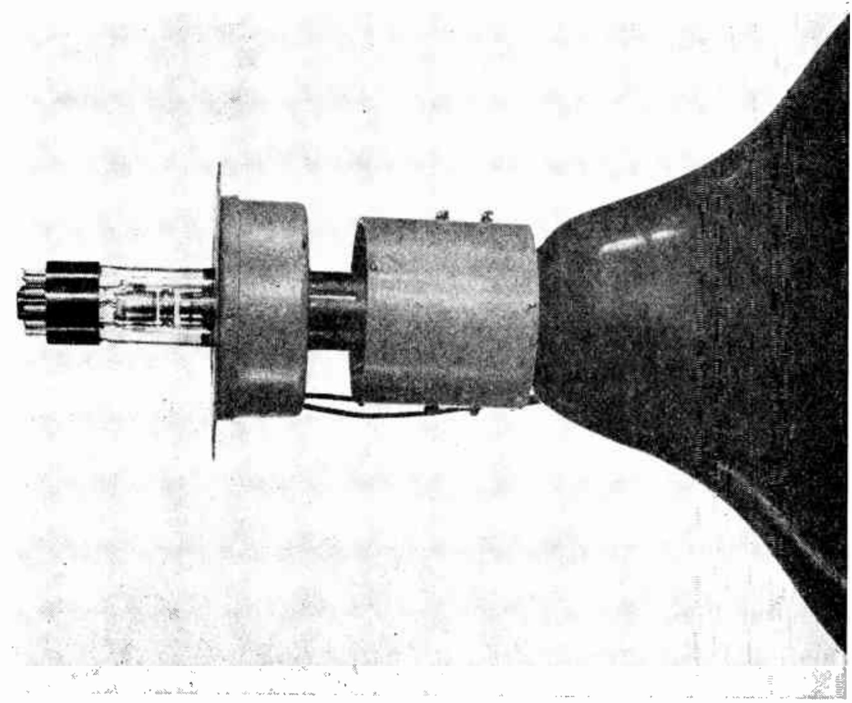


FIG. 2.23 Focusing coil and magnetic-deflection yoke in relative positions about the neck of the cathode-ray tube gun. The focusing coil is located in the direction of the tube's base. The deflection yoke is at the upper end of the gun assembly, near the large glass bulb of the tube. (Courtesy of Allen B. Du Mont Labs., Inc.)

To reduce the total energy stored in the magnetic field for a given deflection increment, the field must be confined and the reluctances of return magnetic paths minimized. This regulation is accomplished by means of iron cores, usually constructed of high-permeability magnetic material. Some yokes utilize a lamination similar to the stator lamination typical of small-motor design; others employ air cores or combined magnetic and air cores. Whatever the type, the deflecting field is usually made uniform within 2 per cent along any line taken perpendicular to the undeflected beam and in the direction of beam deflection. In one yoke design that employs an air core the vertical deflection windings are formed over the horizontal windings, and the entire coil assembly is placed inside a surrounding soft-iron tube employed as a housing. This tube serves to obtain a reduction in the reluctance of the return magnetic path of the vertical windings. The windings are so formed that they have hollow center sections, thus reducing the concentration of flux in the center. The coils must, in any case, be capable of high over-all frequency response. This is essential because, to produce an undistorted saw-toothed wave shape, they must respond to harmonics of the fundamental of the frequency applied. Herein lies much of the difficulty in

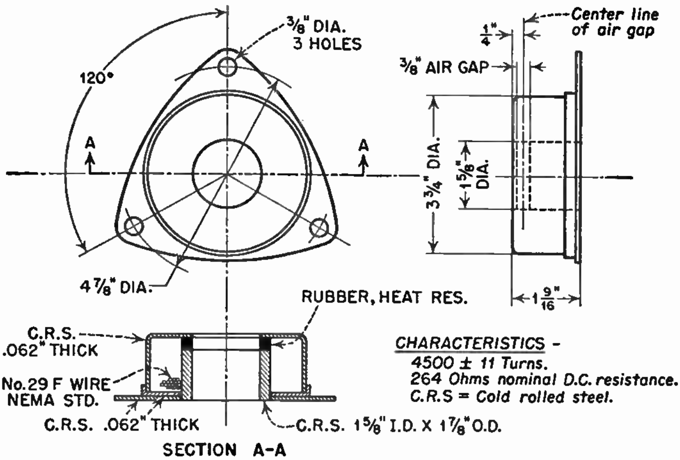


FIG. 2.24 Diagram of the construction of a typical focus coil.

proper magnetic-coil design. The coils of the deflecting-yoke assembly must be shielded from the field of the focusing coil when both are used as accessory to the television cathode-ray tube. Shielding is usually accomplished by placing a shield along the axis of the gun between the focusing coil and the deflection-yoke assembly. The construction of a modern shielded focus coil is shown in Fig. 2.24. A deflection yoke is shown in Fig. 2.25.

In reviewing the action that takes place when an electron traverses the transverse field set up by the deflecting yoke, certain fundamental considerations must be observed. These have been best expressed by Maloff and Epstein.

The magnetic field that deflects the beam is described by its field intensity $\bar{H}$, and the force demonstrated by a single electron moving in this field and possessing velocity $\bar{v}_0$ is

$$\bar{H} \times \bar{v}_0 e$$

And the force is related to the mass m of the electron and the resulting acceleration $\bar{a}$ as follows:

$$m\bar{a} = e\bar{H} \times \bar{v}_0$$

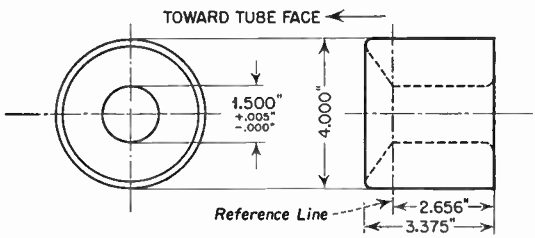
Thus, the acceleration becomes

$$\bar{a} = \bar{H} \times \bar{v}_0 \frac{e}{m}$$

which in scalar notation is expressed by the equation

$$a = \frac{e}{m} H v_0 \sin \theta$$

the sin θ representing the angle between the direction of velocity of the



OVER-ALL DIMENSIONS OF COMPLETE ASSEMBLY

CHARACTERISTICS	HORIZONTAL *(1 to 6, 2 jumped to 7)	VERTICAL *(4 to 8, 5 jumped to 7)
Inductance	8.3 Mh.	50.0 Mh.
Resistance D.C. (Approx.)	14.0 Ohms	68.0 Ohms
Maximum Current (Peak to Peak saw-tooth) 15,750 cps scanning speed 60 cps " "	982 Ma.	320 Ma.
Maximum Surge Voltage 7 Microsecond duration (15,750 cps) 100 Microsecond duration (60 cps)	1750 V.	300 V.
NOTE: This deflection yoke is designed for use with picture tubes requiring 50° magnetic deflection		

FIG. 2.25 Diagram of the design of a conventional magnetic-deflection yoke.

electron and the magnetic-field intensity. The direction of a is perpendicular to the plane through H and v_0. The electron cannot increase velocity while traversing the magnetic field because the direction of acceleration is perpendicular to v_0. Consequently, only its direction may be changed. The radius of curvature R of the orbit can be calculated from the law of conservation of energy as follows:

$$\frac{mv^2}{R} = Hev \sin \theta$$

$$R = \frac{mv}{eH \sin \theta}$$

And when $\sin \theta$ is equal to unity, the above equation becomes

$$R = \frac{mv}{eH}$$

with m, e, and v retaining their original values.

An electron leaving the second anode and entering a layer of uniform magnetic field of intensity H will describe a circle under influence of the field, and the radius R of the circle is expressed by the equation

$$R = \frac{mv}{eH} = m\frac{\sqrt{2v\frac{e}{m}}}{eH}$$

$$= \frac{\sqrt{2v\frac{m}{e}}}{H} = \frac{k}{H}$$

where v = potential difference through which the electron has fallen
k = a constant determined experimentally

Maloff and Epstein have shown that if the angle between the incident and the refracted beam is β, then,

$$\sin \beta = \sin \alpha = \frac{L}{R}$$

$$= \frac{LH}{\sqrt{2V\frac{m}{e}}} = \frac{LH}{k}$$

and

$$y_1 = R(1 - \cos \alpha) = R(1 - \sqrt{1 - \sin^2 \alpha})$$

$$= R\left(1 - \sqrt{1 - \frac{L^2}{R^2}}\right)$$

$$= R - \sqrt{R^2 - L^2}$$

It is shown that if W is the total deflection of the beam away from the axis through the tube, then D is the distance from that point at which the beam enters the magnetic field.

$$W = y_1 + (D - L) \tan \alpha$$

and

$$\tan \alpha = \frac{\sin \alpha}{\cos \alpha} = \frac{\frac{L}{R}}{\sqrt{1 - \frac{L^2}{R^2}}}$$

$$= \frac{L}{\sqrt{R^2 - L^2}}$$

and

$$W = R + \frac{DL - R^2}{R}$$

$$= D\frac{L}{R}$$

To a close approximation, the amplitude of deflection may be calculated through use of the following equation:

$$\text{Deflection} = \frac{0.4LlIN}{\sqrt{V}}$$

where L = distance from the center of the pair of coils to the screen in centimeters
l = length of that portion of the beam lying within the magnetic field in centimeters
I = current in the coils in amperes
N = number of turns
V = final anode potential in volts

Through examination of the above equation, it will be seen that the amplitude of deflection is inversely proportional to the square root of the final anode potential in volts. Hence, a decrease in applied d-c potential results in increased deflection sensitivity. Moreover, the deflection is directly proportional to the distance separating the center of one pair of deflecting coils from the fluorescent screen as well as to the current flowing through the coils.

The current passing through the inductance represented in one coil is roughly proportional to the field intensity H that is desired to satisfy a particular design problem and to the reciprocal of the number of turns employed in the winding. Thus,

$$I = \frac{H}{N} = H\sqrt{L}$$

However, the field intensity H is an equality with the ratio of screen deflection W over the product of D, which is the distance from the point where the beam enters the magnetic field, and L, the length of the magnetic yoke. So, since

$$H = \frac{W}{DL} \text{ (to a good approximation)}$$

then,

$$I = \frac{W}{D\sqrt{L}}$$

Therefore, with the length of the yoke increasing, and the inductance kept constant by reducing the number of turns, the approximate amount of current required is proportional to the square root of the reciprocal of the length of the yoke.

It has been shown that if the deflecting circuit is maintained within 20 per cent of the gun-to-screen distance, then an increase in the length of the deflecting yoke by a factor of 2 will yield the same result as though only one power tube were used to produce the desired deflection instead of two power tubes for the shorter coil.

In electromagnetic deflection, it is important to prevent cross talk between the pairs of coils. Cross talk is the effect produced when the current in one set of coils is induced into the other pair, resulting in an erratic or inaccurate trace on the fluorescent screen of the tube. If the cross talk is not due to spurious coupling of the vertical or horizontal driving circuits, it can be eliminated by adequate design of the coils and deflecting-yoke assembly, particularly so that unwanted currents oppose each other and cancel. In some instances, it can be eliminated by connecting horizontal coils in shunt, and vertical coils in series.

When a magnetic deflection system is employed, it is occasionally necessary to clear up defocus at the screen which results from use of a nonsymmetrical yoke. This defect is present when the picture will not focus properly throughout the entire useful area of the fluorescent screen. Cross talk is also present under these circumstances.

2.13 Luminescent Screens. To produce an image upon the screen of the cathode-ray tube, the energy of the electron beam must be converted into visible light so that it may be viewed by the human eye. To accomplish this, the inner surface of the viewing end of the tube is suitably coated with a phosphor chemical. This chemical emits light, referred to as "luminescence," when bombarded with high-velocity electrons. Thus, the coated screen fluoresces at the point under bombardment by the electron beam, and the property is termed "fluorescence." For a short interval after bombardment the screen continues to emit light. The property of the screen to do so is termed "phosphorescence." Any luminescent materials which possess the properties of fluorescence and phosphorescence are described as "phosphors."

Of the large numbers of organic and inorganic phosphors known at the present time, only two groups are employed in the preparation of fluorescent screens for cathode-ray tubes. These two inorganic groups include the sulphide and the silicate phosphors. Organic phosphors cannot be utilized in the preparation of screens for cathode-ray tubes, since high temperatures occur at the screen when under electron bombardment, as well as in the manufacturing processes sometimes used in preparing the screen, and also because the phosphor material is operated in vacua. The inorganic phosphors are actually chemical compounds of such well-known metals as zinc, calcium or cadmium, tungsten silica and sulphur. Although the theory of luminescence of phosphors is not well developed at this time, it is known that infinite amounts of metallic impurities in the metals seem essential to optimum performance of a number of the phosphors. These impurities are called "activators." Some metals which appear pure when examined spectroscopically are virtually nonluminescent. Much research is now in progress to determine more about the physical and chemical properties of the various commercially used phosphors.

Willemite, which produces a green or yellow fluorescence, is chemically known as "zinc orthosilicate" ($ZnSIO_4$) and includes small traces of manganese and other metals (see Figs. 2.26 and 2.27). Natural deposits of willemite are located near Franklin Furnace, N.J., and the material taken from these deposits was used in the preparation of screens by some manufacturers when cathode-ray tube screens were first prepared in this country. However, the impurity content of natural phosphor is not constant and results in many rejects. The discovery of willemite is credited to A. Levy, who named the material in honor of King Willem I of the Netherlands.

Most manufacturers make use of synthetic willemite, the process having been developed by W. S. Andrews of General Electric. In his process, Andrews first produced synthetic willemite by employing manganese as an activator. In its preparation suitable amounts of zinc oxide, silica manganese activator, and flux are mixed and then fused into a uniform substance. It is then cooled, ground, sieved, and made into a proper solution for application to the glass end of the cathode-ray tube.

A screen coated with willemite is termed a "medium-persistence screen." This term means that the period during which light decays after bombardment is in the order of milliseconds and is situated in the range between screens demonstrating fast and slow decay periods. For various types of phosphors, decay time can be in the order of a few microseconds up to several minutes. Thus, screen persistence can be varied through the application of different phosphors, and the phosphor selected for a particular tube depends upon the use to which the tube is to be put. Zinc orthosilicate has a very high conversion efficiency of luminous radiation to total electron-energy input. Also, it has been shown that the

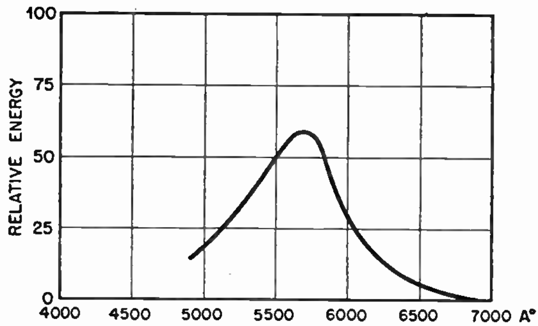
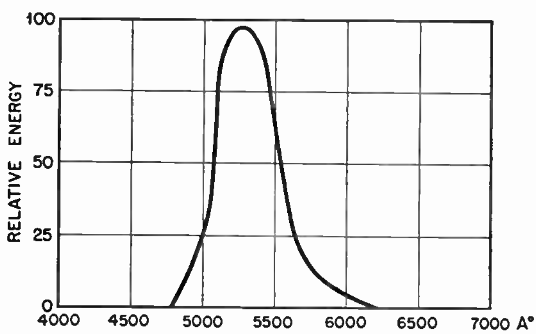


FIG. 2.26 Spectral characteristics of a fluorescent screen coated with artificial willemite [$(ZnO + SiO_2)$: Mn], the material having been quenched rapidly from a melt. This screen demonstrates a distinctly *yellow* luminescence.

wavelength at which maximum spectral radiation obtains almost coincides with the wavelength of light to which the eye exhibits greatest sensitivity.

The efficiency of a willemite screen varies from 1.0 to 2.5 cp. per w. and is a function of the thickness of the luminescent screen, the diameter of the particles of willemite used, the d-c potential applied to the second anode and other accelerating electrodes, the degree of saturation of the phosphor, and the material used as an activator. Whether willemite

FIG. 2.27 Spectral characteristics of a fluorescent screen coated with artificial willemite [$(ZnO + SiO_2)$: Mn], the crystal structure of which has been formed through gradual cooling. This screen demonstrates a *bright green* luminescence.



exhibits a green or yellow luminescence depends upon the temperature to which the synthetic material is heated and the manner in which it is cooled in the process of manufacture. If the material is cooled slowly, the resultant phosphor will exhibit a bright-green luminescence; but if it is quenched rapidly from a melt, the luminescence will be yellow.

At this time, zinc orthosilicate is the most useful material for visual observations and is widely applied to cathode-ray tubes employed in oscillographs. It is also used to prepare screens for electronic viewfinder tubes, an accessory to some late television cameras, as well as in some television line monitors. Unfortunately, it is not useful for motion-picture photography, since a certain amount of phosphorescence is present and results in a dim haze that follows any trace photographed with moving film.

Calcium tungstate is sometimes used as a phosphor and produces pale-blue luminescence. A screen prepared of this material has a very fast

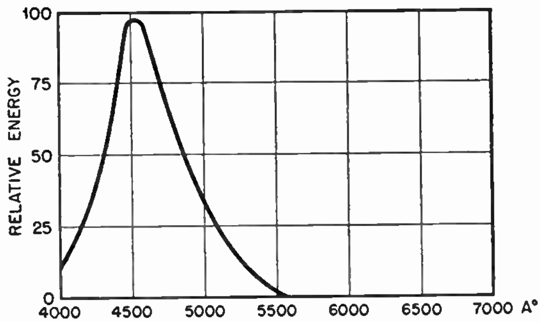


FIG. 2.28 Spectral characteristics of a fluorescent screen coated with silver-activated zinc sulphide (AnS:Ag). This screen demonstrates a characteristic *blue* luminescence.

decay period, the light output suffering a reduction from full brilliance to 10 per cent in 10^{-7} sec. Since its emission is highly actinic and its decay period short, it is often applied to the screen of tubes used for photographic purposes. The efficiency is low, being about 0.3 lumen per w. The peak radiation of calcium tungstate applied to a screen departs quite radically from the peak of the curve indicating luminous response

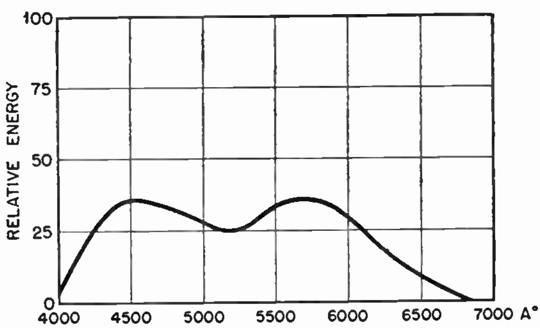


FIG. 2.29 Spectral characteristics of a *white* fluorescent screen coated with zinc cadmium sulphide and silver-activated zinc sulphide.

of the human eye, and such a screen is therefore of little use for direct visual observation of phenomena.

Zinc sulphide is also used in the preparation of screens. It produces a blue luminescence with short phosphorescent decay (see Fig. 2.28). The light output when the material is activated with silver is about 3 to 5 c. per w., which is very high.

Zinc-cadmium sulphide is another of the group of sulphide phosphors sometimes applied to cathode-ray tube screens. This material produces a yellow luminescence of higher efficiency than zinc sulphide. The persistence characteristic of zinc-cadmium sulphide is very similar to that of zinc sulphide.

For tubes used in television line monitors and receivers, a mixture of zinc sulphide and zinc-beryllium silicate is usually employed. The preparation results in a so-called "white screen," the yellow fluoresence of the second substance and the blue fluorescence of the first combining to provide a white. Actually, the screen so produced is nearer a shade of light gray, owing to the fact that the combined colors are not true colors and thus do not yield a true white. In the preparation of the two materials, it is most important that they be so activated that the persistences of the two colors are almost equal. Otherwise, there will be no color separation, and a blue or yellow posttrace will show on the screen. Green-blue zinc sulphide mixed in proper proportions with zinc-cadmium sulphide will also produce a near-white screen suitable for television applications (see Fig. 2.29). Since present television involves a monochromatic system, reproducing black through shades of gray to white, the so-called "white screens" are most suitable for present use.

Manufacturers of cathode-ray tubes employ a number of methods of applying the phosphor to the inner side of the end of the glass envelope. The method first employed was called the "settling technique." It does not lend itself well to mass production, because the process is much too slow. In this method, a liquid medium is first admitted to the neck of the glass blank, the blank being fixed vertically in a position free from vibration. A second solution, containing just enough phosphor to cover the screen to the desired thickness, is next admitted. This solution contains not only the phosphor but also a mild electrolyte, usually ammonium carbonate, which is added to keep the phosphor particles charge-free. Otherwise, they become negatively charged, owing to the fact that the dielectric constants of the particles and of the distilled water used in the solution are not the same. The result of this difference is that the phosphor settles on the screen unevenly and with fine streaked lines appearing. The solution must be kept at low temperature to prevent convection currents, which cause irregular deposits. After the powder is deposited on the screen, in a matter of 3 to 8 hr., the solutions are siphoned off and the tube baked. Later techniques have reduced the time element involved.

In Europe, the inner side of the tube blank end is first coated with a binder solution such as cellulose or cellulose acetate. The phosphor, ground into a powder, is then dusted on while the tube is gently rotated. The powder in excess of that required to coat the screen surface properly and uniformly is then poured out, producing a very uniform layer of phosphor (see Fig. 2.30).

The most acceptable method of coating is a fast, dependable process involving the use of a liquid spray. The complete interior of the blank is suitably coated. Excess material is then wiped out, leaving only the inner surface of the tube end covered. In this process, the spray solution is made up of selected particles of the phosphor, with distilled water or acetone used as the carrier. Semiautomatic machines are employed. The face of the blank is preheated to a temperature of 200 to 300°C. The bulb of the blank is secured in a rotating vertical chuck, and the nozzle of a high-pressure spray gun is admitted into the neck. The

FIG. 2.30 Circular motion applied to a 10-in. cathode-ray tube in the chemical laboratory of North American Philips Company, Inc., at Dobbs Ferry, N.Y. By this method, the phosphorescent powder is distributed over the inner face of the tube. Before the powder is placed in the tube, a liquid adhesive is applied to the inner surface. This makes the phosphor adhere permanently to the glass. (Courtesy of North American Philips Company, Inc.)

chuck is operated at a speed of about 120 r.p.m., and a harmonic motion of about 20 c.p.m. is applied to the spray gun. Thus, a uniformly coated screen of good quality is obtained. Finished screens are shown in Fig. 2.32.

As has been said, the choice of a screen depends upon the purpose to which the cathode-ray tube is to be put. The principal characteristics that may be selected by a choice of material are

1. Color of the screen
2. Phosphorescence and duration of decay
3. Luminescent efficiency
4. Actinic efficiency
5. Saturation potential

The color of the screen when treated with various phosphors has already been discussed, as has the phosphorescence attributed to the various materials. The screen actinic efficiency is a measure of the ability of a viewing screen to convert the electrical energy of the electron beam to radiation which affects a given photographic surface. The term is sometimes expressed in microwatts per watt, but for ease of measurement it is usually expressed in actinic power per watt relative to a screen of

FIG. 2.31 Spectral apparatus for measuring the thickness of the phosphorescent coating which has been applied to the face of the tube. (Courtesy of North American Philips Company, Inc.)

known characteristics. Screen actinic efficiency is not to be confused with either screen luminous efficiency or screen radiant efficiency. The former is a measure of the ability of the screen to produce visible radiation from the electrical energy of the electron beam and is expressed in candlepower per watt. Screen radiant efficiency is the measure of the tube screen's ability to produce luminescence from the electrical energy of the electron beam. It is expressed in microwatts per watt.

Saturation potential is the limiting value of the potential applied to the second anode, beyond which any further increase in potential fails to produce any increase in luminous output. It is above the rated second-anode potential for most commercially available tubes and not a practical problem.

Brilliance of the trace is a function of the thickness of the material of which the end of the glass envelope is made, since the image appearing is almost always viewed from the side opposite to that on which the phosphor

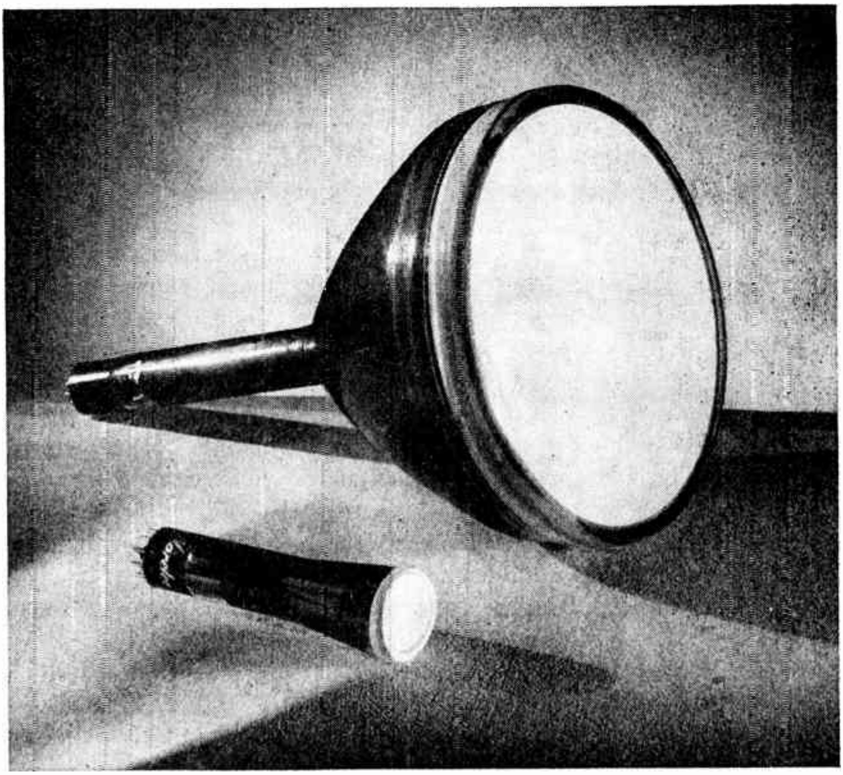


FIG. 2.32 Appearance of the fluorescent screen of the finished cathode-ray tube. The upper tube is a Norelco 10-in. flat-faced television cathode-ray tube. (Courtesy of North American Philips Company, Inc.)

is deposited. Brilliance is also a function of the electron velocity and will rise with an increase in accelerating potential. Beam current increases as accelerating potential rises, resulting in improved brilliance. This factor is made use of in projection-type television tubes. In these tubes very high accelerating potentials are employed to ensure a brilliant screen before the image is projected onto a larger screen by means of an optical lens system. The maximum beam energy, as well as that point at which high-voltage breakdown occurs between elements, is limited by maximum cathode emission. In projection-type tubes, breakdown also sometimes occurs as a result of irregularities along the inner walls of the envelope that have been coated with Aquadag or similar coatings to provide a coating for the intensifier electrode. This condition has been somewhat alleviated in certain types by coating the outer walls with a similar substance, to some extent equally distributing the charge along the inner wall, which seems to draw away heavy charges that collect at points where imperfections in the envelope result in nodules extending out from the inner wall of the bulb. In addition, the potential is more evenly distributed throughout the entire inner surface of the coating.

The trace brilliance of the screen for a given beam energy is dependent upon the writing rate of the spot in inches per second, and there is a maximum writing rate that is difficult to exceed. The maximum known writing rate at present, occurring in any type, is given at about 1,000 km. per sec.

It must be pointed out that all screens must be field-free of imperfections or blemishes. This condition is especially true in television where a considerable portion of the total screen area is employed in reproducing the image. It must also be pointed out that pattern marks are very easily burned into the screen if the electron beam is permitted to remain too long in one screen position. In television receivers and viewing monitors, where high electron voltages obtain at the point of impact, it is well that the beam be extinguished before the horizontal and vertical sweep voltages are removed. The brilliance control on a receiver should be set for minimum brilliance before the receiver is placed out of operation. Otherwise, the beam will impinge at a spot near the center of the screen when the sweep voltages are removed. The result is a bad "burn," which can eventually introduce eye fatigue in viewing.

A tube having a relatively flat face is particularly suitable for use in television equipment, since any great curvature of the screen results in viewing fatigue. Moreover, the image will seem distorted to the eye if the curvature is too great. The production of a perfectly flat-faced tube is a difficult development problem when it is considered that the atmospheric pressure exerted on the face of a typical 12-in. television cathode-ray tube is about 1,700 lb. Such a tube, having a radius of curvature of 16 in., exclusive of the edges of the screen, has a thickness of ¼ in., which yields a safety factor between 3 and 5. In tubes up to 7 in. face diameter, soft glass of lime or lead content is currently used. In the large blanks prepared for television cathode-ray tubes, Nonex or Pyrex glasses are utilized, because both of these glasses demonstrate excellent thermal and mechanical properties. With the introduction of improved synthetic plastics, which have low porosity plus good thermal and mechanical properties, it is predicted that blanks may be some day more inexpensively produced, resulting in a great reduction in the price of cathode-ray tubes.

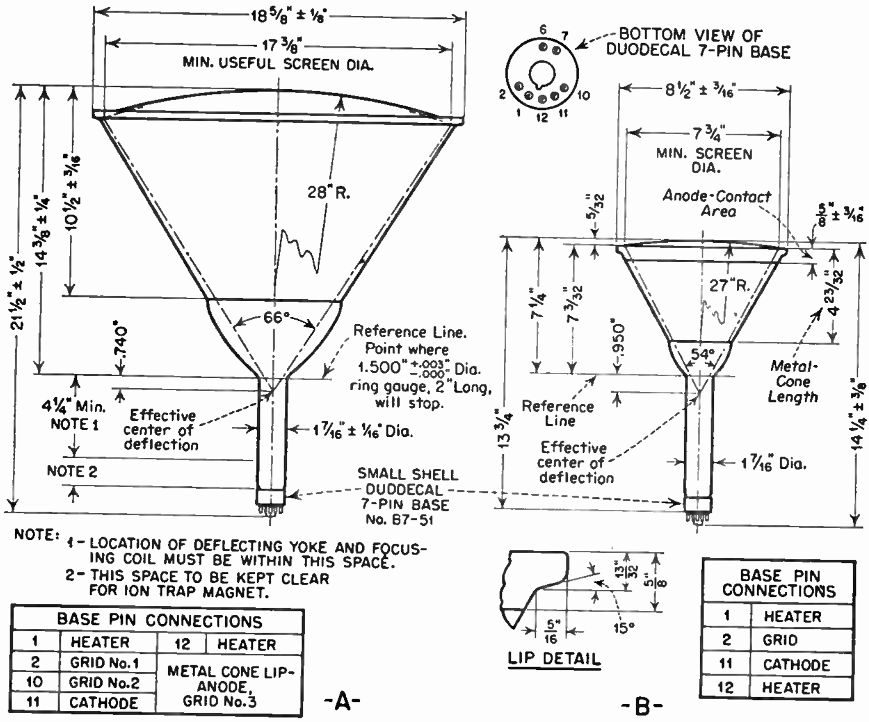
2.14 The Metal-Backed Luminescent Screen. An important problem in the manufacture of cathode-ray tubes for television receivers has been to obtain adequate brightness at the screen. R.C.A. engineers have considerably improved one type of picture tube in this respect by developing a tube with a metal-backed luminescent screen.

Previous attempts to improve screen brightness have principally involved either an increase in the beam power of the tube or an improvement in the luminescent materials used at the screen, so that more light is developed when the beam power is converted into light. Laboratory studies have shown, however, that at least 50 per cent of the light generated at the screen of the average picture tube is directed back toward the electron gun of the tube and does not reach the viewer's eye. Another 15 to 25 per cent is lost by internal reflection in the glass of the tube face. It can be shown that only 25 to 35 per cent of the light generated at the screen is usefully directed toward the viewer's eyes. Thus, much of the light is lost, insofar as the viewer is concerned, and constitutes a serious waste of energy.

In the R.C.A. metal-backed tube, a thin coating of aluminum is applied by evaporation to the back of the cathode-ray tube face. This coating is so thin that there is only negligible absorption of the electron beam at the desired operating potentials. It is opaque, relatively smooth, and highly light-reflecting, so as to act as a mirror. The layer has sufficient conductivity to conduct the full beam current, yet it is sufficiently strong to withstand the stresses due to coming under the full impact of the focused electron beam. The aluminum backing will not react with the fluorescent materials with which the screen is coated. One advantage of the aluminum backing is that it will stop heavy ions, but will pass electrons quite readily. When the aluminum-backed screen tube is operated at normal operating potentials, the ion spot does not usually develop. Use of the tube results in improved efficiency of conversion of electron-beam energy into useful light, improved contrast, and almost complete elimination of the ion spot under ordinary operating conditions.

2.15 The Metal-Cone Picture Tube. Of great interest has been the recent development of the metal-cone type of picture tube for use in television receivers. This tube differs from the conventional cathode-ray tube in that a major portion of the envelope comprises a spun-metal cone of 28 per cent chrome steel. The cone serves as the second anode of the cathode-ray tube and is affixed to the glass enclosing the gun structure at one end. The lip at the mouth of the metal cone (see Fig. 2.33) is designed for a compression fit with the glass face plate of the tube. This arrangement provides a vacuum tight metal-to-glass seal at the point where the face plate and cone join, and the "fit" at the junction differs considerably from that employed in forming a metal-to-glass seal in the fabrication of high-power transmitting tubes.

In the current commercial design of these tubes, the chrome-steel wall section of the cone is made 0.066 ± 0.015 in. thick and is spun into the required shape. The process lends itself well to mass-production tech-



BASE PIN CONNECTIONS			
1	HEATER	12	HEATER
2	GRID No.1	METAL CONE LIP-ANODE, GRID No.3	
10	GRID No.2		
11	CATHODE		

BASE PIN CONNECTIONS	
1	HEATER
2	GRID
11	CATHODE
12	HEATER

FIG. 2.33 *A*. Type 19AP4 metal-cone 19-in. picture tube. *B*. Type 8AP4 metal-cone 8-in. picture tube.

niques. The face plates for the metal-cone tubes, on which the fluorescent screen material is settled, are made of ordinary window plate glass. A slight curvature is provided so that the face plate may withstand normal atmospheric pressure without implosion.

The new *gray glass* has been used to advantage by some manufacturers. So-called "gray" glass is an especially prepared product, intended to improve picture contrast under conditions of high ambient lighting in the room in which the television receiver is operated. Gray face plate glass for metal tubes has a transmission efficiency of approximately 70 per cent. The neutral-density filters ordinarily placed over the face of the cathode-ray tube screen for this purpose possess a transmission efficiency that varies from 30 to 80 per cent, depending upon the manufactured product.

Deflection angles of 50 to 55 deg. are common in conventional cathode-ray picture tubes employing all-glass envelopes. Some of the new metal-cone tubes are being produced with a shorter gun structure. The new Du Mont type 16FP4 16-in. metal-cone, short picture tube has a deflection angle of 62 deg. The short metal-cone type 19AP4 has a deflection angle of 66 deg. Since the deflection angle of a cathode-

Fig. 2.34 Type 19AP4 metal-cone picture tube, the largest diameter cathode-ray tube in current commercial production employing a metal cone of chrome steel. The plate-glass face is treated with a P4 (white) phosphor, and it is designed for use in large-screen television receivers making use of direct viewing. (Courtesy of Allen B. Du Mont Labs., Inc.)

ray tube determines to a great extent the length of the tube along its principal axis, there is an increased deflection angle required for proper operation of the new short metal-cone tubes. Practical operation of these new tubes indicates that resolution at the center of the tube screen has improved somewhat over comparable all-glass types. This improvement is due to the fact that in bringing the gun closer to the screen of the tube, the magnification ratio of the electron optical lens system has been improved. Resolution at the edges of the screen is at least as good as that obtained with tubes possessing all-glass envelopes.

The use of the metal cone for a greater portion of the envelope provides improved shielding of the tube beam from the effects of external extraneous magnetic fields. It is more economical to manufacture than a comparable all-glass tube and is much lighter in weight. The type 19AP4 19-in. short-gun metal-cone tube is 6 in. shorter than a 20-in. screen diameter all-glass picture tube. The 16FP4 16-in. metal-cone tube with short gun is ¼ in. shorter than the type 15AP4 15-in. all-glass picture tube. This difference permits the use of a shallower cabinet, thereby effecting an economy in receiver production costs. The 19-in. metal-cone tube with short gun weighs 14½ lb. compared with 32 lb. for the all-glass 20-in. picture tube.

These tubes all possess P-4 white medium-persistence fluorescent screens and are designed for magnetic deflection and focusing. It is possible with the 19AP4 tube to obtain a highlight brightness of 25 ft.-L. or more on a 11¾ × 15¾ in. picture area at the screen. This brightness is achieved with the use of a standard R.M.A. No. 106 focusing coil and a 0.146-amp. focusing current, which is measured in series with the winding. The second-anode potential for the 19-in. metal-cone tube is 13,000 v. d-c, although satisfactorily defined images have been obtained with second-anode potentials as low as 9,000 v. The second-anode potential is applied directly to the metal cone, the outer surface of which is painted red to signify that a high potential is in use. With the application of pulse-type power supplies, however, the current present is very low and not ordinarily considered lethal. It is best, however, to exercise the usual precautions when there is a possibility of coming into contact with the outer surface of the metal-cone tube.

It is not difficult to obtain deflection of the beam across the major dimension of the 19-in. tube screen in the horizontal direction. Sufficient sweep amplitude is provided through application of a General Electric type 77J–1 yoke and a single type 6BG6–G horizontal deflection-amplifier tube. This driver tube, operating within normal tube ratings from a 325-v. filtered d-c plate power supply and with General Electric type 77J–4 linearity and width controls, offers complete screen deflection. Only 0.075-amp. plate current to the driver tube is required, one type 6W4GT damper tube, and one type 1B3GT tube being employed as the high-voltage rectifier.

When the General Electric type 77J2–2 yoke is employed, satisfactory screen deflection can be obtained through use of a single 6AU5–GT vacuum tube as the horizontal driver, operating within rated limits. Plate potential in this case may be reduced to 300 v. d-c at 70 ma. or less. The use of the two driver tubes indicated yielded the results described here. It is quite possible that other tubes may be utilized with equally good results. It is unnecessary to provide a special short yoke for the 19-in. cone tube in order to obtain 66-deg. deflection if the focus-coil assembly is made adjustable along the principal axis of the tube. Special short yokes, however, have been made available for use with the tube.

Because of the many advantages of the new metal-cone tubes, it is believed that they will gradually supplant current all-glass types for use in television receivers. In order that the reader may compare at least two types of the new tube, both a 19-in. and an 8-in. metal-cone tube are described in Fig. 2.33.

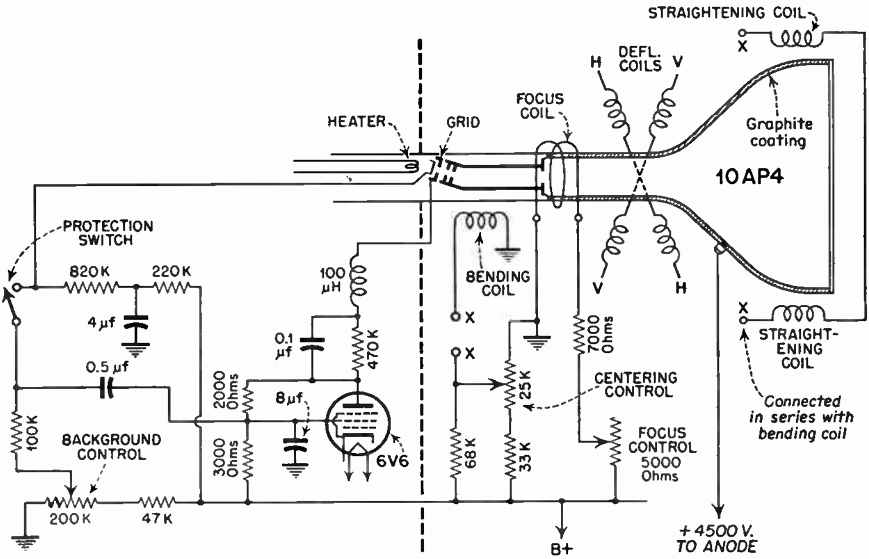


FIG. 2.35 Bent-gun type of cathode-ray tube and associated circuits.

2.16 Ion Spot. In practically every type of cathode-ray tube there exists a small amount of residual gas after evacuation has been carried to practical limits. This gas eventually produces a dark-brown inactive spot at the center of the fluorescent screen. The negative ions are propelled against the screen material along with the electrons that make up the beam, and since the ions possess greater mass than the electrons, they bombard the active phosphor of the screen with appreciable force. Screens treated with sulphide phosphors are found to be particularly sensitive to ion bombardment.

To prevent the appearance of this ion spot at the fluorescent screen of the tube, an ion trap is ordinarily applied in certain types of television cathode-ray tubes. One arrangement of such a trap is referred to as the "bent gun." The construction of a cathode-ray tube employing the "bent gun" is illustrated in Fig. 2.35, the tube being a type 10AP4 Philco television cathode-ray tube.

The electrons and heavier ions pass through the grid aperture and are propelled in a straight line. Since the anode is bent, it is evident that they would normally make contact with the metal wall of the anode, never reaching the fluorescent screen at the face of the tube. To avoid this, a magnetic bending coil is placed around the neck of the tube and physically located next to the bent anode. The magnetic field produced by the bending coil results in the normal electron path toward the anode wall being changed. By regulating the deflecting force, the electron beam can be made to curve in such a manner that the lighter electrons are projected through the gun without coming in contact with the anode wall; whereas the heavier ions, unaffected to a great extent by the magnetic field, travel in a straight line, strike the anode, and are trapped.

R.C.A. applies another form of ion trap in its type 7DP4 and type 10BP4 television cathode-ray tubes. A magnet is placed adjacent to the electron gun and external to the tube. The relative position of this magnet is adjusted until a spot of optimum brightness is obtained at the fluorescent screen of the tube. The electrostatic lens located between the first and second anodes is so developed that an oblique gap occurs between these two elements of the gun. The magnetic field produced by the coil, external to the neck of the tube, provides a compensating deflection of the electron beam. The result is that the lighter electrons are propelled toward the fluorescent screen in the normal manner, but the heavier ions are not affected to any appreciable extent by the magnetic field. Striking the inner second-anode surface, the ions are collected by this element. It must be remembered that although both the electrons and ions constitute negative particles, the electrons are much lighter and of less mass. Thus, it is easy to bend the electrons by means of the applied magnetic field, while this same field has little or no effect upon the heavier ions. Since both the electrons and ions are negative particles, they are both attracted by the positively charged second anode.

The use of ion traps is warranted particularly where high second-anode potentials are made use of and such is invariably the case in both large-screen direct viewing and projection-tube operation. The greater the second-anode potential, the higher the velocity with which the heavy ions are propelled toward the screen in the absence of an ion trap. The terrific bombardment of the fluorescent screen by these heavy ions soon results in degradation of the chemical phosphor, with the development of the characteristically brown circular ion spot or blemish which impairs viewing of the reproduced television image. Practically all cathode-ray tube manufacturers now produce picture tubes employing ion traps of one type or another.

2.17 Cathode-Ray Tube Production. Although various references to individual manufacturing processes involved in typical tube production have been made throughout the discussion of the cathode-ray tube, a summary at this point will impart to the student or engineer a clear, over-all understanding of the subject. The various cathode-ray tube manufacturers make use of any of a great number of processes to arrive at the same finished product and no attempt will be made to discuss at length the many different methods involved in manufacturing. Instead, a typical process in each category will be broadly described. This method should present a fundamental concept of the manufacturing problem as a whole.

In the fabrication of no other electronic device are so many industries called upon to supply the necessary basic materials. Parts for the cathode-ray tube originate in the fields of chemistry, metallurgy, plastics, ceramics and glass. The field of chemistry supplies barium, strontium, and calcium carbonates, zinc silicates and sulphides, cellulose and cellulose nitrates, aluminum and magnesium nitrates, lead sulphide, Aquadag, Aquagraph, Dixonac, carbon black, sodium silicate, alcohol, ammonium carbonate, formic and acetic acids, and many other acids and solvents. Chemistry also supplies numerous alkaline-earth compounds as useful binding and cleansing agents.

Metallurgy supplies copper, copper-nickel alloys, copper-clad iron, nickel, chrome nickel, manganese, tungsten, stainless steel, and beryllium. The ceramics industry supplies high-temperature insulations made of aluminum oxides and silicates, porcelain, and natural and synthetic lava. The glass industry supplies soft glass of lime or lead content, as well as the hard glasses known under the trade names of Nonex and Pyrex. The latter two products are almost universally used in the production of television cathode-ray tubes, since they have excellent thermal and mechanical properties and are fairly inexpensive.

The design of the glass tube blank is important, since it must be so mechanically strong as not to implode under atmospheric pressure when in operation. The blank should have a sufficient margin of safety to withstand three to five times normal atmospheric pressure. The screen end of the blank requires the greatest thickness to withstand the outside pressure. The more curved the screen is made, the greater pressure it can safely undergo. Since a perfectly flat screen would be most suitable for television images, the designer must compromise between a design which affords the desired flat screen and one that ensures excellent mechanical strength. A 12 in. diameter tube usually has a wall thickness of approximately ¼ in., although this dimension varies from ⅛ to ¼ in. with different manufacturers.

In the manufacture of the blank, a hot molten mass of the desired

FIG. 2.36 Production of the glass blank for the cathode-ray tube at the great glass works at Corning, N.Y. To the left one sees the hot molten mass ready to enter the steel mold. To the right is the glass blank as it comes from the mold. (Courtesy of Allen B. Du Mont Labs., Inc.)

amount of glass is poured into a steel mold made to the desired specifications. When withdrawn from the mold, the blank is of the desired shape for use in construction of the tube. To ensure that the wall structure of the blank is even and not subject to imperfections, the blank is examined by polarized light. The inner walls of the blank must also

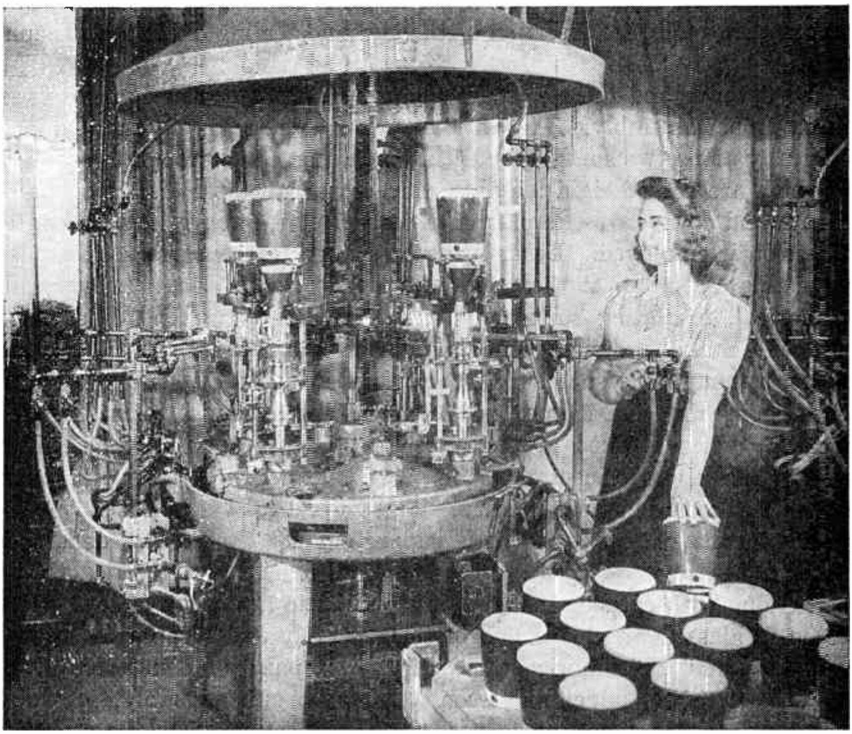


FIG. 2.37 Complete gun and stem assembly being sealed to the already-prepared blank on an automatic sealing machine. (Courtesy of Allen B. Du Mont Labs., Inc.)

be free from flaws and chemically cleaned. The production of experimental glass blanks through the use of glass-blowing techniques is shown in Fig. 2.36.

A preheating operation occurs before the intensifier terminal is inserted through the wall of the tube to make contact with the conductive coating inside. This lead wire is sealed into and becomes an integral part of the wall structure of the glass blank. After this tiny lead has been inserted and sealed, the tube blank is annealed for the purpose of relieving stresses that occur during the operation, i.e., when the lead is inserted.

The next step in the manufacture of a cathode-ray tube is to apply the coating of fluorescent material onto the inner surface of the screen end of the tube. The coating is usually applied by the spray method already described. After application, the material is baked in especially designed ovens, a process that eliminates residual binders and solvents incident to the coating process.

When the screen of the tube is completed, the electrically conductive material providing either an intensifier electrode or second-anode electrode, or both, is sprayed upon the interior walls of the blank. The tube is then ready for insertion of the gun and sealing off to the vacuum pump.

The cathode and the electrodes making up the electron gun are fixed into a proper assembly. The various elements are mounted and clamped vertically along two small cylindrical insulating rods, through the centers of which are placed rigid metallic connectors that later electrically terminate and connect to one pair of deflection plates above if electrostatic deflection is employed. Leads are spot-welded to the various electrodes along this assembly, at the point where they clamp about the vertical, cylindrical, insulating supports. Additional heavy vertical leads support and make electrical connection with the other set of deflection plates, although one such support does not extend along the full length of the gun. Instead, it does extend downward beyond a circular wafer of mica, which is fixed at the screen end of the second anode. This mica wafer serves to insulate the leads and the supports passing through and to ensure mechanical rigidity. This second lead is electrically connected to one of the other leads supporting the first set of deflecting plates.

The gun, with cathode inserted, is mounted to a number of lead wires sealed in glass at the lower end of the assembly and technically known as the "stem." The horizontal and vertical pairs of deflecting plates are welded to the upper or screen end of the gun assembly, provided that electrostatic deflection is used. All connections must be strongly welded to eliminate subsequent opens or shorts, which may occur if the welded joints do not possess sufficient mechanical strength.

The completed gun and stem assembly is next sealed to the prepared blank on an automatic sealing machine. In the process, mechanical pressure is applied to the entire mount when the glass bulb is forced over the supporting snubbers. It is here that weak joints and poor construction are likely to show up.

Following the sealing operation, the tube is baked, the cathode is broken down, and the mount parts are radio-frequency bombarded in vacuum to liberate residual gases. In the exhaust operation, which varies widely among the several manufacturers, the tube is first sealed to an exhaust manifold. The equipment employed for exhausting the tube comprises a mechanical force pump in series with an oil aspirator. In the exhaust operation, the barium and strontium carbonates at the cathode are converted to oxides of these materials, and large amounts of gas are released. The temperature of the grid is increased by increasing the heater voltage as well as by radio-frequency bombardment.

Before conversion of the barium and strontium carbonates to oxides and activation, the temperature of the gun assembly is increased several times by induction methods to about 700°C. The increase in temperature forces out residual gas from the metallic parts of the assembly. The process of cathode activation continues until gas pressure within the tube is reduced to the absolute minimum with the equipment employed. To remove gas to a further degree, the "getter," a small amount of pure barium fixed to a target and supported at the lower end of the gun assembly, is vaporized. This process is termed "gettering." The "getter" is vaporized by placing the tube in a strong radio-frequency field which increases the temperature of the barium to the point at which vaporization occurs.

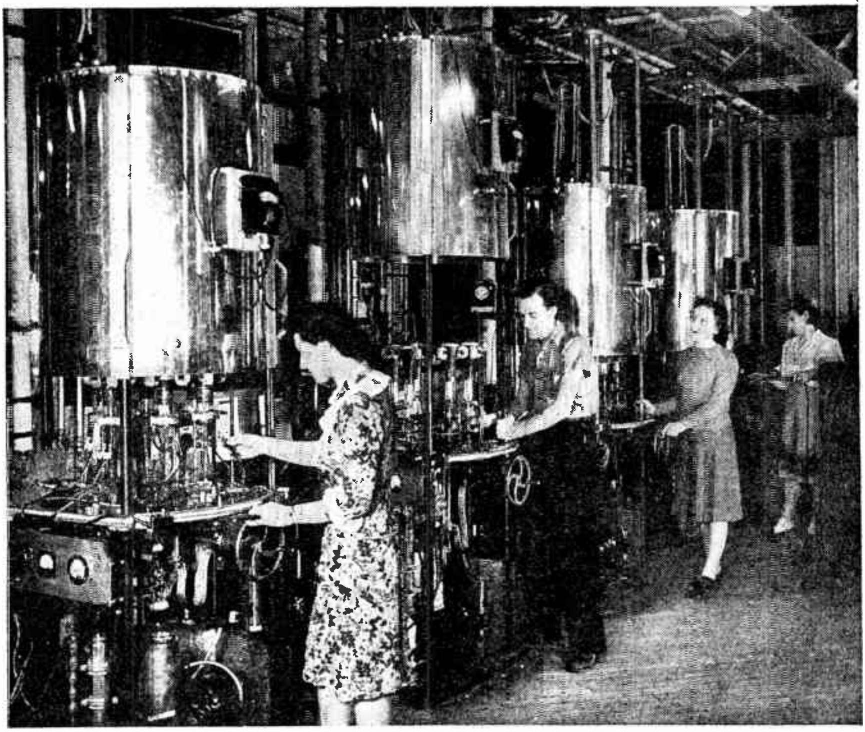


FIG. 2.38 Procedure after sealing. The tubes are baked, the cathodes broken down, and the mount parts radio-frequency bombarded in vacuum to liberate residual gases which are evacuated from the tube. (Courtesy of Allen B. Du Mont Labs., Inc.)

After exhaustion of gas, the tube is tipped off. By means of this operation the amount of gas within the envelope is increased, but it is eliminated by reaction with the active "getter" employed. After the tube leaves the exhaust station. the leads are inserted and soldered into a number of pins, which are hermetically sealed into a molded phenolic

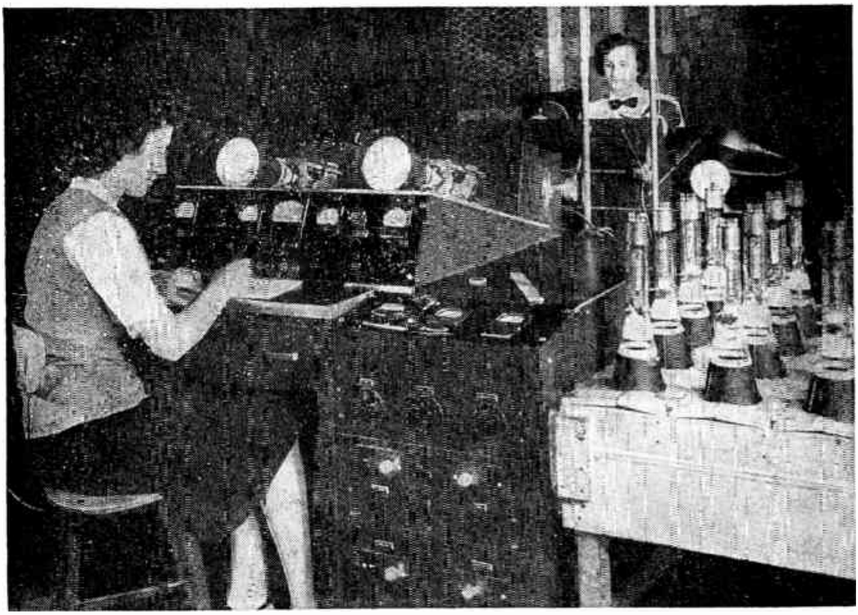


FIG. 2.39 Typical test console. The Du Mont cathode-ray tube must pass 18 electrical and 12 mechanical tests after manufacture. (Courtesy of Allen B. Du Mont Labs., Inc.)

plastic base. This process is carried out through use of an automatic basing machine. After the tube is "seasoned," it is ready to undergo as many as 18 electrical and twelve mechanical tests before being packaged for sale.

BIBLIOGRAPHY

1. THOMSON, J. J., "Cathode Rays," *Phil. Mag.*, Vol. 44 (1897), p. 293.
2. TRESSLER, M. E., "The Cathode-Ray Tube and Its Application," *General Electric Review*, Vol. 18 (1915), p. 816.
3. ZWORYKIN, V. K., "Improvements in Cathode-Ray Tube Design," *Electronics*, November, 1931, p. 188.
4. JOHNSON, J. B., "The Low Voltage Cathode-Ray Tube," *Bell System Technical Journal*, Vol. XI (1932), p. 1.
5. WATT, R. A. W., *The Cathode-Ray Tube in Radio Research*, His Majesty's Stationery Office, March, 1933.
6. ZWORYKIN, V. K., "On Electron Optics," *J. Franklin Inst.*, Vol. 215 (May, 1933), pp. 535–555.

7. STINCHFIELD, J. M., "Cathode-Ray Tubes and Their Applications," *Electrical Engineering*, Vol. 53, No. 12 (December, 1934), p. 1608.
8. "R.C.A. Cathode-Ray Tubes and Allied Types," *Technical Series TS-2*, R.C.A. Manufacturing Company, Harrison, N.J., 1935.
9. MYERS, L. M., *Television Optics*, Sir Isaac Pitman & Sons, Ltd., London, 1936.
10. LEVY, L., and D. WEST, "Fluorescent Screens for Cathode-Ray Tubes for Television and Other Purposes," *J. Am. Inst. Elec. Engrs.*, Vol. 79 (1936), p. 11.
11. ZWORYKIN, V. K., "Iconoscopes and Kinescopes in Television," *RCA Review*, Vol. 1 (July, 1936), pp. 60–84.
12. LEVERENZ, H. W., "Problems Concerning the Production of Cathode-Tube Screens," *J. Optical Soc. Am.*, Vol. 27 (January, 1937), pp. 25–35.
13. LANGMUIR, D. B., "Theoretical Considerations of Cathode-Ray Tubes," *Proc. I.R.E.*, Vol. 25, No. 8 (August, 1937), p. 977.
14. MALOFF, I. G., and D. W. EPSTEIN, *Electron Optics in Television*, McGraw-Hill Book Company, Inc., New York, 1938.
15. MEZGER, G. R., *The Hot-Cathode Low-Voltage Cathode-Ray Tube*, Allen B. Du Mont Laboratories, Inc., Passaic, N.J., 1939.
16. IAMS, H., "A Fixed Focus Electron Gun for Cathode-Ray Tubes," *Proc. I.R.E.*, Vol. 27, No. 2 (February, 1939), p. 103.
17. KLEMPERER, O., *Electron Optics*, Cambridge University Press, 1939.
18. ZWORYKIN, V. K., and G. A. MORTON, *Television*, John Wiley & Sons, Inc., New York, 1940.
19. ATWOOD, BANKER, KLINE, LEMPERT, CHRISTALDI, *A Practical Guide for Cathode-Ray Tube Design*, Allen B. Du Mont Laboratories, Inc., Passaic, N.J., 1943.
20. BEERS, J. R., "Cathode-Ray Tube Development," *Communications*, July, 1944.
21. BEERS, J. R., "Cathode-Ray Tube Manufacturing Problems," *Communications*, September, 1944.
22. BEERS, J. R., "Cathode-Ray Tube Testing," *Communications*, October, 1944.
23. BEERS, J. R., "Cathode-Ray Tube Special Designs," *Communications*, November, 1944.
24. SWEDLUND, L. E., "Improved Electron Gun for C. R. Tubes," *Electronics*, March, 1945.
25. CHRISTALDI, P. S., "Cathode-Ray Tubes and Their Applications," *Proc. I.R.E.*, Vol. 33, No. 6 (June, 1945), pp. 373–381.
26. "Television Receivers in Mass Production," *Electronics*, June, 1947.

REVIEW QUESTIONS

2-1. (a) Describe the construction of an oxide-coated cathode. (b) Why is the cathode said to be "indirectly heated"?

2-2. What is meant by "potential barrier"?

2-3. Explain the operation of the modern cathode-ray tube, and show the construction of the tube by means of a simple diagram.

2-4. (a) What is the "electron gun" of a cathode-ray tube? (b) Describe the function of the gun, and name its principal parts. (c) What is the function of each element?

2–5. (a) What is meant by "fluorescent screen"? (b) State how the fluorescent screen may be applied commercially.

2–6. (a) What is meant by "long-persistence" screen? (b) Why is an ion spot or blemish sometimes formed on the screen of a cathode-ray tube? (c) How may the ion spot be prevented through special tube construction?

2–7. Explain how the tube is "based."

2–8. What is the function of the intensifier electrode?

2–9. (a) Name the principal phosphors in current use. (b) Explain the purpose and application of each.

2–10. (a) Describe several types of cathode-ray tube and explain their construction. (b) What are the advantages of the "metal-cone" picture tube?

CHAPTER 3

THE CATHODE-RAY OSCILLOGRAPH

3.1 The Time Base. Man, since antiquity, has shown an insatiable interest in the measurement of time. The early Greeks, Romans, Egyptians, and Babylonians used the sundial and the water clock to convert the passage of time into some unit whereby it could be accurately gauged or measured. Even the almost forgotten civilization of the Incas yields evidence of the sundial as a means for time measurement. The position of their principal god, the sun, was plotted as the earth revolved on its axis.

The only difference between the methods employed by the Incas and those employed today lies in the precision by which time measurement may be achieved. While the Incas' measurements were in units of parts of a day, the radio engineer may now measure the flight of time in terms of fractions of a microsecond. By means of the cathode-ray oscillograph, he may graphically view an electrical wave accurately plotted against any suitable time base, thereby obtaining an intelligent picture of the action which takes place more rapidly than the human eye has ability to follow. Thus, any potential, regardless of amplitude and phase, and almost without regard for frequency, may be compared against a selected and suitable time base and the results analyzed and investigated for such information as may be desired.

The voltage that we desire to analyze may be applied to the vertical deflecting plates of the cathode-ray tube, usually through an amplifier, and a sweep voltage of known time base may be applied to the horizontal pair of deflecting plates. The sweep voltage will then produce uniform motion of the luminescent spot at the screen of the tube, causing it to sweep or trace out the shape of the unknown voltage waveform applied to the vertical deflecting plates. The luminescent spot may be moved across the screen at a velocity that can be made to vary in some predetermined manner with respect to time, or it may be moved across the screen at constant velocity. In each case it produces a luminous and clearly defined trace. If signals are applied to the screen so as to disturb the spot, thus creating a visual indication of their presence, then the separation between the two disturbances on the screen provides an accurate measurement of the time interval between the two applied disturbances.

The sweep voltage producing uniform motion of the spot across the screen is termed a "saw-toothed voltage," since the shape of the voltage waveform resembles the teeth of a saw. When the recurrent frequency of the saw-toothed sweep voltage is applied to the horizontal deflection plates and adjusted to synchronism with the frequency of an alternating voltage applied to the vertical deflection plates, the waveform of the latter voltage will appear stationary on the screen. This occurs even though the known frequency of applied voltage under investigation is very high, because of the ability of the time-base generator to synchronize its operating frequency with the frequency of the unknown signal applied to the vertical plates of the cathode-ray tube. In instances of recurrent phenomena the spot starts its excursion each period at an identical electrical point along the wave of the unknown. The wave

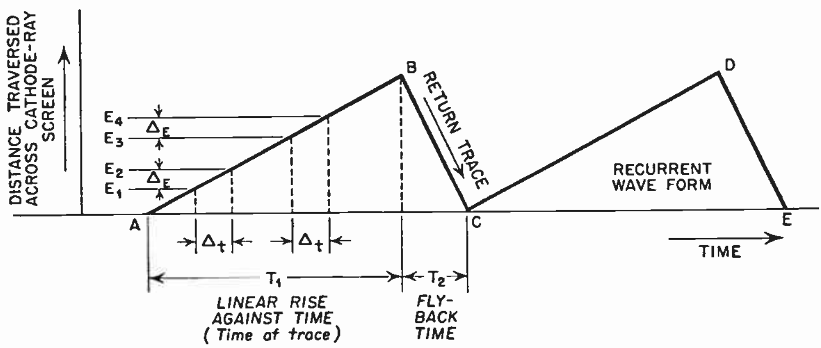


FIG. 3.1 Ideal saw-toothed-voltage waveform.

appearing on the fluorescent screen is therefore stabilized. With the pattern "locked in," or synchronized, the retrace of the wave which occurs many times per second, appears to the eye as a still image. This phenomenon is the result of the persistence characteristic of the screen and the persistence of vision of the eye.

A saw-toothed waveform is plotted in Fig. 3.1. By suitable circuit design, the voltage is made to increase from point A along a straight inclined line to point B. If the circuit producing the saw-toothed voltage is properly designed and adjusted, this increase will appear linear and without distortion. Now, if this voltage appearing between points A and B is applied to the horizontal deflecting plates of a cathode-ray tube, the luminescent spot of the tube will move across its screen, forming a time base. The time base will be precisely linear with time if an increase ΔE v. occurs in Δt sec. anywhere along the inclined slope AB, since the spot moves uniformly with respect to time between any two points selected along the base.

The sweep voltage returns to zero at C, and the time required for the voltage to return to zero amplitude from maximum is termed the "fly-back time." It can be seen that the fly-back time is much less than the time required to obtain a rise in voltage along the forward inclined slope from point A to point B. Thus, the luminescent spot is swept across the screen at a velocity too great to result in emission of much light at the screen, and the return trace is usually not visible to the naked eye. The return trace may be blanked out completely by suitable means, so that it is completely invisible. Such is the case in television apparatus.

An extinguishing signal may be applied to the grid or cathode of the cathode-ray tube by making use of a differentiating circuit, thus rendering the return trace completely invisible. This circuit is described in detail later (pages 442–448), and its application in circuits employed in high definition television systems will be discussed.

In the conventional method of applying the time base to the cathode-ray tube, the spot is moved from left to right to produce the pattern and is immediately returned to retrace a subsequent and, in most cases, identical pattern. Thus, the time interval T_1 is much greater than that of T_2. As a matter of fact, in actual and practical circuit design T_2 is made a small percentage of trace time, so that the line BC is practically vertical and the fly-back time is made constant for any frequency to which the sweep generator is adjusted. No attempt is made in television or oscillographic apparatus to maintain the fly-back portion of the sweep voltage waveform linear, since there is no advantage in doing so. Only the forward slope is generally employed for any practical use.

In television, two time bases are utilized to deflect the electron beam both horizontally and vertically. This subject is discussed in greater detail elsewhere in the text (pages 102–112). It is, however, conventional to scan the screen of the cathode-ray tube horizontally 525 times while traversing the screen twice vertically. Thus, each vertical traverse of 262.5 horizontal lines is displaced by half a line, so that alternate sweeps are interlaced. Since the picture repetition rate is 30 frames per second, the horizontal sweep frequency is 30×525, or 15,750 c.p.s., while the vertical sweep frequency is 60 c.p.s. The frequency of each field of 262.5 lines may be viewed by the eye if the time surface, or raster, of the viewing screen is examined at the upper or lower vertical leading edge. The beginning and end of each field may be so observed and is one check to determine whether proper interlacing is being used.

The time base is not always made linear with respect to time, sometimes it is made sinusoidal or a very complex waveform. Time bases may be divided into three general classifications, namely, sinusoidal, saw-toothed, and mixed sinusoidal and saw-toothed. The sinusoidal time base may be either of two types: one involving a single frequency or one involving two frequencies. The sinusoidal time base for electrostatic deflection of single frequency will produce either a straight-line trace or a circular trace. The sinusoidal time base involving two frequencies for electrostatic deflection will produce either a spiral or a radial trace on the fluorescent screen. The mixed sinusoidal and saw-toothed base for electrostatic deflection will produce either a spiral or a radial trace. A saw-toothed time base for electrostatic deflection may involve either a single frequency or two frequencies. The use of two frequencies in the time base for electrostatic deflection will yield the television raster, or time surface.

Either a one- or two-frequency time base may be employed for electromagnetic deflection. If two frequencies are employed, they result in the television raster, or time surface, already referred to. In the latter case, both horizontal and vertical sweep voltages must be absolutely linear; otherwise, the television image will evidence severe distortion, and persons or objects appearing on the screen will be all out of proper physical proportion either vertically, horizontally, or both.

Although an inductive time base is possible to produce, it is a most unsatisfactory device at the present time. Thus, the capacitive form of time base is applied almost universally in all present television and oscilloscopic apparatus. In general, three devices are necessary to produce such a time base. These are a *charging device*, which comprises a suitably chosen capacitor and current-regulating device, a discharging, or fly-back, device, and a switching device. The charging device is a capacitor, and the current-regulating device is either an inductance, a resistance, a saturated diode, a pentode, or one of various types of feed-back circuit. The fly-back, or switching, devices are either externally or self-operated. If externally operated, they include a vacuum tube or a commutator or switch. If a self-operated fly-back device is employed, it is either a gas triode, a vacuum-tube trigger circuit, or a spark gap. If an externally operated vacuum tube is used as a fly-back device or switching device, it takes the form of a pulse-operated switching tube or a back-coupled amplifier demonstrating at least one stable condition.

3.2 Capacitive Time Base. About 1924, G. W. Anson of Great Britain first attempted to construct a linear saw-toothed time base involving the use of a neon lamp. In its usual form, this device is a two-electrode tube, the envelope of which is filled with neon gas under low pressure. The gas in such a tube becomes ionized when a potential is applied across the two electrodes of the device. The potential resulting from ionization of the gas depends upon the pressure of the neon gas within the bulb, the surface condition, and the metal of which the electrodes are made. Ionization usually occurs at about 130 v. applied potential, and deionization takes place at about 100 v. Some two-electrode tubes ionize at 55 v. potential.

A simple neon time base, such as is shown in Fig. 3.2, can be made up. The capacitor C_1 is charged through a high resistance R_1, and this capacitor will be subsequently discharged when the charge upon it reaches the striking voltage of the tube. There is, therefore, a range of about 30 v. between striking and extinguishing voltages (see above). The repetition frequency of the device can be varied by changing either the value of the capacity C_1 or the amount of charging resistance R_1. However, the important point is that the capacitor is charged and discharged with respect to time. If it is desired to examine a certain potential, it may be connected across the resistor R_2, which is seen to

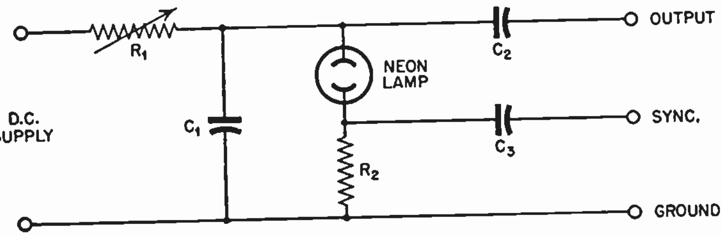


FIG. 3.2 Elementary neon time base.

be in series with the neon lamp. The time base may then be brought into synchronism with the potential to be studied and analyzed.

Such a capacitive time base operates on the principle that if a steady source of d-c potential is connected across a capacitor and resistor, series-connected, then current will flow into the capacitor, causing it to acquire a potential, Q/C, where Q is the capacitor charge in coulombs and C is the capacity of the capacitor in farads. The rise in voltage across the capacity is exponential in shape and is not linear. The time base described above was generally unsatisfactory for many reasons. It was not until A. W. Hull of General Electric, in 1929, introduced the Thyratron that voltage efficiency, due to increase in the separation between striking and extinction potentials, provided sufficient output voltage to enable the construction of practical sweep-voltage generators.

The Thyratron tube not only provides larger separation between striking and extinction voltages, but the separation can be brought under convenient control. Such a tube employs a hot-cathode and control grid, and a small amount of mercury is contained within the glass envelope of the device. As the temperature of the cathode shows an increase, some of the mercury is vaporized; and as the pressure of the vapor is a function of bulb temperature, both it and room temperature, in which the bulb is operated, have an effect upon the vapor density and upon tube operation. A threshold effect appears when grid and plate voltages applied are such as to cause a certain value of plate current to flow. This results in ionization of the vapor in the space, plate to cathode. A cloud of ions then surrounds the grid, and it loses control. The result is an arc occurring between plate and cathode with a potential drop of 15 to 18 v. It will be seen that if grid bias and plate voltage are of such values that insufficient plate current flows to start ionization, then the tube behaves like a vacuum tube biased slightly under plate current cutoff. Therefore, as the capacitor charges, the plate voltage increases until the potential gradient is sufficient to ionize the vapor and heavy current passes, which rapidly discharges the capacitor. Then the cycle begins again.

3.3 Thyratron Saw-Toothed Generator. The saw-toothed sweep-voltage generator employing a Thyratron tube is far more satisfactory than earlier generators which made use of the neon lamp for many reasons. Of importance is the fact that the voltage drop across the Thyratron tube is less than the drop across a neon lamp. Also, the Thyratron will pass a considerably larger instantaneous current and deionization takes place at a faster rate than the same action occurs in the neon lamp. As a result, the capacitor, across which the Thyratron is connected, is discharged in less time. Consequently, a generator employing such a tube is capable of generating a higher sweep frequency which can be accurately synchronized. At the same time, the Thyratron circuit demonstrates inherently greater stability, since ionization obtains more dependably than is possible with the neon lamp.

The Du Mont type 208 oscillograph utilizes a Thyratron in its saw-toothed generator, and the total frequency range is such that voltages at frequencies of 2 to 50,000 c.p.s. may be readily obtained at its output. The circuit is illustrated in Fig. 3.3. The wide range of this instrument is obtained by connecting a bank of eight capacitors across the output of the Thyratron. Any one of the capacitors may be readily inserted by means of a tap switch with front of panel control. This tap switch provides rough frequency control, and any frequency within the range of the capacitor selected may be obtained by operating resistor R_{32}. Thus, it provides vernier adjustment to the precise desired frequency.

An R.C.A. type 884 Thyratron tube is employed in the generator. This tube is of convenient size. Replacements are easily obtained, and it has proved itself to be a rugged, dependable type. It is used in many other oscillograph generator circuits.

The operation of the 884 as a sweep-circuit oscillator is based on the fact that a negative potential applied to the grid either maintains plate-current cutoff or quickly loses control, which is a function of d-c plate potential. After grid control is lost, it can be restored only by a reduction in plate potential below that required for ionization of the gas within the tube. The action is controlled by means of a capacitor in shunt with the plate circuit and charged through a current-limiting device. The capacitor discharges through the tube when the plate potential reaches that required for breakdown. When the capacitor discharges through the tube, the plate voltage suffers a reduction, the grid regains control, and the cycle is repeated.

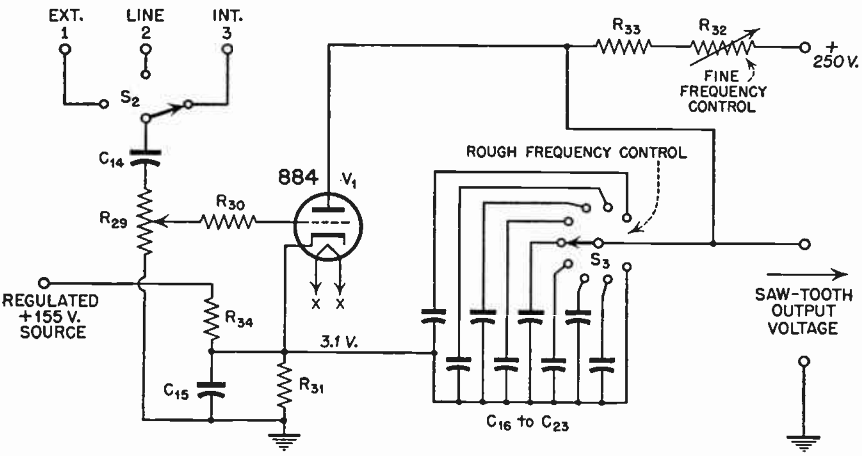


FIG. 3.3 Thyratron saw-toothed sweep generator, Du Mont type 208 oscillograph.

The grid of the tube controls the start of plate current flow, and for any given grid potential there is a value of plate potential at which discharge will start. Once the discharge starts, it cannot be influenced by the grid, but can be terminated through reducing the plate voltage below the ionization potential of the gas. The rate of deionization is rapid, and a reduction in plate voltage will result in prompt current cutoff.

In the Thyratron sweep generator of the Du Mont type 208 oscillograph a fixed bias of plus 3.1 v. is applied to the cathode of the 884, the grid being effectively grounded. Thus, though positive potential is used in biasing, it is the same as though a negative potential of the same magnitude had been applied to the grid. The power supply, from whence this bias voltage is obtained, is well regulated effectively to stabilize operation of the tube.

In simple terms, the capacitor selected and switched in shunt with the plate circuit is charged by the plate-voltage supply through resistances $R_{32}R_{33}$. The applied grid bias prevents current flowing through the tube until the potential across the capacitor and plate circuit reaches breakdown. When the capacitor potential is reduced below the ionization potential of the tube, the negative grid attracts any positive ions to itself, and any electrons are driven to the other elements of the tube. This results in deionization of the space between plate and cathode. The discharge current no longer flows on the deionization period of the cycle of operation, the grid again takes control, and the capacitor begins to charge again for another operating cycle.

The voltage at any instant is given as

$$e = E\left(1 - \varepsilon \frac{-t}{RC}\right)$$

where E = applied voltage
R = resistance in ohms
C = the capacity in farads
t = interval in seconds after the voltage is applied
ε = a base of natural logarithms (2.718)

The voltage across the capacitor at any instant is given as

$$e = E\left(1 - \varepsilon \frac{-t}{RC}\right)$$

The time required to charge any of the shunt capacitors to any voltage is VC/I where I is the uniform charging rate expressed in amperes. The number of saw-toothed pulses produced per second is I/VC, neglecting the time required for discharge, which is only of importance at high frequencies. The value of C includes tube capacitance as well as stray circuit capacitance, which slightly reduces the value of calculated capacitance.

Where it is desirable to obtain a sweep voltage of improved linearity, the charging resistor may be replaced by a pentode vacuum tube, as shown in Fig. 3.4. The operation of the pentode is such that the plate current is at a constant value within the range of voltage applied across the tube. The current passing through the capacitor must also flow through the pentode replacing the charging resistor. Because the current is a moving charge, the current passing into the capacitor increases the charge. The potential on the capacitor is a function of the capacity of that capacitor and the amount of charge. So, if the current flowing into the capacitor is of constant magnitude, then the rise of voltage across the capacitor will be linear. This situation obtains because equal amounts of charge are added during equal units of time. The frequency of a saw-toothed generator may be varied by varying the bias applied to the pentode and by varying the capacity. Thus, a constant current of varying amplitude is passed.

3.4 Synchronization. It is possible to synchronize the sweep generated by the Thyratron through application of an external sychronizing signal to the grid of the tube (see Fig. 3.3). The synchronizing signal is applied to the grid through a voltage divider in order that its magnitude may be under control at all times.

Synchronization occurs when the frequency of the sweep is locked in with the frequency of the signal under observation; hence, the image on the luminescent screen of the cathode-ray tube will appear stationary. When it is desired to observe more than one cycle of the applied signal, the sweep circuit is adjusted to a submultiple of the observed signal frequency. If two complete cycles are observed on the screen, then the sweep frequency is adjusted to one half that of the applied signal

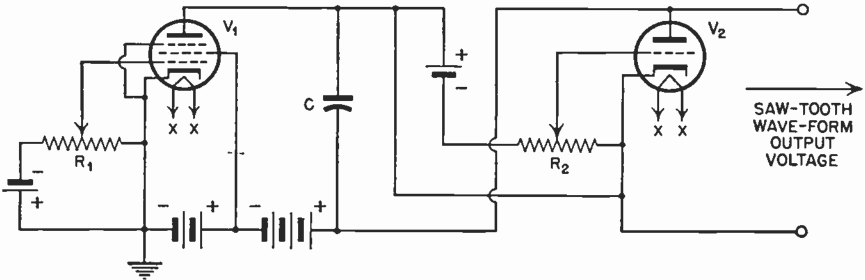


FIG. 3.4 Controlled charging-current saw-toothed generator.

frequency. It is adjusted to one fourth the signal frequency when four complete cycles are received on the screen. If the frequency of the waveform to be observed exceeds 5,000 c.p.s., at least three complete cycles should be observed on the screen, since fly-back distortion is then of no consequence.

3.5 Time-Base Linearity. It has been mentioned that time-base linearity is of extreme importance in television applications. For instance, if the forward slope of the horizontal and vertical saw-toothed waveforms, as applied in television apparatus, are nonlinear, the reproduced images suffer serious linear distortion. If the vertical saw-toothed waveform is nonlinear, the image reproduced on the screen of the receiver or line monitor cathode-ray tube will "pack" or "pull" at some point, or points, along the vertical axis of the picture. Conversely, if the forward slope of the horizontal saw-toothed waveform is nonlinear, the reproduced image will "pack" or "pull" at some point, or points, along the horizontal axis of the picture.

If the image appearing on the fluorescent screen is that of a human being, with the subject filling most of the screen vertically, the head of the subject will seem compressed or elongated vertically if one portion of the forward slope of the vertical saw-toothed waveform is nonlinear. Nonlinearity at the other extreme of the forward slope of the waveform will result in "packing" or "pulling" at the lower extremity of the subject, and the lower extremities of the body will appear entirely out of proportion to the rest of the body. The same condition obtains with a nonlinear horizontal saw-toothed waveform, though the picture will "pack" and "pull" along the horizontal axis of the image.

A saw-toothed waveform is nonlinear when the slope of the waveform varies from a straight-line amplitude versus time characteristic. Therefore, the charging rate is said to be not constant with time throughout the forward slope. The charging current must remain constant if a perfectly linear time-base potential is to result. The condition may be easily checked in television equipment by a number of convenient methods. One such method will be discussed. A matte-finished white card may be divided into squares of equal area, with the squares ruled off in India ink. It must have a dimensional ratio of 4 : 3, which is the standard aspect ratio in television. This card is placed on an easel in front of the television camera and flooded with light. The light must be equally distributed over the complete area of the card. Then, if the image is viewed on the screen of a line monitor that has previously been checked for good linearity, the squares should appear just as uniform as to shape, form, and area as they appear on the test pattern before the camera. Any departure indicates nonlinearity.

It is assumed, of course, that no error is introduced through placing the card at an oblique angle on the easel, that the camera has previously been adjusted on its pan and tilt top so that it is precisely level, and that the easel is exactly parallel with the front of the camera. Also, an axis through the lens must fall at the exact center of the test pattern. A spirit level will aid in properly leveling the camera and the horizontal member of the easel which supports the test pattern, or card.

If the image appears nonlinear, then it is possible, with the aid of a reliable oscillograph, to trace the horizontal and vertical saw-toothed waveforms throughout the apparatus, from circuits in which they are generated, through deflection amplifiers, to the horizontal and vertical deflection coils or plates at the pickup tube. Eventually, the nonlinearity is isolated in some particular circuit within the system. The oscillograph, of course, is connected at high impedance across the circuit from point to point, and its internal time-base generator frequency is synchronized with the known frequency of the saw-toothed waveform under investigation.

It is important that the raster of the monitor tube be first adjusted to the proper aspect ratio, with proper blanking inserted. When two linear time-base potentials are applied at right angles to each other by connecting them to the horizontal and vertical pairs of deflection plates or coils of the cathode-ray tube, the time surface, or image, appearing on the fluorescent screen is termed a "raster." At this point it might be well to define the term "raster."

The complete raster appears in the time required to scan two fields of 262.5 lines or one frame of 525 lines. The lines produced during alternate fields are displaced vertically by one half the distance between the lines of one frame, so that alternate fields of 262.5 lines are interlaced. The horizontal time base is sometimes called the "line time base," and the vertical time base is called the "frame time base." The raster is, in effect, a time surface.

Another method of checking "saw" linearity is to apply a modulating signal to the cathode or grid of the cathode-ray tube, with the modulating signal oscillator synchronized with the frame time base. The frequency of the modulating signal is adjusted to thirty or forty times the frame frequency and produced by a time base or oscillator. As a result, horizontal black bars appear across the fluorescent screen of the cathode-ray tube. Nonlinearity is indicated by unequal spacing of the horizontal reference bars. The spacing may be easily and conveniently measured by means of a small translucent scale.

Now, should the frequency of the modulating signal be raised to a multiple of the repetition frequency of the line time base, i.e., the horizontal time base, then alternate black and white vertical stripes will appear on the screen. These stripes will appear equally spaced if the horizontal sweep is linear or unevenly spaced if the horizontal sweep is nonlinear. To obtain a stationary marker of this nature, it is necessary to synchronize the horizontal saw with the modulating signal. The vertical sweep may be operated either in synchronism or free running. Measurements are made from the leading edge of one bar to the leading edge of a succeeding bar. A square-wave generator of about 20 v. output can be used for production of the modulating frequency, although a beat-frequency oscillator with synchronization is more desirable.

Temperature compensation of "saw" circuits is desirable if linearity, once adjusted, is to hold constant for any appreciable length of time. The ambient gradient of temperature in rooms in which deflection circuits are operated must not be allowed to become too great if the "saws" are to remain linear. If capacitors having a negative temperature coefficient are used in shunt with capacitors having a positive temperature coefficient, the two resulting in the required capacity, there is less variation from the absolute linearity to which the "saws" are once adjusted.

Mica capacitors should be used wherever judicious design will permit. These should have voltage ratings which allow ample safety factor. Overloaded capacitors demonstrate temperature rise and a change in capacitance and result in poor and unstable saw-toothed waveform linearity. Any plate potential that is supplied should originate at a well-regulated source. It has been found that bias voltage derived from a stabilized electronic rectifier proves the most suitable. Battery bias is also an acceptable means of obtaining constant biasing potential.

Bias voltage obtained from a dropping resistor in the voltage-divider network of a plate-potential rectifier, which is used to supply plate power to the same saw-toothed generator or amplifier, is not acceptable. When such a system is employed, it is usually necessary to have the total plate-current demand pass through the biasing resistor to provide the necessary biasing potential. Hence, any change in plate-current demand produces a change in the current passing through the biasing resistor. The change in bias will affect the operating characteristic of any tube so operated, with resultant poor and unstable linearity. It is more expedient to employ a separate rectifier for bias voltage or to employ stable battery bias.

3.6 Horizontal and Vertical Deflection Amplifiers. The cathode-ray tube is inherently an insensitive device. Therefore, if maximum deflection at the fluorescent screen is to be obtained, external potentials in the order of several hundred volts must be applied to the deflection plates. The input voltages from the signal source usually are not this great. Thus, it is necessary to increase the amplitude of the deflecting potentials. A suitable amplifier is necessary to permit the study of voltages with insufficient magnitude to result in useful direct deflection at the screen.

The use of deflection amplifiers imposes a limitation on the character of the signal that may be used. When the signal that is to be analyzed or observed is directly applied to the deflection system of the cathode-ray tube, the maximum amplitude obtained will be limited only by the maximum full-scale beam deflection. The maximum upper limit of applied frequency will be limited by the transit time of the electron beam traversing between the deflection plates and the shunt capacitance existing between the external terminals to which the internal plates make electrical connection. In conventional cathode-ray tubes, transit-time effects limit the usefulness to frequencies below 200 mc. per sec. when accelerating voltages of approximately 1,500 v. are employed. At higher frequencies the capacitive reactance due to shunt terminal capacitance is so low that it effectively loads down the signal applied, reducing its amplitude. In some special types of cathode-ray tube that are designed to operate at extended high-frequency range, the deflection-plate terminals are located directly in the walls of the blank and are placed as physically close to the deflecting plates as possible. This arrangement reduces the effective terminal capacitance.

When a d-c potential is applied directly to the plates, the beam deflection is a function of the amplitude of the applied signal potential. The beam will remain fixed in its deflected position until the d-c deflection potential is removed from the input terminals. In the complete circuit of the conventional cathode-ray oscillograph, a variable d-c potential is made use of for horizontal and vertical positioning of the spot applied to the screen.

Any amplifier employed in the cathode-ray oscillograph to increase the amplitude of the applied signal, so that full-scale deflection can be achieved, must thoroughly satisfy a number of design requirements. There must be no frequency discrimination, either contributed by the amplifier itself or by the attenuator circuits applied at the input of the amplifier to control signal amplitude. Phase distortion must also be kept to an absolute minimum. The maximum possible d-c and peak input voltages must also be taken into consideration, the minimum signal voltage being determined by that amplitude which results in minimum beam deflection permitting useful study of the applied signal. The useful or operating voltage ratings of capacitances used for input coupling, as well as the voltage range of the input amplifier stage, determine the maximum input signal voltage that may be safely applied. A generous safety factor is usually allowed in determining the ratings of parts used in amplifier construction. Tubes are selected for their ability to remain constant as to characteristics over a wide ambient-temperature gradient, and they must be uniform as to type. The selection of a proper input attenuator is of the utmost importance, since the distributed capacitance of most high-resistance potentiometers is appreciable and sometimes results in serious phase distortion as well as frequency distortion, especially at the higher frequencies. Such effects must be compensated for.

The *vertical-axis amplifier* must be carefully designed since it is called upon to pass and amplify pulses, square waves, and waveforms that are not always of a strictly sinusoidal character. Hence, the over-all and transient-frequency response of this amplifier must be such that it can amplify, without appreciable distortion, many irregular wave shapes and many types of input signals.

The *horizontal-deflection amplifier* must also be carefully designed. It is used to increase the amplitude of the saw-tooth waveform, which, when applied to the horizontal deflection plates of the cathode-ray tube, results in uniform movement of the spot from left to right along the screen. When the spot travels from a position at the left of the screen to a position of full deflection at the right, it snaps back to its original position, and then repeats. The saw-toothed waveform used for horizontal deflection is rich in harmonic content. Thus, the amplifier must be capable of passing, without appreciable frequency or phase distortion, signals above and below the mean saw-toothed frequency. Usually, the frequency range extends from a few cycles to about 50,000 c.p.s., or greater.

The vertical and horizontal amplifiers should have identical frequency and phase characteristics, since if the relationships of two signals are to be analyzed, each one being applied to a separate axis, identical frequency and phase characteristics are of extreme importance. It is not

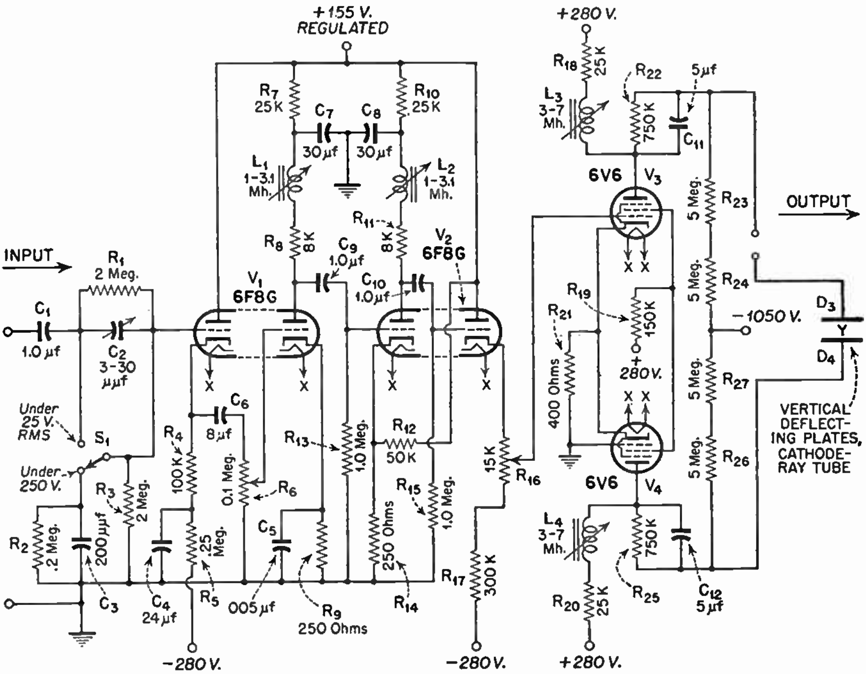


FIG. 3.5 Vertical deflection and paraphase amplifiers, Du Mont type 208 oscillograph.

an easy matter to attain equal phase characteristics in actual design, and considerable care must be exercised in measuring the phase as the two amplifiers are developed.

It can be seen that the use of deflection amplifiers provides an extension of the useful voltage range, while at the same time the amplifiers impose a restriction as to useful frequency range. Figures 3.5 and 3.6 show the circuits employed in the Du Mont type 208 oscillograph. Both of these amplifiers are of excellent design, typical of those found in modern high-quality oscillographs offered to the television engineer and technician. In no other field are high-quality amplifiers of greater importance as an aid in circuit development and analysis.

The Du Mont type 208 Oscillograph has seen such widespread use in the field of radio engineering that many engineers prefer to use it in television applications. To facilitate such use, the Tel-Instrument Co., of Bloomfield, N.J., has designed an inexpensive accessory unit which permits the use of this instrument for the study of extremely sharp pulses, video signals, and other waveforms having very high frequency components. This unit is the Model 1000 Teledapter. The device will also serve as a video amplifier in television-receiver design to drive the control grid of a cathode-ray tube, since the output voltage and permissible capacitance loading are proper for this purpose.

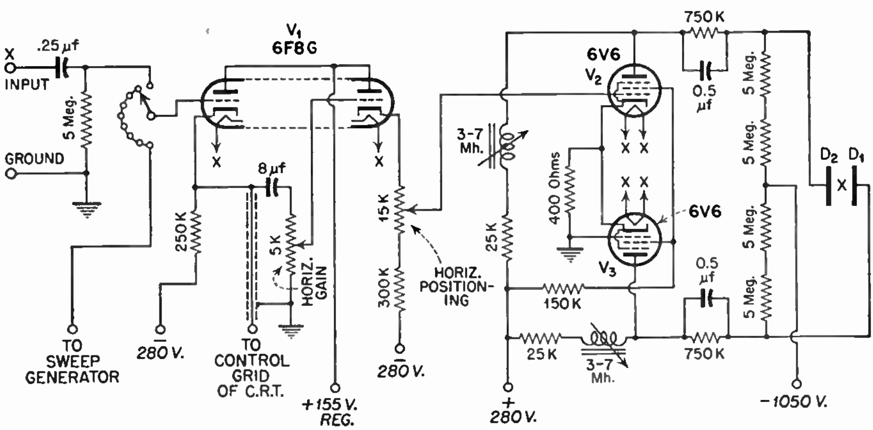


FIG. 3.6 Horizontal deflection and paraphase amplifiers, Du Mont type 208 oscillograph.

The Teledapter is a high-gain video amplifier, with a complete power supply housed in the same case. It is suitably compensated to reproduce a 10-c.p.s. square wave with no greater than 10 per cent tilt and to maintain an output constant within 3 db. to 6 mc. per sec. This frequency response makes the unit suitable for use in investigating high-quality video amplifiers. The unit is equipped with a probe and 4-ft. cable possessing an attenuation constant of 10 : 1. The direct input deflection sensitivity is approximately 28 mv., peak to peak for 1 in. deflection, and up to 2.5 in. of undistorted deflection is afforded. An input attenuator is provided with ratios of 1,000 : 100 : 10 and 1 : 1. The attenuator is of such advanced design that no appreciable frequency discrimination results.

The unit is of such physical size that it matches the Du Mont Model 208 Oscillograph and is intended to be used as a companion unit where precise measurements are to be made.

The input impedance of the unit, when the probe is made use of, is 5 megohms. No overshoot is present on a square wave having a rise time of 0.1 μsec. The instrument serves to make useful, in television, the many type 208 oscillographs now in use. The Du Mont type 241 Oscillograph is more desirable for general use about the studio if a later instrument is to be considered, and there are many other cathode-ray oscillographs on the market which are particularly suited to work in television-engineering applications. The specific requirements of advanced types of oscillographs intended to be used in TV broadcasting applications, will be discussed in the chapter on television broadcasting techniques.

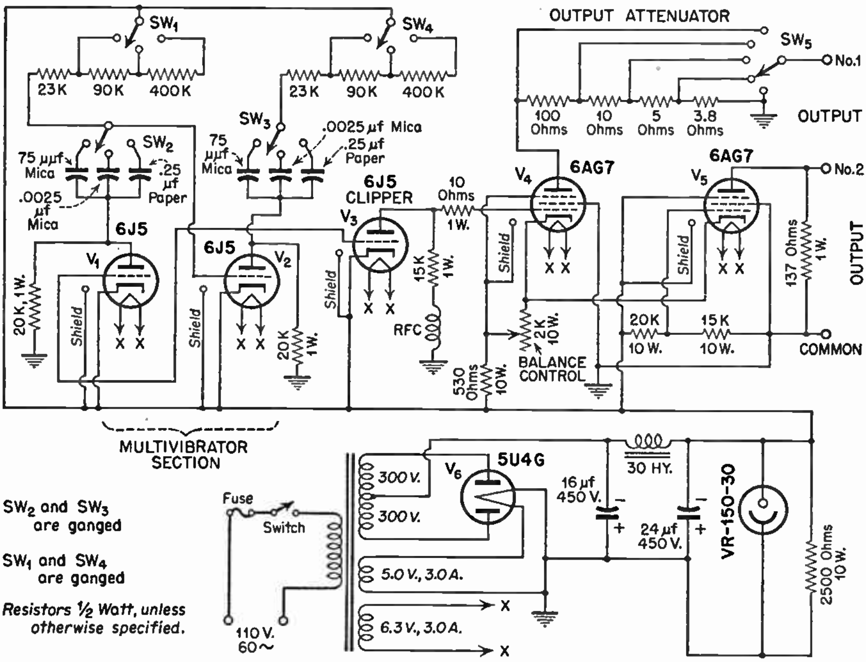


FIG. 3.7 Square-wave generator incorporating multivibrator and clipper; Range 2 c.p.s. to above 100,000 c.p.s.

3.7 Low-Frequency Distortion in Deflection Amplifiers. The characteristics of a deflection amplifier, as employed in a cathode-ray oscillograph, may be best determined by applying a linear square-wave signal at the input terminals of the amplifier and observing the reproduction of this signal at the output of the amplifier. Any departure from the original waveform may then be readily investigated and the amplifier circuit adjusted for distortionless operation. The circuit of a laboratory-type square-wave generator is shown in Fig. 3.7. If this circuit is used, it must be remembered that the chassis is above ground potential and that care must be exercised in its operation. The user must not come into contact with the plate voltage. A number of methods whereby square waves may be generated are possible. Some of these methods produce the square wave directly, whereas others obtain an identical result by squaring a sinusoid by means of a clipper.

When the square wave is applied to the amplifier, the steep front of the wave provides an indication of the high-frequency, or transient, response. The flat top of the square wave indicates the low-frequency response of the amplifier.

The input voltage to the amplifier is usually capacitively coupled by means of a suitably chosen capacitor placed in series with the control grid, while the grid-leak resistor is effectively in shunt with the tube's input (control grid to ground). The time constant of the grid circuit is thus

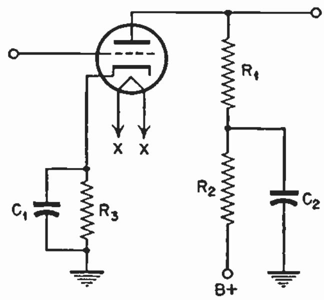


FIG. 3.8 Low-frequency plate-circuit compensation.

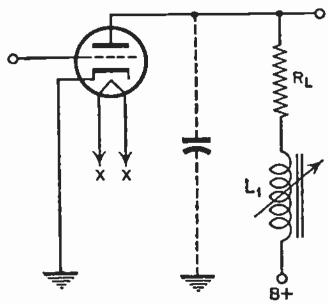


FIG. 3.9 High-frequency plate-circuit compensation.

a function of the product of the input capacitance and the grid-leak resistance. If the values of these components produce too small a time constant, the signal as applied to the control grid will evidence distortion. This distortion arises from the charging and discharging of the series input capacitance through the grid resistor during the flat-top intervals of signal. A very large time constant will eliminate this type of distortion. At the low pass frequencies, however, the necessary value of capacitance becomes too large, inasmuch as only the capacitance may be increased, the value of maximum grid resistance being a function of the current necessary for proper tube operation. Therefore, in judicious design, the time constant CR is kept to the minimum, since its value determines the recovery time from large transient-pulse effects, and plate circuit compensation is employed. A resistance-capacitance network is connected in the plate ciruit of the tube, as shown in Fig. 3.8. When the voltage appearing at the junction of the two series plate resistors is added to the distorted wave obtaining at the control grid and amplified by the tube, the resultant wave at the plate output, with proper adjustment of the plate compensation network, is a reproduction of the input applied square wave, but without distortion.

In actual practice, the value of the necessary components for the plate-circuit compensation circuit may be ascertained by substituting a decade resistance box and decade capacitance box, with short connecting leads, for the values of *CR* and then adjusting the ratio and values of the two circuit components until the square wave at the amplifier's output is identical with that of the input. The decade resistance and capacitance boxes may then be removed from the circuit and permanent fixed values substituted, as indicated experimentally. The effects of stray capacitance may slightly alter the values indicated if care is not exercised in reducing these effects to the minimum when the proper values are being determined.

3.8 High-Frequency Distortion in Deflection Amplifiers. The stray capacitance introduced by wiring, the relation of components to each other and with respect to ground, together with the interelectrode capacitances of the tube, may be represented as an equivalent shunt capacitance across the tube's output. This shunt capacitance decreases the plate-load impedance with an increase in pass frequency and results in attenuation of high pass frequencies. Since the plate load impedance must be maintained (and thus the stage gain) constant over the desired frequency range of the amplifier, some means of compensation must be employed.

In some instances, a slug-tuned inductance is added in series with the plate load network, so that its inductive reactance will effectively counteract the effect upon plate impedance by the variation of the capacitive reactance with frequency introduced by the presence of the shunt circuit and stray capacitances (see Fig. 3.9). The impedance of a network of this type can be made fairly constant from zero pass frequency to some higher frequency where the proportions of the network are such that the reactance of *C* is equal to the resistance of *R* and twice the reactance of *L*. The impedance of the network has been shown to be

$$Z = X_c \sqrt{\frac{R^2 + X_L^2}{R^2 + (X_c - X_L^2)}}$$

If the value of series *L* is increased above optimum, a rise in the upper high frequency region will occur, owing to resonance at a certain product of *LC*, where the inductance of *L* is that contained in the added slug-tuned coil and *C* is due to stray circuit capacitance. High-frequency distortion is the result, since all frequencies are not passed at equivalent amplitude. The distortion of the square wave arising from overpeaking is shown in Fig. 3.10. It is the result of oscillation at the beginning of each half cycle of the square wave. Thus, the inductance must not be adjusted to the point where overpeaking of the square wave obtains and should not exceed an optimum value which results in linear reproduction of the square wave. This optimum adjustment indicates the highest pass frequency at which the particular amplifier is capable of operating without distortion. Other forms of square-wave distortion are shown in the figure referred to above and may be used by the reader as a guide in identifying types of distortion encountered in equipment adjustment or operation.

3.9 The *Z*-Axis Amplifier of an Oscillograph. Thus far, in the consideration of amplifiers associated with the cathode-ray tube in typical oscillograph circuits, only the vertical-, or *Y*-axis amplifier and the horizontal-, or *X*-axis amplifiers have been discussed. There is a third, the *Z*-axis amplifier, included in the complete oscillograph circuit.

The *Z*-axis amplifier output is useful in providing intensity modulation of the electron beam. Its most important purpose is to provide a means whereby a timing signal may be impressed upon the pattern. The timing signal is developed externally and applied to the input of

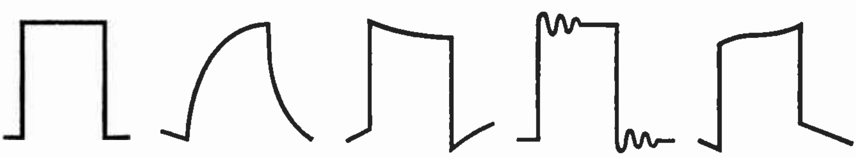


FIG. 3.10 Types of square-wave distortion introduced in poorly designed or adjusted oscillograph or video amplifiers.

the *Z*-axis amplifier in the form of sharp pulses of short duration and higher frequency than that of the signal, producing the pattern upon the tube's fluorescent screen. The higher frequency rate provides greater accuracy with which the time interval between certain related events may be determined. The linear time base, already described in the previous discussion (pages 135–140), is made essentially linear in the form usually found in commercial oscilloscopes or oscillographs, but it does not permit the precise timing that the modulation amplifier will provide.

The frequency response of the *Z*-axis amplifier must be more uniform than that of the *X*- and *Y*-axis amplifiers, and the upper frequency limit must be greater, because it must often pass a frequency considerably higher than that to which the *Y*-axis amplifier has been adjusted. A lower output voltage is required for complete modulation of the electron beam; thus, low-impedance output circuits are employed at the final amplifier tube for greater high-frequency response. Fewer tubes are needed in this amplifier, since the external signal applied to the input is usually taken from a signal generator with moderately high output. The over-all gain of the amplifier therefore is not very great, which leads to simplified design. Occasionally, a blanking pulse is applied to the amplifier input and serves to eliminate the fly-back of the saw-toothed generator. When the blanking pulse is used to provide intensity modulation of the electron beam, a means is sometimes provided for reversing the polarity of the modulating voltage, permitting a reduction or increase in beam intensity.

In intensity modulation a sweep voltage of short duration is employed. A positive square pulse of voltage is applied to the control grid in order to make the trace visible. The pulse increases to a potential sufficient to permit electrons to flow in the beam at the precise instant that the sweep starts; the voltage then falls back at the conclusion of the sweep. Thus, the intensity of the trace is increased during the sweep. It is often necessary to employ intensity modulation for a predetermined period of time. In such cases, a negative pulse of the desired time interval is applied to the cathode so as to decrease the bias to that value where the intensity-modulation signals on the screen are able to control the brightness of the trace.

Not all commercially available oscillographs incorporate a Z-axis amplifier, since the routine investigation of waveforms does not require the use of such a circuit. However, the better equipment, and particularly that used for precise laboratory investigation, has this special amplifier.

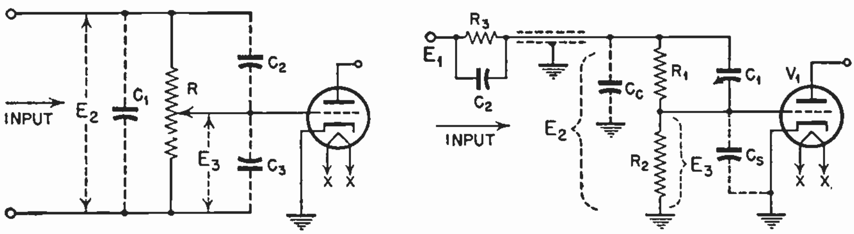
3.10 Attenuators Used in Amplifier Input Circuits. The deleterious effects of circuit and stray capacitances are usually of no concern in audio-amplifier design, but they are of considerable importance in the design of oscillograph amplifiers as well as of video amplifiers used in television applications. If the oscillograph amplifier has a wide useful-frequency range, the same care must be exercised in its construction as in that of a wide-range video amplifier.

Of much concern is the input circuit. The amplifier input must operate at high impedance, usually in the order of 2 to 5 megohms, so that no loading of the circuit under test or observation will obtain. Also, the input capacitance must be kept to the minimum; otherwise, high-frequency signals will be effectively shunted to earth before they reach the control grid of the input vacuum tube. This condition is readily understood when it is realized that as the capacitance increases, the reactance to earth is decreased. In judicious design, input capacitance is often held in the order of 20 to 60 $\mu\mu$f. in commercial apparatus.

Whereas deflection-amplifier design is usually considered excellent if the upper useful range approaches about 100 kc. per sec., this upper frequency limit must be extended to several megacycles in order that the oscillograph may be employed in directly investigating the characteristics of video amplifiers associated with high-definition television systems.

New oscillographs can now be obtained that have a flat frequency response to 5 mc. per sec. or more. In these new oscillographs not only has the frequency response been extended, but the response to transit or pulse signals has been made such that negligible distortion occurs.

It will be seen that careful design, input to output, is essential in the production of an oscillograph amplifier to meet such advanced operating requirements. At the input, careful attention must be given to attenuator design. The input signal must be attenuated to that value which the input tubes can satisfactorily accommodate without overload and consequent distortion. This requirement dictates the use of a high-impedance, low-capacitance voltage divider across the input terminals of the amplifier.



-A- UNCOMPENSATED

-B- COMPENSATED

Fig. 3.11

Unfortunately, a simple potentiometer, such as is used for gain control at audio frequencies, will not satisfy the design requirement. Such a potentiometer will produce a change in input impedance with a change in the position of the slider, and the impedance will be sufficiently altered so as to cause frequency and phase distortion in the input signal applied to the amplifier.

The distributed capacitances C_2 and C_3 (Fig. 3.11*A*) produce a voltage division at the higher pass frequencies. This division of voltage is essentially constant and is not dependent upon the position of the slider along the resistance winding of the potentiometer. Therefore, as the arm is moved up and down the resistance, the relative voltage division obtaining across the sections of potentiometer and capacitance C_2 and C_3 will change, resulting in severe frequency distortion. This condition can be eliminated through use of a compensated potentiometer.

The output voltage delivered to the input tube is a function of the position of the potentiometer arm at its lower extremity with respect to earth. The voltage is represented as E_3 in Fig. 3.11*B*, and the input voltage to the potentiometer is represented as E_2. Neglecting the input cable or leads, the ratio of potentiometer input to output voltage will be independent of pass frequency if the time constants of R_1C_1 and R_2C_s

are made equivalent. The additive value of circuit and stray capacitances C_s is fixed, and the design problem involves the determination of the proper values for R_1 and R_2 to produce the desired voltage ratio; then adjusting C_1 to that value where

$$T_c = R_1C_1 = R_2C_s \quad \text{or} \quad C_1 = \frac{R_2C_s}{R_1}$$

Therefore, in stepped attenuator design, the capacitance of C_1 must be adjusted for each step of the attenuator. Since the additive value of R_1R_2 must remain constant, these values must be varied with each step of attenuation.

The voltage division will be independent of frequency if we consider R_1 and R_2 as one component of resistance, and if the cable and associated capacitances are added to the effective capacitance of C_1 and C_s in series as one element of capacitance C_s and then by adding C_2 across the isolation resistor R_3, selecting its value so that the time constants of R_3C_2 and $(R_1 + R_2)C_e$ are equivalent. E_2 becomes

$$\left(\frac{R_1 + R_2}{R_1 + R_2 + R_3}\right) E_1$$

But, by selecting a reduction factor of 10 and increasing the gain of the amplifier by 10, the over-all gain remains the same. In addition, the coupling and attenuating system not only operates at an impedance high enough not to load the signal source seriously, but minimum distortion obtains. The input impedance will comprise a resistance equal to the sum of R_1, R_2, and R_3 with a parallel capacitance equal to C_2 and C_c series-connected. The effective input impedance may then be calculated for any pass frequency through use of the equation

$$Z_{\text{in}} = \frac{RX_c}{R^2 + X_c^2}$$

In order to limit the loading of the input signal, a low-capacitance cable connects to the source of signal. An isolating resistor placed in series is also a usual commercial practice in better instruments. Of course, all components used in the input circuit, particularly the coupling capacitance, must have sufficient voltage rating to withstand with a generous safety factor the maximum signal voltage usually incurred in routine testing and operation of the apparatus.

Recently it has been found that with the use of a cathode-follower input stage, a broader range of input signal obtains. The improved circuit is shown in Fig. 3.12. If R_1 and R_2 are both low in value, the circuit capacitances will be of no consequence, even when the upper limit of frequency lies in the range of several megacycles. Capacitance

C_1 is used as a blocking capacitance to remove the d-c potential from the potentiometer R_2. This circuit is used with the fixed stepped attenuator described above. It permits the design of input circuits which give

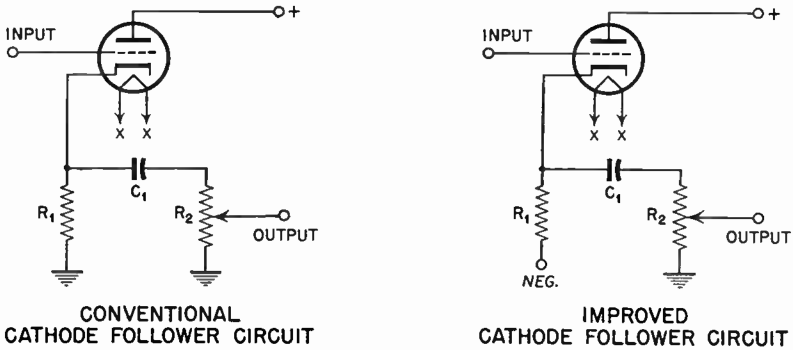


FIG. 3.12

the modern oscilloscope a frequency range so broad that television amplifiers and related apparatus may be investigated directly. Thus, the modern cathode-ray oscillograph is the most versatile and indispensable tool in the hands of the television engineer or technician.

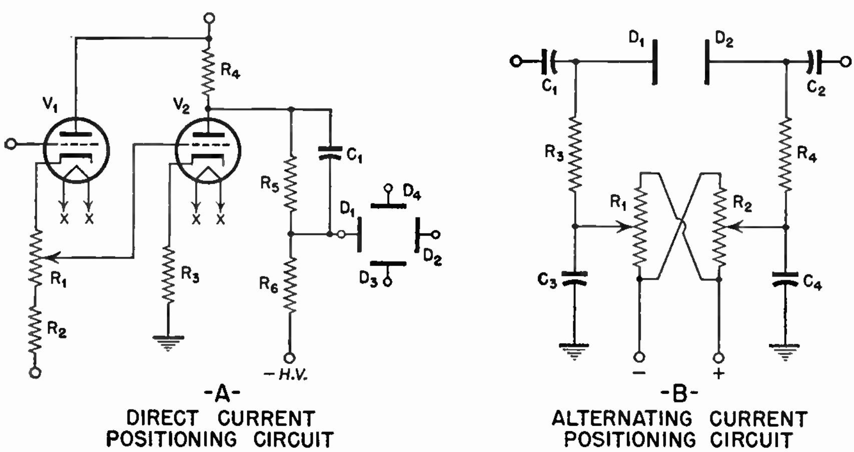


FIG. 3.13

3.11 Oscillograph Positioning Circuits. In making use of the cathode-ray oscilloscope or oscillograph it is desirable to move the image to that part of the fluorescent screen most convenient for viewing. When an electrostatic type of cathode-ray tube is employed in the equipment, positioning is obtained through application of a d-c potential to the deflecting plates of the tube. Such a circuit is illustrated in Fig. 3.13*A*.

The cathode of the vacuum tube V_1 operates at positive d-c potential with respect to earth, and R_2 is connected to a negative source of supply. Therefore, some point on R_1 can be adjusted to zero d-c potential, and a d-c voltage is made available for application to the control grid of vacuum tube V_2. The d-c plate current of this tube is thus made variable with resultant d-c positioning. The resistor R_4 constitutes the plate load for the deflection amplifier V_2, and R_5 and R_6 returned to a high negative d-c potential provide d-c voltage division to maintain plate D_1 at zero d-c potential with respect to earth. The capacitance C_1 reduces attenuation of the alternating signal component, since it offers a low-reactance signal path around R_5. Resistor R_5 is made a large value, so that the time constant of C_1R_5 will not provide or produce low-frequency attenuation. The use of d-c positioning eliminates the lag inherent in a-c positioning systems. This lag is caused by the time required for capacitance C_1 and C_2 (Fig. 3.13*B*) to establish a steady d-c potential after the positioning control potentiometers R_1 and R_2 are adjusted to some new value.

3.12 Power Supply for the Cathode-Ray Oscillograph. The current demand of the conventional cathode-ray oscillograph is very small, rarely exceeding 100 μa. of plate current for the tube itself, and thus greatly simplifying power-supply design. A half-wave rectifier is entirely satisfactory. It must, however, be well filtered so that the hum component in the d-c output does not result in modulation of the beam.

The required high voltages dictate that the power transformer be of good electrical design. An adequate safety factor must be allowed in the selection of all components. Because of the high voltages delivered by the supply, the d-c output should be interrupted automatically before the user has access to any part of the circuit or components. The interruption is usually accomplished by inserting a safety switch in series with the primary of the power transformer. Should the cover be removed from the equipment, the switch will open automatically and prevent the user from coming into direct contact with the dangerously high potentials present.

Figure 3.14 presents the circuit diagram of a typical power supply associated with an intensifier-type cathode-ray tube. It will be noted that three rectifiers are employed, two type 2Y2 tubes and one type 80 tube. One of the type 2Y2 tubes supplies 2,000 v. for the intensifier electrode, and the circuit is that of the conventional half-wave rectifier. A single capacitor of 0.1 μf. capacity shunts the output of the rectifier tube, providing adequate filtering of the rectified direct current. Although in this particular circuit 2,000 v. of d-c potential is supplied to the intensifier electrode, as many as 30,000 v. are applied to some projection-type cathode-ray tubes used for large-screen television. When such high potentials are involved, care must be exercised to provide adequate insulation at the transformer, as well as a generous safety factor in the selection of the circuit components. In the circuit illustrated, a 20-megohm bleeder is in shunt with the filter capacitor.

A second type 2Y2 tube supplies the d-c potential to the other high-voltage electrodes of the cathode-ray tube. It will be noted that the positive side of this second rectifier circuit is maintained at ground potential, so that a maximum of −2,000 v. d-c potential is available for the

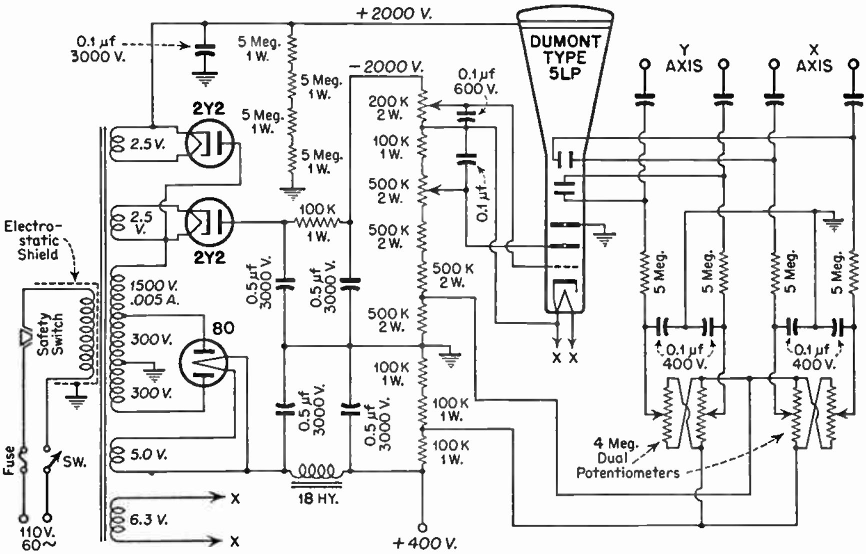


FIG. 3.14 Typical power supply for intensifier-type cathode-ray tube.

cathode-ray tube. Capacitor input is employed at the filter to increase the d-c potential at the filter output, and a second L-type filter section is usually employed to provide sufficient attenuation of the ripple component. A voltage divider across the output of the filter allows selection of the various d-c potentials required for the electrodes of the cathode-ray tube.

A third type 80 rectifier tube provides d-c potential for the positioning circuits, already described in the text, as well as a source of direct current for the deflection amplifiers and auxiliary circuits of the typical oscilloscope or oscillograph. This rectifier circuit employs capacitor input to increase the amplitude of the d-c potential available at the filter output. A low-pass L-type filter section is present to effectively attenuate the hum component. A suitable voltage divider across the output permits selection of the desired potentials required for proper operation. The type 80 tube is operated as a single-phase, full-wave rectifier, whereas the other two rectifiers are operated as single-phase, half-wave rectifiers.

In the usual circuits employed in oscillographs, the second anode is operated at ground potential, which permits the deflecting plates to be operated at approximately ground potential. Such a method of operation facilitates coupling the deflecting plates to the external deflection circuits and permits direct connection to the deflecting plates without danger of accidental shock to the user. When the accelerating electrode or second anode is so operated, it becomes necessary to insulate the transformer winding that provides heater voltage to the cathode-ray tube for the full accelerating voltage, since the heater and cathode are both operated at a negative potential with respect to ground equivalent to this potential. This condition must be taken into consideration when designing the power transformer. A safety factor of at least 100 per cent is generally allowed in commercial design and should be the criterion for excellent design.

It is customary to operate the intensifier electrode at a potential 30 to 100 per cent greater than that applied to the second anode or accelerating electrode, although the ratio is made much greater in the operation of projection-type cathode-ray tubes for large-screen television. It must be remembered that the more the intensifier-electrode potential is increased, the shorter is the life expectancy of the fluorescent screen, because the electron bombardment of the active materials of the screen is increased owing to increased electron velocity. Thus, it is evident that the intensifier voltage should not be increased above optimum for any desired application.

The negative grid voltage for the cathode-ray tube is provided by a rheostat or voltage-dividing potentiometer at the negative end of the divider across the rectifier filter output. Adequate range is provided to allow variation of grid bias from zero to a value equal to maximum cutoff potential for the tube at the normal accelerating potential for the particular cathode-ray tube. The voltage-dividing potentiometer employed for focusing control must be capable of making available to the focusing electrode a range of voltage corresponding to that range over which the voltage required for focus is permitted to vary for the particular type of cathode-ray tube under consideration. The normal operating potentials for the various electrodes are usually specified by the manufacturer in an information sheet supplied with the tube or are available upon request.

Any transformer used in an oscillograph power-supply circuit must be fully shielded electrostatically. The shielding obviates the possibility of electrostatic coupling to the heater winding, which can result in intensity modulation, and eliminates the possibility of undesirable electrostatic coupling between high- and low-voltage windings of the transformer. In addition to proper insulation, the transformer should be impregnated against moisture. The impregnation will prevent moisture from entering

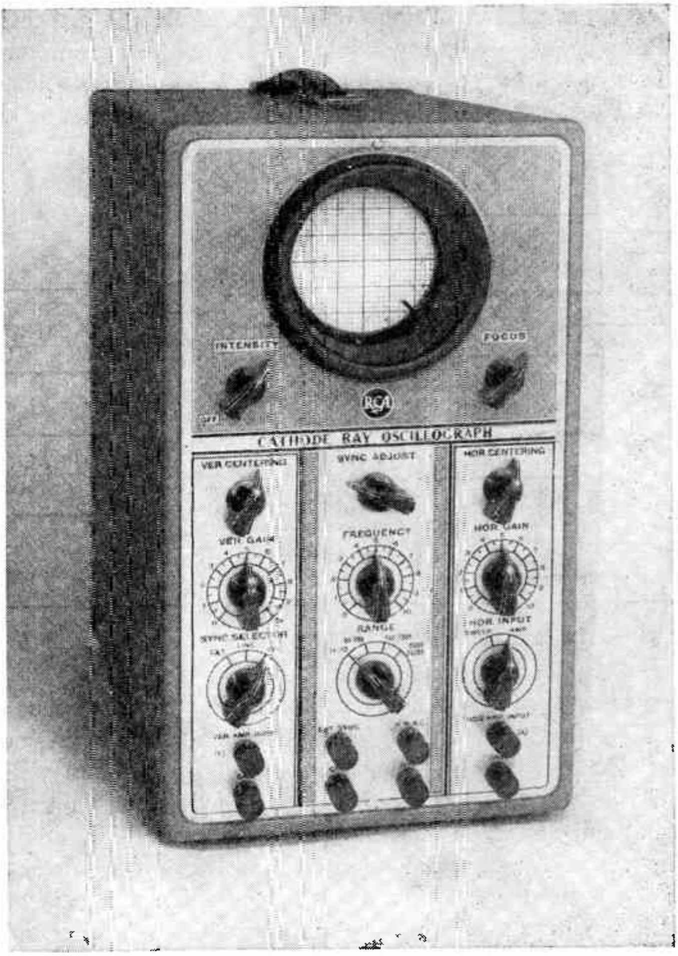


FIG. 3.15 R.C.A. type 155-C cathode-ray oscillograph. This is an example of the type of test instrument available to the television engineer and technician for simple routine equipment testing and maintenance. (Courtesy of Radio Corporation of America.)

the windings and causing breakdown to ground or between layers. In addition, the primary circuit of the power transformer must be properly fused, as is true of any power-supply circuit.

3.13 Photography of Cathode-Ray Tube Patterns. It is easy to make a photographic record of the phenomena appearing on the fluorescent screen of the cathode-ray tube. Before entering into a detailed discussion of how the photograph is conventionally obtained, it will be well to review briefly the types of fluorescent screens available in commercial-type tubes.

Standard tubes with four types of screens are on the market: P1, P2, P4, and P5. The P1 screen produces a green trace of medium persistence, and the P2 screen produces a green trace which demonstrates long persistence. The P4 screen, which is employed in the reproduction of television images, results in a white, or nearly white, trace. The P5 screen is a

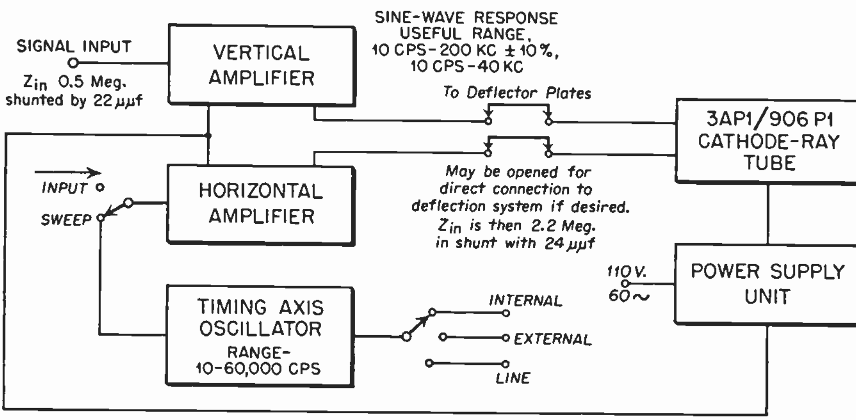


FIG. 3.16 Block diagram of R.C.A. type 155-C cathode-ray oscillograph.

short-persistence screen producing a blue trace. Since various types of films are necessary for the photographing of images appearing on screens of different types, it is well to consider carefully just what type of screen is available before choosing the film for the particular photograph.

The usual roll-film type of camera may be used. The addition of a portrait attachment will permit increasing the size of the desired photograph. It is well to calibrate the focusing scale on a camera of this type with the aid of a piece of ground glass before loading the camera with film. In this method of calibration, the distance separating the camera lens from the fluorescent screen of the cathode-ray tube, and the magnification, should be recorded for each position of focus shown on the scale of the camera.

The required exposure time will be a function of the camera lens speed expressed as an *f* value, the magnification of the pattern, the film used, and the type of luminescent screen available at the cathode-ray tube.

If a photograph of a stationary pattern on the screen is desired, the shutter of the camera can be left open as long as has been experimentally determined to obtain the required negative density. If it is desired to

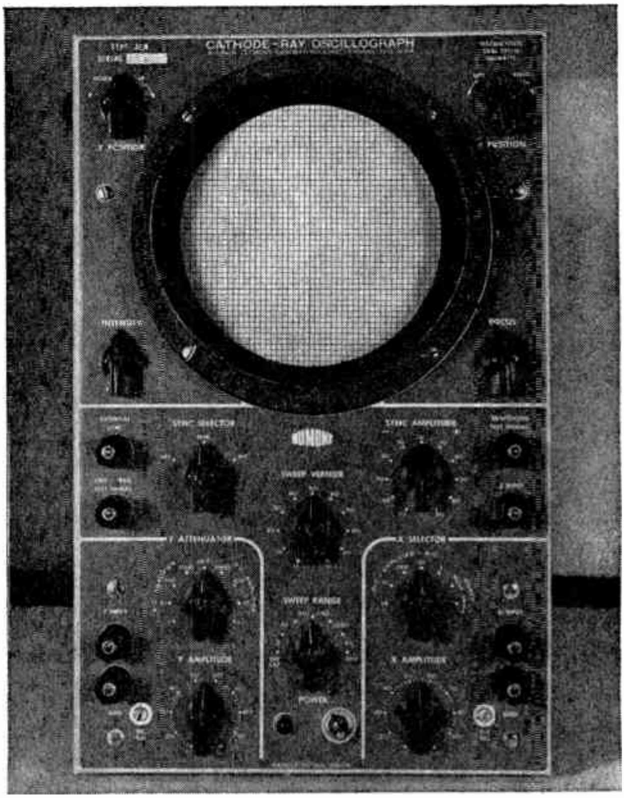
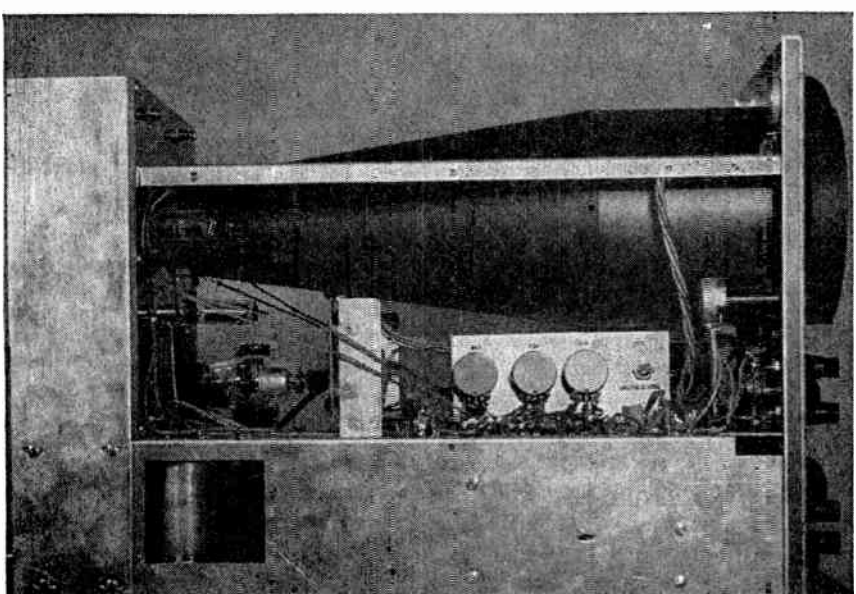


FIG. 3.17 A cathode-ray oscillograph, the most versatile instrument at the disposal of the television engineer. Illustrated is the Du Mont type 304 5-in. instrument; below is the same instrument with the case removed. (Courtesy of Allen B. Du Mont Labs., Inc.)



photograph a square wave, it will be necessary to overexpose brighter portions of the pattern in order that dim portions of the trace may be satisfactorily recorded. Overexposure is necessary because the writing rate of such a pulse changes over various parts of a complete cycle, which results in brightness variation.

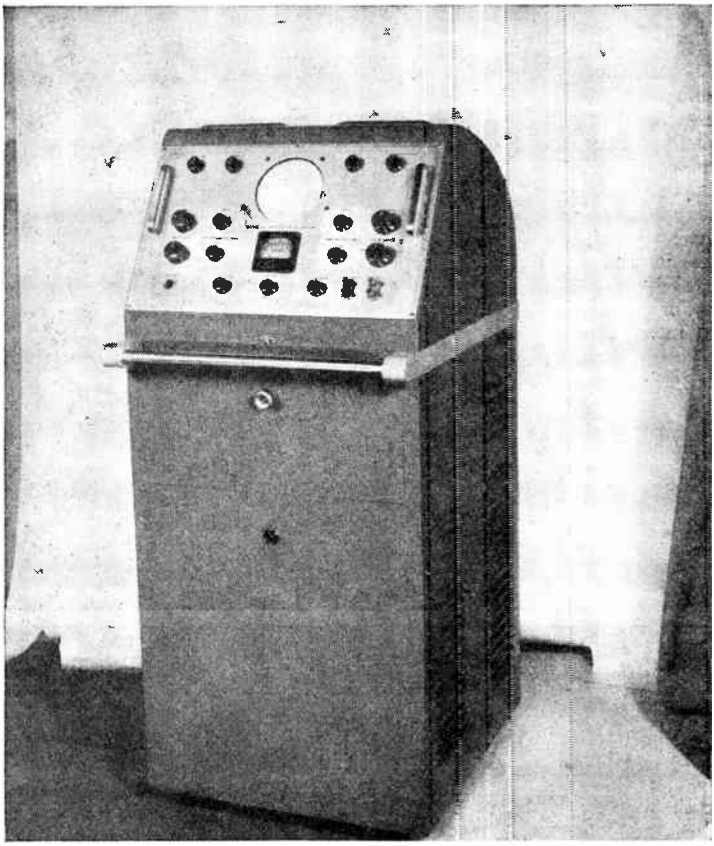


FIG. 3.18 R.C.A. type 715-B laboratory oscillograph, an instrument that may be used at the television control room, at the transmitter, or in the development or research laboratory for routine waveform investigation. It incorporates response which is flat to 11 mc. per sec., triggered sweep, time-base marker (at 1-μ sec. intervals), an input calibration meter, and other features making it especially useful to the television engineer and technician. (Courtesy of Radio Corporation of America.)

For the photographing of transient phenomena, where only a single trace of the pattern appears on the tube screen, the photographic effect becomes a function of the velocity of the spot as it traverses the screen. In the moving-film method of photographing the trace, the spot, appearing on the screen, is deflected by the signal along one axis. The time axis is provided by the movement of the film in a direction perpendicular to spot deflection. In the stationary-film method, a single but linear sweep of the fluorescent spot by one set of deflection plates provides the time base. The signal is applied to the other deflection plates. The camera shutter is opened before the transient occurs and is closed afterward. There is a limit to the writing speed that can be satisfactorily recorded by either method, but the moving-film method possesses the advantage of producing a time base of unrestricted length, although there is a restriction as to the allowable screen-persistence time.

Writing rates of 1,500 in. per sec. may be successfully photographed on a P1 screen by using an accelerating potential of 1,000 v., a magnification ratio of 0.5, a lens opening of f/4.5, and an emulsion having Weston speed rating of 24. An increase in the writing rate is obtained through use of a P5 screen and a faster film. Photographic recording of writing rates as high as 100,000 in. per sec. and greater have been made.

TABLE 3

DATA FOR PHOTOGRAPHING CATHODE-RAY TUBE SCREENS

	Screen		
	Type P1 (Medium-persistence, green radiation)	Type P2 (Long-persistence, blue-green radiation)	Type P5 (Short-persistence, blue radiation)
Roll film	1. Verichrome 2. Super-XX 3. Panatomic X	1. Verichrome 2. Regular N.C. 3. Panatomic X	1. Verichrome 2. Regular N.C. 3. Panatomic X
Plates	1. Eastman Super Panchro Press 2. Eastman Ortho Press 3. Eastman 50	1. Eastman Super Panchro Press 2. Eastman Ortho Press 3. Eastman 50	1. Eastman 40 2. Eastman Ortho Press 3. Eastman Universal
Film packs	1. Verichrome 2. Super-XX 3. Panatomic X	1. Verichrome 2. Panatomic X	1. Verichrome 2. Panatomic X
35-mm. roll film	1. Super-XX Panchromatic 2. Plus-X 3. Panatomic X	1. Super-XX Panchromatic 2. Plus-X 3. Safety Positive Film	1. Ortho Negative 2. Super-XX Panchromatic 3. Safety Positive Film

The making of any photographic record of the pattern should only be attempted in subdued light. Greater contrast then results between pattern and background. The camera must be rigidly supported and, of course, sharply focused on the pattern. Table 3, prepared by Allen B.

Du Mont Laboratories, will serve as a guide in photographing the cathode-ray tube pattern.

For the photography of the so-called "black-and-white screens" (P4), it is recommended that the following materials be used: Tri-X-Pan, Super-XX, Super Panchro Press, Super Ortho Press, and Ortho-X.

BIBLIOGRAPHY

1. Tressler, M. E., "The Cathode-Ray Tube and Its Application," *General Electric Review*, Vol. 18 (1915), p. 816.
2. Johnson, J. B., "A Low Voltage Cathode-Ray Oscillograph," *J. Optical Soc. Am.*, Vol. 6 (1922), p. 701; and *Physical Review*, Vol. 17 (1921), p. 420.
3. Wold, P. I., and E. B. Stephenson, "Velocity of Sounds by a Phase Indicating Device," *Physical Review*, Vol. 21 (1923), p. 706.
4. MacGregor Morris, J. T., and R. Mines, "Measurements in Electrical Engineering by Means of Cathode-Ray Tubes," *J. Inst. Elec. Engrs.* (*London*), Vol. 63 (1925), p. 1056.
5. Dye, D. W., "Improved Cathode-Ray Tube Method for the Harmonic Comparison of Frequency," *Proc. Phys. Soc.* (*London*), Vol. 37 (1925), p. 158.
6. Wood, A. B., "The Cathode-Ray Oscillograph," *J. Am. Inst. Elec. Engrs.*, Vol. 63 (1925), p. 1046.
7. Rasmussen, F. J., "Frequency Measurements with the Cathode-Ray Oscillograph," *J. Am. Inst. Elec. Engrs.*, January, 1927; and *Trans. Am. Inst. Elec. Engrs.*, Vol. 45 (1926), p. 1256.
8. Van Dyke, K. S., "The Use of the Cathode-Ray Oscillograph in the Study of Resonance Phenomena in Piezo Electric Crystals," *Physical Review*, Vol. 31 (1928), p. 303; and *Proc. I.R.E.*, Vol. 16 (1928), p. 763.
9. Hull, A. W., "Hot Cathode Thyratrons: Part I, Characteristics," *General Electric Review* (1929), p. 213.
10. George, R. H., "A New Type of Hot Cathode Oscillograph—Its Application to the Automatic Recording of Lightning and Switch Surges," *J. Am. Inst. Elec. Engrs.*, Vol. 48 (July, 1929), p. 534.
11. Ardenne, M. von, "A Braun Tube for Direct Photographic Recording," *Experimental Wireless* (*London*), Vol. 7 (1930), p. 66.
12. Osbon, W. O., "A New Cathode-Ray Oscillograph," *Elec. J.*, Vol. 28 (1931), p. 322.
13. Johnson, J. B., "The Low Voltage Cathode-Ray Tube," *Bell System Tech. J.*, Vol. XI (1932), p. 1.
14. Wood, A. B., "Recent Developments in Cathode-Ray Oscillographs," *J. Inst. Elec. Engrs.* (*London*), Vol. 71 (1932), p. 41.
15. Watt, R. A. Watson, *The Cathode-Ray Tube in Radio Research*, His Majesty's Stationery Office, London, March, 1933.
16. Haller, C. E., "A Linear Timing Axis for Cathode Oscilloscopes," *Rev. Sci. Instruments*, July, 1933.
17. Taylor, H., and Orth, "Cathode-Ray Tubes for Oscillographic Purposes," *Electronics*, Vol. 6, No. 12 (December, 1933).

18. WALLER, L. C., "A Practical Cathode-Ray Oscillograph for the Amateur Station," *QST*, Vol. XVIII, No. 3 (March, 1934).
19. KUEHNI, H. P., "A Low Voltage Cathode-Ray Oscillograph with Fluorescent Viewing Screen," *Gen. Elec. Rev.*, Vol. 37 (September, 1934), p. 429.
20. STINCHFIELD, J. M., "Cathode-Ray Tubes and Their Applications," *Elec. Eng.*, Vol. 53, No. 12 (December, 1934), p. 1608.
21. ARDENNE, M. VON, "Distortion of Saw-Tooth Wave Forms," *Electronics*, November, 1937.
22. HAWKINS, G. F., "Linear Saw-Tooth Oscillator," *Wireless World*, May, 1939.
23. REICH, H. J., "Trigger Circuits," *Electronics*, August, 1939.
24. ZWORYKIN, V. K., and G. A. MORTON, *Television*, John Wiley & Sons, Inc., New York, 1940.
25. PUCKLE, O. S., *Time Bases*, Chapman and Hall, Ltd., London, 1944.
26. CHRISTALDI, P. S., "Cathode-Ray Tubes and Their Applications," *Proc. I.R.E.*, Vol. 33, No. 6 (June, 1945), pp. 373–381.
27. "Television Receivers in Mass Production," *Electronics*, June, 1947.
28. FELDT, R., "An All-Purpose Screen for High Voltage Cathode-Ray Tubes," *The Oscillographer*, Allen B. Du Mont Laboratories, Inc., July–August, 1947.
29. ABBENHOUSE, R. P., "General Purpose Precision Oscilloscope," *Electronics*, August, 1949.

REVIEW QUESTIONS

3–1. (a) Why is the cathode-ray oscillograph a useful instrument in television? (b) Name some of its important uses.

3–2. Describe the purpose of the horizontal- and vertical-deflection amplifiers of a cathode-ray oscillograph.

3–3. What is meant by the "zero-axis amplifier" of an oscillograph?

3–4. Describe the function of synchronization as applied to the cathode-ray oscillograph.

3–5. By means of a simple block schematic, show the principal circuits of a cathode-ray oscillograph.

3–6. (a) How may the display of an oscillograph be photographed? (b) What are some of the precautions to observe?

3–7. Explain why a specially designed attenuator is necessary at the input to the vertical amplifier of the oscillograph.

3–8. (a) What is meant by the X and Y attenuators of the instrument? (b) Describe their use.

3–9. How may the cathode-ray oscillograph be used as a precision electronic voltmeter?

3–10. Discuss the deflection circuits of an oscillograph.

CHAPTER 4

ELECTRON TUBES FOR IMAGE PICKUP

4.1 General. The image pickup tube employed in the conventional television camera is essentially an optical-video transducer; i.e., the light reflected from the subject being televised is optically focused upon a suitable target within the tube. The light producing the image is then converted into variations of electrical current so that the resulting video signal may be amplified and finally used to modulate suitably a radio-frequency carrier. Thus, the image pickup tube is the first link in the chain of equipment required to transmit a high-definition television picture successfully.

Of the pickup tubes developed for use in present all-electronic television systems, four have attained widespread recognition in practice. These are the Iconoscope, the Orthicon, the Image Dissector tube, and the Image Orthicon. All were developed by R.C.A. engineers and physicists, except the Image Dissector, which was developed by Philo T. Farnsworth. The Iconoscope in the past enjoyed by far the greatest general acceptance, but it has recently been almost entirely supplanted by the Image Orthicon, principally because of the infinitely greater sensitivity of the latter. The Iconoscope is still the tube almost universally used in the televising of motion-picture film, but the Image Dissector has found some application in this respect too.

The *Iconoscope* was the first choice of engineers for studio pickup work for many years because of its inherently greater resolution capability and desirable gamma characteristic. Gamma has been defined as the slope of the characteristic expressing the output amplitude as a function of the input amplitude, both being indicated on a logarithmic scale. The portion of the light spectrum over which the tube demonstrates useful sensitivity, and the gamma property of the tube, make its use practical for pickup from scenes with ample lighting. There is no particular problem due to high light saturation.

The Iconoscope has found widespread application indoors for direct pickup of live talent in the studio. The tube produces what might be termed a "clean" picture, and its resolution is such that it can reproduce any picture detail capable of transmission over the accepted and standard television channel. Its storage property has resulted in general use of the tube in televising motion-picture film, although special projection is necessary. However, the Image Orthicon has now been almost universally accepted as a more desirable tube for both indoor and outdoor applications, for reasons which will be shown later.

The Iconoscope is not without its faults. The most undesirable characteristics of the tube result in spurious shading signals and undesirable flare, both of which must be electrically compensated for if an acceptable image is to be transmitted. The spurious shading signal makes it necessary for the station to employ special equipment and highly trained personnel to effect the compensation, namely, a shading generator and a skilled shading operator. This additional equipment and personnel, unfortunately, complicate the transmitting setup and are the principal disadvantage of the Iconoscope. Edge flare at the mosaic or target can be combated through special rim-lighting systems, and the problem is not without practical solution (see pages 188–190).

Also, the mosaic of the Iconoscope constitutes a relatively large physical area, since the magnitude of the picture signal is a function of the picture area. Its area is much larger than that of the Orthicon, the Image Orthicon, and the Image Dissector tube and therefore requires large and expensive optical lens systems. Too, the fact that the electron gun of the typical Iconoscope is at an angle of about 30 deg. with reference to the horizontal plane of the mosaic results in a keystone-shaped image at the tube's output. Special "keystoning" circuits are needed to correct or compensate for this condition, so that the transmitted image will be perfectly rectangular in shape in order to satisfy the standard aspect ratio requirement.

The *Orthicon* tube, now replaced by the Image Orthicon tube, has a sensitivity of four to five times greater than that credited to the current Iconoscope. For this reason it was, for a time, employed in outdoor pickups, where unfavorable lighting conditions are sometimes encountered. However, the picture produced with the early Orthicon lacks the "snap" and brilliance of one obtained with the Iconoscope or the later Image Orthicon. This deficiency in the Orthicon tube has been attributed to its strictly linear gamma characteristic. Owing to the linear gamma characteristic, an increase in picture-detail brightness by a factor of 2 is said to result in an increase in video signal by the same factor. This gamma characteristic, which has the effect of compressing the whites in a picture, is a very undesirable attribute. It can be changed through suitable gamma correction in the video amplifier following the Orthicon, though the "snow," or noise, level is said to increase in proportion. Occasionally, sharp increases in light in a scene will result in instantaneous saturation of the whites in the picture because of the Orthicon's extreme sensitivity.

The Orthicon has a mosaic of small area, and lenses of shorter focal length for a given field may be satisfactorily employed. Lenses of longer focal length and of large effective aperture may be practically employed for difficult telephoto work. A major drawback to continued use of the Orthicon has been the limited portion of the light spectrum through which it demonstrates useful sensitivity. Practical limitations in Orthicon gun design have resulted in S distortion and in ion spot formation, neither of which is found in Iconoscopes. No shading is required with the Orthicon.

The Farnsworth *Image Dissector* has not found very wide acceptance as a live pickup tube owing to its inherently low sensitivity. It has, however, a decided advantage in motion-picture film scanning. No shading is necessary in practical operation of the tube. The tube has no storage characteristic whatsoever and may, therefore, be used with a standard continuous film projector to produce excellent pictures entirely free of shading. The Image Dissector tube should be more widely used in motion-picture film scanning and could eventually become the principal tube for this application. It has also been used by Columbia Broadcasting System in the scanning of film in color-television transmission.

In recent years, many improvements have been made in all four of the recognized electron tubes for image pickup. These improvements have included increased sensitivity, improved light range, better resolution, and the minimizing of distortion and noise. The Image Orthicon has made by far the greatest advance.

The *Image Orthicon* is an electron tube for image pickup making use of the principle of low-velocity electron-beam scanning, thereby eliminating almost completely the shading problem which is brought about by a high-velocity beam in some other types. It incorporates electron image multiplication and signal multiplication. It is said to approach closely the theoretical limit of pickup tube sensitivity and is about 100 to 1,000 times as sensitive as the type 1850 Iconoscope or the type 1840 Orthicon. The Image Orthicon is capable of transmitting pictures with a limiting resolution of over 500 lines and is relatively free from spurious signals.

The tube is stable at all light levels. At low lights, the signal output increases linearly with light input, whereas at high lights its signal output is relatively independent of light input. The signal output is so high, compared with other types, that the tube's operation is independent of the preamplifier characteristics that are usually considered significant. Its relatively small physical size reduces the dimensions of the television camera, making it especially suitable for portable equipment designed for use out of doors. Small, relatively inexpensive 35-mm. motion-picture camera lenses may be used at the camera, and an improved type of the tube has recently been announced which possesses spectral sensitivity approaching that of the human eye.

Several types are now commercially available to meet practically every operating requirement. One type of the Image Orthicon has been especially designed for direct studio pickup where lighting is not particularly a problem insofar as available candlepower is concerned. Another type has extreme sensitivity for use in outdoor or remote pickups where only daylight is present.

4.2 Storage and Nonstorage Types of Pickup Tubes. Any electron tube used for image pickup in present high-definition television systems functions to transfer the light image reflected from the scene being televised into variations of electrical current in order that the image may be admitted to the control grid of a video amplifier tube. There are two general types of these devices: the storage-type image pickup tube and the nonstorage tube. Both rely upon certain elements emitting electrons when exposed to a proper source of light. Both also utilize a beam of electrons for scanning purposes, although in one case the electrons making up the beam attain high velocity, whereas in another case a low-velocity beam accomplishes scanning of the target.

In one *storage-type electron pickup tube* the photoelectric current resulting from one element of the image effectively charges a capacitance for a period of time equal to the actual scanning time of the complete picture. The capacitance is discharged once during the time required to scan the complete picture, and the capacitance discharge takes place during the time elapsed in scanning one picture element. It is seen that the photoemission takes place throughout the entire period during which the picture is imaged on the target or mosaic, the photoemission accumulating in the nature of a charge at each image point. This accumulated photoelectric charge is released at each picture interval and from each of the elements in proper sequence as scanning takes place.

In the *nonstorage type* of pickup tube no storage of the charge takes place, the photoelectric current flowing only during actual scanning time. Thus, in the storage-type pickup tube, the electric charge due to the photoelectric current is stored by capacitive effect and is subsequently discharged, whereas in the nonstorage type of tube no capacitance is charged and current flows simultaneously with scanning.

Sometimes the storage principle is carried too far in certain tubes and results in a "blur" following or trailing fast action before the camera. The cause of this effect is that the capacitance in which the charge arising from the photoelectric action is stored does not discharge rapidly enough to keep pace with the fast action. Thus, there is an optimum time through which charge and discharge should obtain, and this optimum must not be exceeded in practical pickup-tube design.

The Iconoscope, developed by V. K. Zworykin of R.C.A., is an excellent example of the image pickup tube employing the storage principle, as is the more recent Image Orthicon.

4.3 The Iconoscope. The word Iconoscope, used to describe the pickup tube developed by Zworykin, is derived from two Greek words: *eikon*, meaning "image," and *skopein*, meaning "to watch" or "observe." Thus, the Iconoscope observes the image that is to be transmitted.

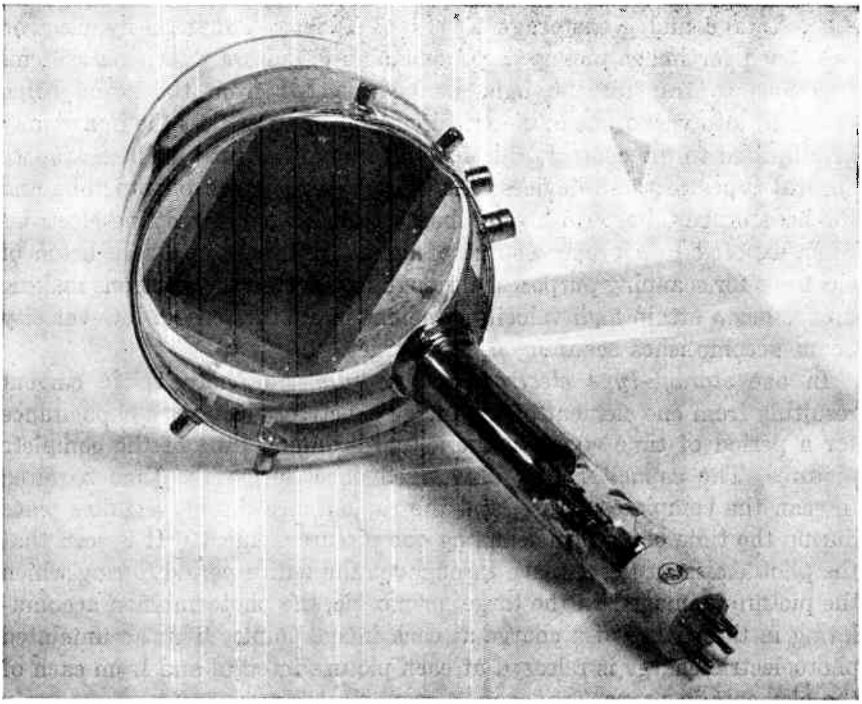


FIG. 4.1 R.C.A. type 1850-A Iconoscope. Location of the sensitive mosaic within the large glass bulb of the device is clearly shown. (Courtesy of Radio Corporation of America, Tube Division.)

This pickup tube, illustrated in Fig. 4.1, comprises a suitable glass envelope of practical and convenient design in which is mounted a mosaic as one component of the device. This mosaic, or target, consists of a thin rectangular sheet of mica having an area of about 100 sq. cm., or 3½ in. × 4¾ in. The mica sheet is suitably coated with a conducting metal film or Aquadag on the surface away from the source of reflected light. The other surface, toward the optical lens system, is coated with myriad small photosensitized silver elements. Each of the elements making up the photosensitive surface is insulated from the other elements. An optical focusing or lens system mounted in front of the tube's envelope in the camera, with its plane parallel with the plane of the sensitized surface, results in reflected light from the scene being imaged upon the mosaic. This incident light leaves a pattern of charges similar in intensity to the light and shade in the scene being televised.

The Iconoscope actually comprises within a single pickup device the elements of a multiple-unit photoelectric cell and a special type of cathode-ray tube. A gun similar to that used in cathode-ray tubes already described is located in such a manner that a beam of high-velocity electrons under magnetic deflection strikes the sensitized side of the mosaic at an angle of 30 deg. from the normal. Since the reflected image is normal to the same surface, the location of the gun does not interfere with transmission of the reflected light image.

The pattern of charges on the photosensitized mosaic, corresponding to light and shade in the scene being televised, is scanned by the high-velocity beam originating at the gun. Each beam electron bombarding the mosaic surface releases several secondary electrons. Theoretically, it may be said that the electron current leaving the mosaic is approximately equal to the electron current arriving, since the mosaic comprises an insulated surface. Therefore, with the tube operated in total darkness, so that it is shielded from any extraneous light, the number of secondary electrons that escape is equal to the beam electrons that arrive from the electron gun. Several secondary electrons, however, are released for each beam electron arriving from the gun. Hence, the remainder of the secondary electrons, once released, fall back on the mosaic. The strictly nonuniform manner in which these secondary electrons escape and rain results in a "dark spot" signal which must be "shaded" out in practical operation of this image pickup tube.

To aid in visualizing just what takes place on the mosaic, we may conveniently consider it as a flat surface coated with tiny photoelectric cells, each suitably insulated from the others and each in parallel with a capacitor that electrically couples it to the common signal lead terminating at the control grid of the first tube in the camera preamplifier. When reflected light from the scene being televised is imaged upon this mosaic, these capacitors assume a positive charge owing to loss of photoelectrons from the individual cells. The capacitors are charged by the reflected light until the high-velocity electron beam, under magnetic deflection and accomplishing the desired scanning, returns to an element of the mosaic surface. When bombarded by the beam, the capacitor discharges and the resulting current flows into the output. Thus, a train of impulses of varying amplitude corresponding to light and shade in the reflected image flows to the control grid of the first tube of the camera preamplifier.

Some of the secondary electrons escape from the mosaic surface at very high velocities. They comprise a cloud of secondary electrons, so that the electric field serves to deter the escape of photoelectrons, which have much lower average velocities than those attained by the secondary electrons. The escaping photoelectrons contribute a positive charge to the photosensitive surface of the mosaic when light impinges upon it. Partial dissipation of these charges is brought about by the rain of the secondary electrons. However, enough of them are stored during the time of one frame to result in a strong signal being transmitted to the preamplifier when the stored charge is released by the electron beam that accomplishes the scanning.

The mosaic surface has a capacity of approximately 100 $\mu\mu$f. per sq. cm. The average potential of the mosaic in total darkness is said to be 0 to -1 v. with respect to the second anode of the tube. The area of the mosaic under the electron beam is said to assume a potential of about 3 v. The section of the mosaic over which the beam has already passed, or traversed, will assume a potential which slowly decreases in magnitude as the distance between a point in this area and the position of the beam increases.

The efficiency of the Iconoscope is very low, averaging about 5 to 25 per cent, as a result of the photoemission from the mosaic being unsaturated. The storage principle of the tube, however, results in sufficient output to yield a brilliant image after amplification and reproduction. The sensitivity of an Iconoscope that was developed several years ago was such that a scene illuminated with 50 to 100 ft.-c. of light and imaged upon the mosaic through an f/2.7 lens produced a useful picture with less than 10 ft.-c. illumination at the mosaic, and with a signal-to-noise ratio greater than 30. Modern Iconoscopes possess even greater sensitivity.

4.4 Construction of the Iconoscope. If the photograph of the R.C.A. Iconoscope (Fig. 4.1) is examined, it will be seen that an evacuated glass envelope of suitable and convenient size encloses the device. The glass blank is dipper-shaped. A long tubular arm encloses the electron gun and conducts leads from the gun terminating in the "gun press" at the extreme end of this arm, where these leads are suitably based. This electron gun is fixed at an angle of approximately 30 deg. to the normal through the center of the mosaic, which is located within the large bulb of the blank. This type of construction prevents interference with the necessary optical system, through which the reflected light is admitted.

At one end of the large glass bulb of the device is an optical window through which reflected light from the subject may be imaged upon the photosensitized surface of the mosaic fixed within. This optical window is actually a curved shell which caps the blank at the end above the extended gun section. This window is made optically clear and free of any imperfections that would interfere with efficient transmission of reflected light from the scene or subject being televised. The optical lens and focusing system of the television camera is located just outside this window, and the axis of the necessary lens system coincides with the central normal from the mosaic surface. The image is therefore focused through this window upon the useful photosensitized surface of the mosaic.

Several leads are sealed in the walls of the glass envelope and are suitably capped for convenient connection to the external circuit. One is the signal lead which electrically connects the signal plate of the mosaic to the external circuit. The other leads terminate the common collector ring. Several external connections are provided, all of which contact this collector ring, which provides a convenient connection to the most direct and at the same time the most convenient ground. The leads from the external signal cap and the external collector-ring cap to the external circuit must be short and as direct as possible, and must have the least possible distributed capacitance. Otherwise, particularly in regard to the video signal, the reactance will prove sufficiently low at the higher video frequencies to shunt effectively the high-frequency signal current to ground.

The mosaic is rigidly fastened within the blank so that it can withstand the usual mechanical vibration incurred under operating conditions. Its edges are enclosed with a dull-finished metal rim to protect it against mechanical shock and to prevent warping under the temperature rise involved in the tube's normal operation. The dull finish also reduces the possibility of spurious light reflections. This rim must be appropriately lighted to prevent edge flare when the tube is in operation. This so-called "edge flare" takes the form of quite brilliant illumination at the outer edges or rim of the reproduced television picture. It occurs when the electron beam of the gun traverses the metal rim of the mosaic during the active scanning process. The large area of the mosaic, as well as its thin construction, imposes a very difficult manufacturing problem which must be solved by the fabricator.

The electron gun of the Iconoscope is illustrated in Fig. 4.2. It functions as an electron optical system for the generation of a small-diameter beam of electrons, which is made to scan, through magnetic deflection, the sensitized mosaic. The resolution capability of the pickup tube is in general a function of the diameter of the scanning spot produced by the electron beam at the point of incidence with the mosaic. The gun consists of a thermionic cathode, a suitable control grid, and a first and a second anode. A cylinder of nickel, its end coated with strontium and barium oxides, serves as a cathode. This cylinder encloses a tungsten heater element and the cathode assembly. The construction is quite similar to that found in ordinary cathode-ray tube gun design. The control grid is a nickel cylinder with an aperture at its far end.

Mounted coaxially and beyond the control grid in the direction of the mosaic is the cylindrical first anode. This anode has two cylindrical disks toward its far end, and each enclosed disk has a circular aperture at its geometrical center for masking the beam. The inner surface of the upper end of the neck and a part of the bulb, including a narrow ring about the inner circumference of the tube near the neck, are metalized. This coating serves as a second anode, as well as a collector for the secondary electrons originating at the mosaic. In its entirety, the gun

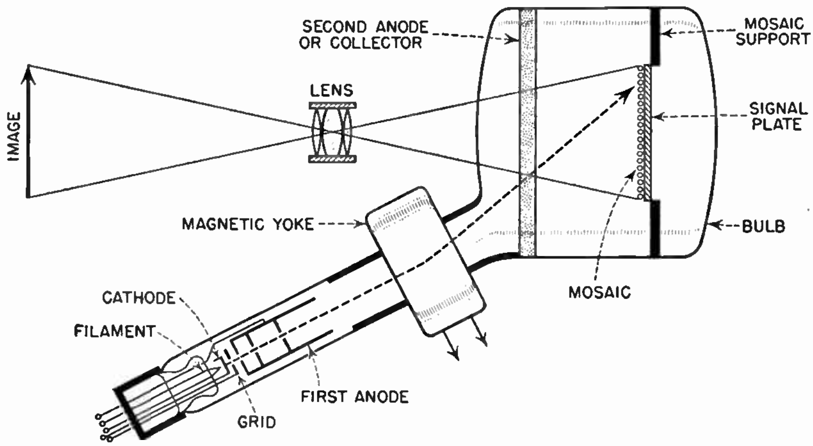


FIG. 4.2 Schematic diagram of R.C.A. Iconoscope.

comprises a two-lens electron optical system. The first lens is situated near the emitting cathode, and the other lens is located between the first and second anodes. The primary lens consists of the cathode, the control grid, and the first anode. The control grid serves to regulate the beam current. The second lens is formed between the first and second anodes. This lens operates to image the crossover obtaining near the cathode onto the sensitized mosaic within the bulb of the tube. It will be noted that three apertures are located within the first anode cylinder. These form the aperture stop and mask off secondary electrons emitted by the first anode.

4.5 The Mosaic of the Iconoscope. The mosaic is the most important single element within the structure of this pickup tube. The base for the construction of this target is a thin sheet of selected mica, approximately 1 to 3 mils in thickness. Its dimensions are 3.5 in. vertically by 4.75 in. horizontally. This dielectric is coated with a highly photosensitive surface having low transverse conductance on the one side and a conductive metalized film on the other. Mica is selected because of the absence of foreign particles, fractures, and irregularities. It must be perfectly clean.

Silver oxide is usually imparted to the surface that is to be photosensitized. This oxide is reduced to a very fine powder by grinding in a ball mill and is then applied to the previously prepared sheet of clean,

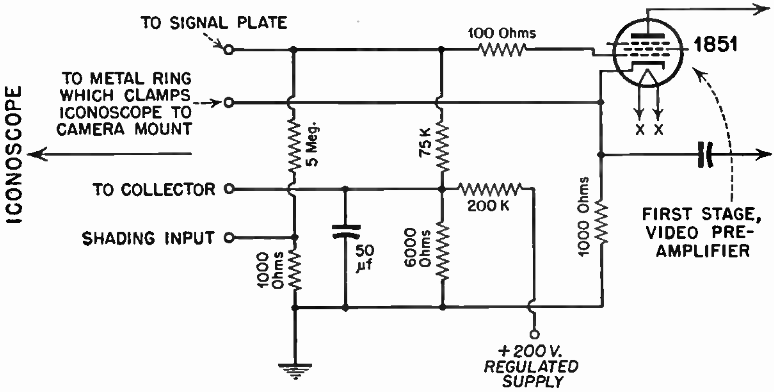


FIG. 4.3 Coupling circuit at input to video preamplifier at camera. Shading is introduced into system at low level.

pure mica by being allowed to settle through air. After settling, the temperature of the mica is raised rapidly until it is greater than the reduction point of the prepared silver oxide. The increase in temperature

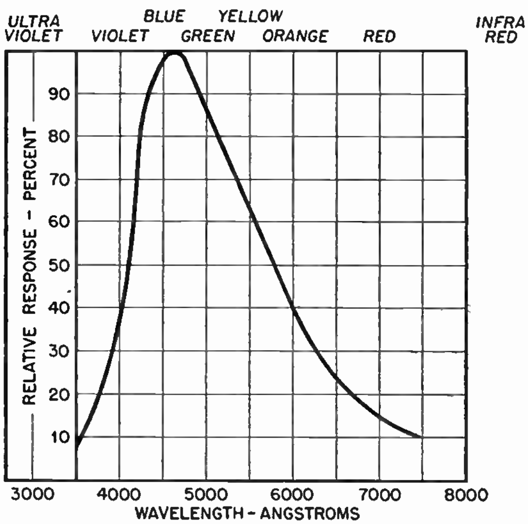


FIG. 4.4 Spectral sensitivity characteristic of the R.C.A. type 1850–A Iconoscope and the type 1840 Orthicon.

reduces the silver oxide to silver. In this process, the silver oxide reduces to silver without the individual globules forming into a connecting conductive film. Thus, the individual silver elements do not make electrical contact with one another and are suitably insulated for all practical purposes. The reverse side of the mica sheet is next metalized by either sputtering or evaporation to provide the signal plate of the tube.

A heavy sheet of mica is used to back up the photosensitized and metalized mica plate. This second sheet of mica prevents warping of the mosaic and facilitates clamping the target within the bulb. It also provides a mount for the signal-plate lead for external connection to the video preamplifier. If the construction of the Iconoscope is carefully examined, it will be seen that the mosaic is firmly and securely mounted by means of suitable supports on the large glass bulb or envelope.

In a recent commercial production of the mosaic, a somewhat different method was used to form the target. The selected sheet of pure mica was sensitized by oxidizing, admitting caesium, and then baking at high temperature. When the baking is completed, a thin coating of silver is vaporized in vacua from especially prepared filaments and imparted to the surface of the mica sheet in fine droplets. The target then passes through another baking process. The mosaic so produced comprises a target covered with extremely small droplets of silver, each properly photosensitized with caesium oxide. All the droplets are insulated from one another. Before the mosaic is formed, a film of cryolite is evaporated on the mica sheet, which permits the admittance of a sufficient quantity of caesium to result in good photosensitivity without the possibility of reducing the insulation resistance between adjacent droplets of silver.

If the Iconoscope is carefully handled under operating conditions and not subjected to unnecessary stress and strain, the mosaic will be so rugged that it will not warp or change shape. This condition will persist even under the increased temperature normally encountered in operation where inefficient ceiling lighting produces considerable temperature rise at the camera housing. It should be noted here that the photosensitized surface must never be subjected to direct rays of light. Correct methods of handling to ensure proper protection of the sensitized surface are treated in detail on pages 194–196.

In practical operation of the Iconoscope in a television camera several irregularities may at times be noted by the engineer. One of these is described as *rivet trailing.* A dark streak will be seen traversing the final image in a horizontal direction across the screen. If the amplitude of the horizontal sweep is changed, it will be found that the beam is actually scanning one of the rivets fixed in the rim along the edge of the mosaic. The condition can be quickly corrected by so adjusting the sweep amplitude control that the trailing is eliminated. In other words, the picture is "stretched horizontally" until the beam no longer traverses the rivet.

Sometimes an Iconoscope is found to have a *mosaic that is not completely sensitized* over the entire area of the mosaic. This fault usually occurs at the lower or upper edge adjacent to the rim and results in less brilliance in the final image at that portion of the mosaic surface. The usual practice is to stretch the vertical sweep so that the surface not properly sensitized is no longer scanned. Usually not more than three or four lines are lost with such correction, and the change in vertical size is not detected at the television receiver. Of course, if the vertical size must be increased too greatly in order to cover up the defect, then the aspect ratio of the image is impaired. The tube must then be rejected as unsatisfactory. The effect along the upper or lower edge of the mosaic that results from such a defect at the mosaic must not be confused with a similar condition that obtains as the result of improperly adjusted or focused rim lighting. The effects are similar. To determine which defect is responsible, the intensity of the rim lighting may be changed if a rheostat is in series with the rim-lighting circuit. The nature of the effect is then readily determined. If the rim lighting is improperly adjusted or focused, this too results in a change in picture brilliance along the edge of the mosaic.

Bright spots sometimes appear on the television screen at some point within the area of the Iconoscope mosaic. These bright spots can usually be traced to reflection from the back lights and can be eliminated by so adjusting them that none of the light strikes the walls of the bulb in such a manner as to be reflected upon the mosaic surface. Such reflected light can also prove injurious to the photosensitized surface if allowed to remain too long at one spot on the mosaic. Correction should be made as soon as the condition is apparent. The engineer must not assume that a previous proper adjustment of the back lighting rules out such a possibility. For example, occasionally the vibration of the camera in movement about the studio floor will be transmitted to the back light mechanism, resulting in a change in adjustment.

If a *burn* on the mosaic due to admittance of too great intensity of illumination is suspected, this can be checked by so operating the horizontal and vertical sweep controls that the entire mosaic and rim can be viewed. Then, by operating the vertical centering or positioning control, it can be determined whether a burn is present on the surface.

4.6 Exhaust and Activation of the Iconoscope. After the Iconoscope has been assembled, it must be sealed to the vacuum system. This is accomplished by means of an exhaust tube in the gun press at the lower extremity of the gun. The final pressure is said to be about 10^{-5} mm. of mercury. The tube is first evacuated to low pressure at normal room temperature. The temperature of the blank is then increased as much as the glass bulb will permit without implosion. The caesium, necessary for activation, is admitted through a side tube in the walls of the glass blank. The sensitivity and the conductivity of the mosaic are functions of the quantity of caesium admitted during the activation process, and the baking brings about a reaction between the silver oxide and the alkali. The silver elements of the mosaic are oxidized by means of a glow discharge formed over the target's surface. High-frequency current provides the temperature rise. The liberated oxygen is removed through a short baking at about 200°C. The sensitivity of the completed mosaic is between 7 to 10 ma. per lumen.

Great care is exercised in conducting the exhaust and activation schedules dictated for the particular design. There is an optimum amount of caesium admitted, which, if exceeded, results in reduced sensitivity, resolution, and storage property. Also, the cathode of the gun must be activated prior to activation of the mosaic surface so that oxides from the cathode will not be imparted to the surface of the target.

4.7 Iconoscope Magnetic-Deflection System. Magnetic fields perpendicular to the mean axis of the electron beam, projected cathode to mosaic, are set up by both horizontal and vertical pairs of deflection coils. This assembly is termed a "magnetic yoke." The electron beam, originating in the gun structure of the Iconoscope and directed toward the sensitized mosaic at high velocity, is deflected by the electromagnetic fields created by these coils. The direction of motion is a function of the polarization of the fields.

Figure 4.5 illustrates a typical Iconoscope yoke. The assembly measures 3 in. along its greatest axis and has an outside diameter of 2¾ in., exclusive of the connecting terminals. In this particular design the terminals are brought out to the rear for greater convenience in making electrical connection to the external driving circuits. The inductance of the vertical coil is 2 mh., as measured at 1,000 c.p.s., while the horizontal coil inductance is 100 mh. at 1,000 c.p.s. The low-impedance vertical winding reduces the power necessary in the vertical amplifier driving this winding and permits operation of the yoke a considerable distance from the driving amplifier, resulting in more economical circuit design. The ratio of cross talk between horizontal and vertical windings, expressed in voltage, is less than 1,000 : 1, which indicates excellent design.

All windings are individually laced, as is the final assembly. Critical portions of all windings are cemented into position prior to bending and final assembly. This method of construction eliminates the possibility of slippage, which would produce electrical distortion of the image. The yoke is thoroughly impregnated after assembly to make it impervious to moisture, which, if allowed to enter the coils, often results in breakdown between layers or turns.

The four deflection coils of the typical yoke, two providing horizontal beam deflection and two providing vertical beam deflection, are suitably enclosed in a magnetic shield. They are very similar in design to the coils previously described in the treatment of magnetic-deflection systems in Chap. 2. This yoke assembly, as the name implies, fits coaxially about the long, cylindrical glass neck of the Iconoscope and very close to the large bulb of the pickup tube. This positioning of the yoke avoids undesirable clipping, which obtains when the beam strikes the stem of the tube and is cut off or clipped.

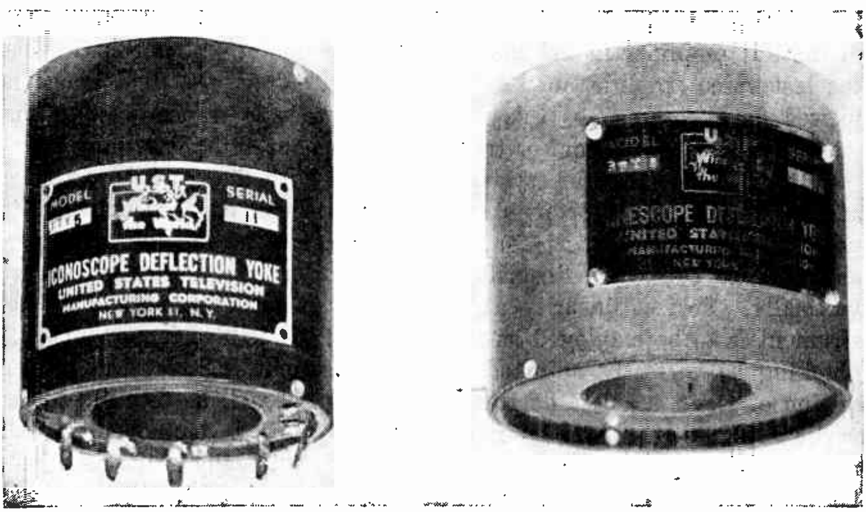


FIG. 4.5 Typical Iconoscope and Kinescope magnetic yokes. The Iconoscope assembly is shown to the left, the Kinescope yoke to the right. (Courtesy of U.S. Television Mfg. Corp.)

The necessary deflection voltages of proper waveshape, amplitude, and frequency are impressed across the respective coils of the yoke, resulting in the beam scanning the sensitized surface of the mosaic in the desired manner. Of course, if the resulting picture is to be perfectly linear both horizontally and vertically, this beam must traverse a uniform magnetic field, which, in turn, dictates that both horizontal and vertical waveforms must be made strictly linear throughout the scanning equipment. Usually, suitable means are provided for linearity compensation within certain limits so that slight variations in waveshape may be readily compensated for during actual operation of the equipment. The circuits, however, are usually adjusted for near-perfect linearity as a matter of routine.

The magnetic yoke suited for use with the Iconoscope is a short yoke of special design. The yoke ordinarily associated with viewing tubes employing magnetic-deflection systems either is of too great length to operate interchangeably or does not have the required electrical specifications. Both types of yokes are shown in Fig. 4.5 for comparison. The yoke assembly must fit rigidly about the neck of the gun in the proper position so that mechanical vibration will not result in a change of placement.

Care must be exercised in adjusting the yoke for proper positioning. The position can be best determined while a standard test pattern is under observation at a line monitor which has previously been adjusted for optimum operation. The term "line monitor" is usually applied to the viewing monitor that operates with its input in shunt with the output of the line amplifier in the control room, the line amplifier constituting the last video amplifier in the camera chain. Thus, the final image is viewed on the screen of this monitor before it is transmitted to the master video control room or transmitter, whichever the case may be.

Of course, the deflection system associated with the cathode-ray tube at this viewing monitor must already have been checked for proper positioning, the raster set for the proper aspect ratio, and test bars employed to check the linearity of the monitor both horizontally and vertically. Perfect linearity at the monitor is essential, since this instrument is to be employed as the reference. It is also important that blanking be correctly adjusted. This adjustment includes the proper setting of right and left horizontal blanking, as well as top and lower vertical blanking. If a 12-in. cathode-ray tube is employed in the monitor, the raster is usually adjusted to 6 by 8 in., the latter being the horizontal dimension. These dimensions coincide with the standard aspect ratio of 3 : 4 and yield a useful screen area of 48 sq. in. Setting the raster to this size eliminates the possibility of distortion at the edges of the image due to curvature of the viewing tube's screen.

In setting up the test pattern before the camera, the pattern must be accurately positioned and leveled at the easel supporting it. As mentioned previously, correct horizontal positioning of the test pattern at the easel can be facilitated through use of a spirit level. The spirit level is placed on the horizontal supporting member of the easel and the support adjusted both horizontally and vertically for precise leveling. Neither the card nor camera must be tilted. If they are, the image will not resolve in proper proportion. It is well to make one check with a level at the top of the camera to be certain that it is properly leveled, and some cameras are regularly equipped with spirit levels to facilitate this check. It is assumed, of course, that the Iconoscope has already been properly positioned in its mount within the camera head.

After it is assured that no serious error in positioning has been introduced in the test arrangement, the test pattern card is suitably illuminated by a source of light and its image reflected upon the mosaic of the pickup tube. The yoke is then carefully rotated about the neck of the gun until both horizontal and vertical positioning of the assembly are at the optimum. If a test pattern inscribed with horizontal and vertical wedges is used, the center of each horizontal wedge—at the outer extremities of the wedge—should fall one half the distance along the vertical dimension of the raster. Usually, a very slight rotation of the standard Iconoscope yoke will rotate the image through several degrees. Therefore, the orientation of the yoke for proper positioning must be very carefully and slowly undertaken. Once the proper adjustment is obtained, the yoke is firmly and securely clamped, so that normal camera vibration will not disturb the adjustment.

It must be remembered that the actual direction that the electron beam traverses under influence of the magnetostatic fields of the yoke occurs at an angle of 90 deg. with reference to the direction of the magnetic lines of force. Thus, if two deflection coils are mounted vertically above and below the neck of the gun, so that magnetic lines of force between the poles are in a vertical direction, then the movement of the electron beam will actually be in a horizontal direction, or at right angles to the vertical plane of the coils. The polarization of the fields will determine whether the deflection of the beam will occur to the left or to the right. If it is desirable to deflect the beam vertically, the deflecting coils must be physically mounted horizontally. Of course, in commercial design, the geometry of the coils about the gun is predetermined by judicious design. It is merely necessary to rotate the yoke about the upper neck of the gun to obtain optimum positioning of the horizontal and vertical traverse, the angular separation of the horizontal and vertical pairs of coils being properly fixed in manufacture.

It must be remembered that the coils of the yoke have some series d-c resistance, as is present in any inductance. This resistance must be overcome if the beam is to traverse a uniform magnetic field. A coil having components of both inductance and resistance can be considered as two separate elements series-connected (see Fig. 4.6). It is desired that the current through the coil take the shape of a perfect saw-toothed waveform. If this current is allowed to flow through a resistor, then a voltage of precisely this same wave shape appears across the resistance. If a current of the same wave shape flows through a pure inductance, then a square-wave voltage must appear across the inductance. Inasmuch as the voltage across the resistor is in series with the voltage across the inductance, the sum of the two voltages produces the shape of the voltage that must be impressed across coil to result in saw-toothed current flowing through the coil.

Figure 4.7 indicates a circuit that develops the desired waveform. The vacuum tube is operated in the trapezoidal generator so that the capacitor C_2 charges on the linear portion of the charging curve, the current flowing in R_3, C_2, R_2 during the charge being made constant. Thus, the voltage across C_2 will rise in a linear manner, and a constant

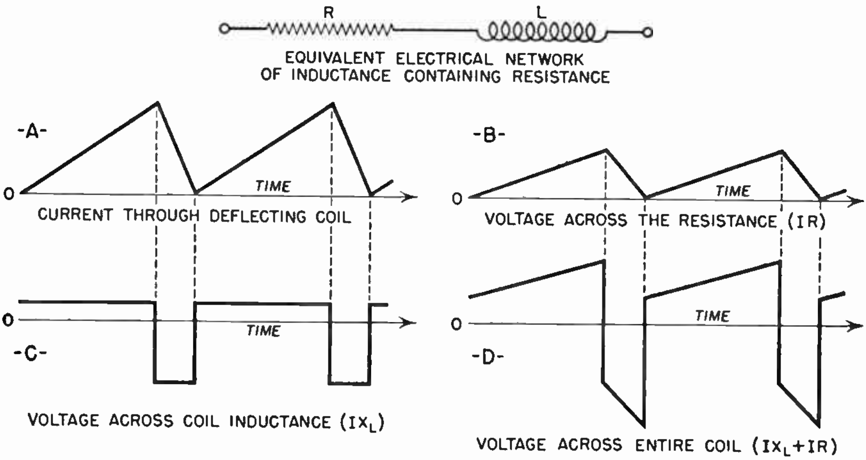


FIG. 4.6 Diagram of the development of the voltage waveform necessary to produce saw-toothed current in a coil containing resistance.

current flowing through R_2 develops a constant voltage across it. When V_1 is made to conduct at time 2 (see Fig. 4.8), the current flowing through C_2 and R_2 reverses as C_2 starts to discharge through the tube.

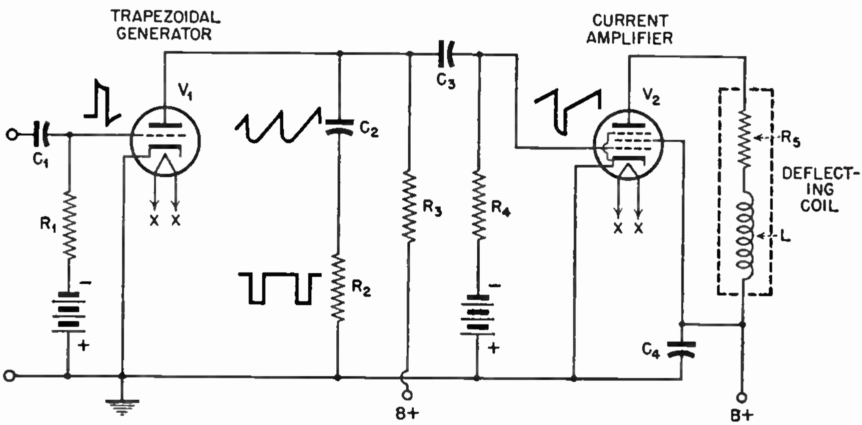


FIG. 4.7 Circuit for development of saw-toothed current wave required for electromagnetic deflection.

This current causes the voltage across R_2 to swing negatively in a rapid manner. This swing occurs as the capacitor discharges from time 2 to time 3 (Fig. 4.8). The voltage at the plate of V_1 is the sum, then, of the voltages across R_2 and C_2, and results in the waveform shown in the illustration at V_2. It is known as a "trapezoidal wave." The axis of this wave is along the line XX' after it passes through the coupling capacitor C_3. The trapezoid $A''A'BB'B''$ results in a perfect saw-toothed waveform current flowing through the deflecting coils, and the beam is made to traverse a uniform magnetic field. The current in V_2 must be reduced to zero at time B'', since the tube is cut off by the negative swing of voltage on its grid. If this negative swing occurs, then the current must

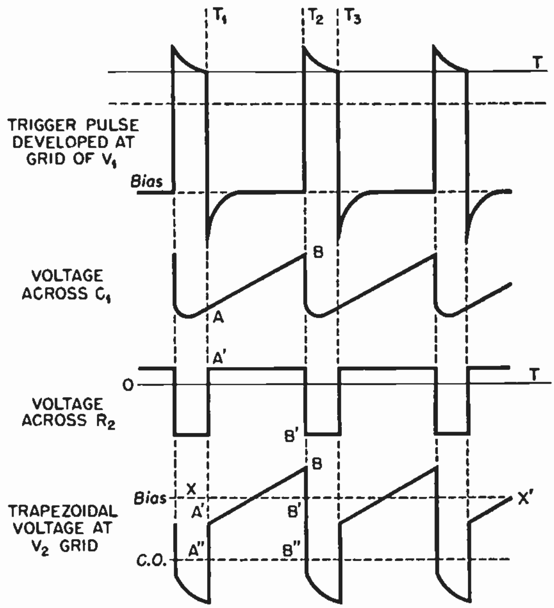
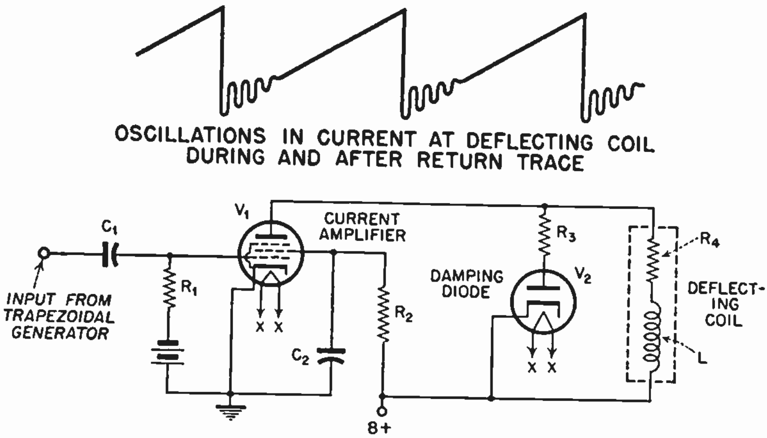


FIG. 4.8 Waveforms present in the circuit in Fig. 4.7.

be reduced to zero at the same instant. To dissipate the energy in the magnetostatic field so that the current will fall to zero, a resistance is sometimes connected in shunt with the deflecting coil.

The presence of the resistor also serves to reduce the Q of the deflecting coil, because in many cases the rapid change of current passing through the coil at the time of retrace shocks the coil into oscillation. Should the Q be sufficiently high, then the oscillations may continue into the next sweep, which results in a nonlinear sweep at the beginning of each trace. Reducing the Q of the deflecting coil has the effect of extinguishing the oscillation before the next trace begins. Since a resistance in shunt with the deflecting coil has a tendency to reduce the current through the coil, a diode is sometimes connected, as shown in Fig. 4.9. When the current through V_1 is raised to provide the forward sweep current, the voltage at the plate of V_1 is less than the supply voltage by the amount of the drop through the deflecting coil. Thus, the cathode of the damping tube V_2 is more positive than its plate, and it fails to conduct. When the current through this tube falls to zero at the conclusion of the sweep, the voltage at the plate rises above the supply voltage as the collapsing field of the inductance tries to generate in the inductance a voltage that will maintain the same current flowing through the coil. The energy in the coil will be dissipated in the resistance connected in series with the plate of the diode, and any oscillations that try to raise the voltage at the plate above the supply



USE OF DIODE AS A DAMPING RESISTANCE ACROSS DEFLECTING COIL TO ELIMINATE OSCILLATION

Fig. 4.9

voltage are effectively damped out. Without this circuit, clearly defined ripples extending vertically from top to bottom of the raster are seen at the left edge of the picture. They are readily eliminated through use of the circuit described. The diode usually employed is a type 5U4G or 6AS7 tube, and the amount of series resistance is determined empirically.

Since magnetic deflection is utilized at the gun of the Iconoscope, it is advisable that the hood of the camera, which encloses the pickup tube in its camera mount, be constructed of some suitable magnetic material. Otherwise, extraneous magnetic fields are apt to change horizontal or vertical centering. The change in centering will produce a shifting in the video image on the viewing screen as the camera is in motion about the studio floor during a performance. In one instance it was noted that when the camera was moved past a vertical steel supporting beam—the pickup tube being unshielded with magnetic material—the resulting image tended to tilt owing to the presence of the magnetic field surrounding the steel beam. This effect necessitated keystone correction by the video control engineer. A shield or hood of good magnetic material is required for the pickup tube housing. Nonmagnetic material such as aluminum or brass is unsatisfactory. This hood must make firm mechanical contact with the remainder of the camera assembly. An excellent contact between the hood enclosing the pickup tube and the remainder of the camera also reduces the noise level in the video system. The hood should be fastened down securely by means of thumb or set screws to allow for convenient removal for servicing.

It must be pointed out here that it is impossible to observe the horizontal or vertical waveform by means of an oscilloscope, because the vertical-axis input of the oscillograph is directly connected in shunt with the horizontal or vertical pairs of driven coils of the yoke. Instead, a small amount of noninductive resistance is connected in series with either pair of coils. When the vertical-axis input of the oscilloscope is shunted across this resistance, the in-phase voltage appears across it and is observed on the screen of the cathode-ray-tube.

Ordinarily, 1 to 2 ohms of resistance are inserted in series with the horizontal pairs of coils and 20 to 30 ohms with the vertical pairs. Only then may the true wave shape be practically observed. Of course, the forward slope of the saw-tooth waveform must be precisely linear with respect to time if the resulting image at the line-viewing monitor or television receiver is to be in proper proportion throughout the useful screen area. The vertical saw tooth, being of lower frequency, is usually less difficult of adjustment.

In observing the "saws" at the yoke in this manner, the voltage across the inserted resistance will be in phase, so that it will indicate a waveform essentially equivalent to that of the current. This, of course, is not true if the drop directly across the inductance of the yoke is observed.

A typical yoke for use with the Iconoscope contains a total of 530 turns, or 265 turns per coil, for the vertical winding. The horizontal pair of coils contain 28 turns, or 14 turns per coil. Thus, the horizontal coil operates at relatively low impedance, which, in turn, demands high current. Usually, a pair of type 6L6, 6AR6, 1611, 802, or 807 vacuum tubes are parallel-connected in the final horizontal deflection amplifier to satisfy the high-current demand. A single type 6F6 or 6Y6 tube is usually employed in the final vertical deflection amplifier to provide adequate current to the vertical pairs of deflection coils. Since more turns are used in these coils and less current is required than for proper horizontal deflection, the magnetostatic field developed is a function of the ampere-turns of each inductance. Owing to the high voltage developed because of inductive kickback at the horizontal coils at fly-back time, exceptionally well-made sockets are recommended for the tubes employed in the final horizontal deflection amplifier. With d-c plate voltage of 250 v. at these tubes, the fly-back voltage sometimes approaches 3 kv. with a typical pair of coils. It must be remembered that the horizontal sweep frequency is relatively high and that the reactance of the coils is therefore very high. A high-reactive voltage drop occurs across the coils, which is discharged during the fly-back time. Sockets made of steatite, isolantite, or other such ceramics are recommended. They must possess firm, positive contacts that will not develop high resistance from oxidation.

4.8 Iconoscope Rim Lighting and Back Lighting. The rim or edge of the mosaic of the Iconoscope must be illuminated if a satisfactory image is to result. The term edge or rim of the mosaic is used to refer to the dull metal frame that is fixed about the edges of the photosensitized surface for mechanical support. Unless this rim is properly illuminated by a suitable rim-lighting system in the camera housing, edge flare will result. This edge flare can be observed at the outer extremities of the reproduced image and is very undesirable.

In one method of rim lighting, several round metal cylinders are employed, two illuminating the upper edge of the rim, and two others for illuminating the right and left edges of the rim. In another, only the top and left rim are illuminated. These cylinders are made of such length as to illuminate appropriately the entire vertical or horizontal rim, whichever the case may be. They are open at either end to admit the lamps that provide the light source. Ordinarily, 6- to 8-v. blue-bead pilot lamps are employed.

A more practical lamp, though, is one of long, tubular shape, such as is used in the medical profession for exploratory purposes. Such a lamp provides greater illumination. One lamp, instead of two, per cylinder, will provide an efficient light source throughout the length of the cylinder. Each cylinder is provided with a slit in the side toward the mosaic so that the light filtering through the slit may be projected upon the rim of the target. The upright cylinder used to illuminate the left edge of the mosaic is clamped at the lower extremity, the mount affording a means of rotation. Thus, the entire cylinder may be rotated at will in order to focus the light directly upon the rim. After adjustment, a screw thread permits clamping. The mount must be rigid so that movement of the camera about the studio floor will not produce vibration that will be transmitted to the assembly and upset the adjustment.

The horizontal cylinder, the one used in illuminating the upper edge of the mosaic, is held in position by means of two clamps, one near each end of the device. The mounting feet of these clamps are slotted and the entire cylinder may be moved up and down, vertically, to afford optimum adjustment of the upper rim lighting. The entire cylinder assembly is fixed just above the aperture in the camera head, through which light is admitted from the optical lens system and through the optical window of the bulb of the Iconoscope. Thus, it does not prevent the reflected light from reaching the photosensitized surface of the tube's target.

The lamps in each cylinder are rotated in the ends of the cylinders so that the axes of the filaments are in optimum position for maximum projection of light. In orienting the lamps within the cylinders, one position will be found, depending upon the geometry of the filament, which results in optimum transfer of light through the slit. The best setting is determined by observing the rim of the mosaic while the lamps are being rotated. Usually, the metal hood of the camera is removed, and a cloth hood or coat is thrown over the Iconoscope to obviate the possibility of external light affecting the adjustment. This enables the engineer to see clearly the amount of light being thrown upon the rim. A black cloth hood such as is used by portrait photographers will prove useful in this adjustment.

A better arrangement for mounting and adjusting the rim lights, though more difficult of mechanical design, employs the same type of cylinder, namely, one with the side slit for projection purposes, but it is equipped with two thumb screws for easy adjustment. A screw is used at each end of the cylinder, and each operates through a tapped angle. Thus, the ends of the cylinder may be raised or lowered vertically to permit more precise adjustment. A small gear arrangement may also be employed at the light socket, or sockets, so that the lamps may be oriented within the cylinder for optimum focusing. If the lamps are orientated within the cylinder, the thumb screws control the rotation.

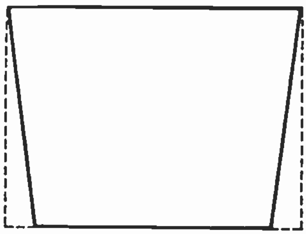
In adjusting the rim lights, illumination should cover only the rim of the mosaic. Any light falling upon the photosensitized surface of the target will result in flare at the portion of the image upon which the light falls. These bright spots may be easily seen if the image is viewed at the line monitor. Lamps and the cylinder mounts are then adjusted until the flare is completely eliminated. To determine whether the observed flare is due to improperly adjusted rim lights, the rim-light circuit may be momentarily opened and closed by means of a switch, thereby isolating the rim-lighting system as the possible cause.

It is common practice to utilize direct current in the rim-lighting circuit. It must be remembered that the video signal at the output of the Iconoscope is at low level; therefore, any extraneous a-c fields surrounding the tube are apt to be induced into the output circuit, and noise or snow will appear in the final image. If the hum field is very heavy, clearly defined hum bars may be seen traversing the picture horizontally. They are broad black or dark bars, evenly separated and extending horizontally across the image, top to bottom of the raster. If alternating current is used in the rim-lighting circuit, careful balancing to ground must be carried out. In most cases, the results will not be very satisfactory. A good d-c source of supply, preferably from a dry-disk type rectifier or storage battery, is generally made use of.

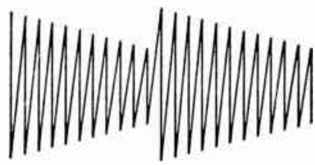
The lamp-circuit potential should be capable of adjustment from the video control room, since it will be found that the optimum value of illumination varies over long periods of time. Also, aging of the filaments in the lamps demands some readjustments in supply potential. Too, the necessary value of illumination varies for different Iconoscopes, and the manufacturing tolerances allowed in the bulb dimensions are so great that no single adjustment ever proves exactly right for another pickup tube. The installation of a proper rheostat in the control room, so that remote control of the potential may be had, is very desirable. Such a control arrangement should provide protection from accidental overload of the lamp filaments, so that they are not overloaded during periods of camera operation in the studio. The lamps are usually connected in parallel. A resistor is inserted in series with the rheostat. Then maximum rotation in a clockwise direction will yield a maximum of about 7.5 v. at the lamp sockets. Any lamps employed should be capable of yielding sufficient illumination without operation near the overload point.

In addition to the lamps used for rim lighting, an additional lamp is operated at the rear of the Iconoscope bulb and directly to the rear of the signal-plate side of the mosaic. This lamp and its fixture are known as the "back light." Its function is to discharge photoelectric materia which was deposited on the walls of the Iconoscope during the manu- facturing process and also seems to improve the secondary-emissio factor of the mosaic. The lamp need not be sharply focused upon the rear of the mosaic to achieve this result. Instead, a diffused lighting of the rear of the target seems to prove most beneficial. At any rate the signal output of the Iconoscope is improved through use of back lighting, as may be readily seen if the amplitude of the video informa- tion produced by the tube is viewed while the amount of illumination is varied, or cut on and off intermittently. Care must be taken tha none of the light originating with the back-light source falls upon the photosensitized front surface of the mosaic, which sometimes occur when the light is reflected from the walls of the tube and onto th mosaic.

4.9 Keystoning. Keystoning circuits are discussed in greater detail on pages 299–300. At this point, however, it should be considered briefly Owing to the fact that the high-velocity beam generated by the elec tron gun of the Iconoscope strikes the mosaic at an angle 30 deg. from the perpendicular, the path of the beam—cathode to mosaic—is longe at the upper edge of the target than along the lower edge. In scanning, beam deflection over the surface is roughly proportional to the actual length of the beam between the deflecting coils and the surface being scanned. For this reason, the length of the top horizontal scanning line is longer than the line at the lower edge of the mosaic surface. The picture that results—without keystone correction—is keystone-shaped. Of course, the final image, the one entering the transmitter, must be perfectly rectangular in shape and must have the proper aspect of ratio of 4 : 3.



FULL LINE ABOVE SHOWS KEYSTONE-SHAPED PATTERN AT OUTPUT OF THE ICONOSCOPE. DOTTED LINE INDICATES CORRECTION NECESSARY.



THE WAVE SHAPE OF THE SIGNAL SHOWN ABOVE IS NECESSARY TO PROVIDE CORRECTION. THE HORIZONTAL SAW-TOOTH VOLTAGE IS MODULATED BY A COMPONENT OF THE VERTICAL SAW-TOOTH VOLTAGE.

Fig. 4.10

Correction is obtained by adding a part of the vertical saw-toothed voltage to the horizontal saw-toothed voltage in proper phase and amplitude to decrease the actual length of the scanning lines at the top of the image while at the same time increasing their length at the bottom of the mosaic. The vertical saw-toothed voltage is used to modulate the horizontal saw-toothed voltage to achieve this result, and special circuits are necessary. Until recently, such circuits were difficult to develop and apply. Present methods, however, afford trouble-free keystoning with a minimum of components. Complete control is afforded and the video engineer has instant supervision at his finger tips. The adjustment, once made, is not permanent. As the camera is moved across the studio floor, extraneous magnetic fields tend to affect the beam positioning. Minute adjustments must be continually made during a performance. As mentioned before, adequate magnetic shielding of the Iconoscope will limit this effect. However, it is believed that the magnetic lines of force about the earth have some effect. Keystoning can be seen to change slightly as the camera is moved in a circle about the studio floor, supposedly clear of any other magnetic fields which might possibly couple and induce spurious voltages into the deflection coils.

Keystoning changes with each Iconoscope used. The degree or percentage of modulation must be corrected after each installation of a new pickup tube. The circuits are usually corrected, therefore, after the new tube is installed. Keystone-amplitude and keystone-balance controls are set for optimum, so that they will operate within the required range necessary to maintain control during operation.

4.10 The Spurious Shading Signal. As has been mentioned, one of the most serious faults of the Iconoscope lies in the spurious shading signal that develops. If correction of the fault is not attempted before transmission, the image received by the viewer will not faithfully represent the light and shade in the scene being televised. The tube efficiency, unfortunately, is limited by the very small difference of potential existing between the second anode and the mosaic. Therefore a great many photoelectrons fall back on the mosaic instead of reaching the second anode where they may be carried off. The result is an actual reduction in the stored charge per picture element.

A study of the Iconoscope shows that if its operation approached the ideal, the beam, in scanning, would exactly replace the emitted electrons that are lost by each element along a particular line. Unfortunately, this is not true. The electron beam which continuously scans the target left to right, except during blanking time, dislodges a great many secondary electrons because it is operating at high velocity. At the point of impact with the target the force is very great. These secondary electrons rain and fall back upon the mosaic unevenly, enabling certain parts of the target to attain a more highly negative charge than other parts. The parts that assume a more highly negative charge produce a greater difference of potential between the parts affected and the second anode. Thus, the efficiency is actually increased at the points along the mosaic surface which are made more negative owing to the uneven rain and fall of secondary electrons. The increase in efficiency tends to bring about a greater emission current to the second anode, as well as a subsequent rise in video output when the more highly negative points along the target are scanned by the beam. Since the charge along each line is strictly cumulative the efficiency ordinarily increases toward the end of a scanning line. If interlaced scanning from left to right is employed, then the right-hand edge of the picture will seem brighter than the left. Too, the unequal rain and fall of secondary electrons will result in bright and dark spots throughout the entire area of the mosaic.

The spurious shading signal is customarily corrected by introducing necessary components of voltage to the normal output of the Iconoscope. These components of voltage are of such phase and amplitude as to counteract the spurious shading signal. The actual output of the pickup tube, added to the shading voltages introduced, results in a net signal voltage the magnitude of which is actually proportional to the true light and shade in the scene being televised. The spurious shading signal increases with an increase in beam current. It is common practice, therefore, to use the minimum beam current that will result in an acceptable picture. Since beam current is usually controlled at a point remote from the camera, the video engineer in the control room can ascertain the proper level to set the beam current for a particular Iconoscope. This setting is made such that control of the shading is easily effected.

Some time is always required to "shade up" a picture properly before it may be satisfactorily transmitted. For this reason, at least two Iconoscope camera chains are ordinarily necessary in the typical television studio where these tubes are used. While one chain is on the air, a video engineer is shading up a second camera chain, making it ready to be switched on the air at the director's request. For smooth operation, a good director never requests a scene until he has first made sure that the camera chain is properly shaded. A video monitor for each chain shows him the finished product. Among television engineers it has often been said that if the picture is not perfect electronically, it is not good artistically. This is very true.

The shading generator or amplifier controls provide for easy adjustment of the phase and amplitude of the voltages used for shading compensation. These controls are adjusted until the average illumination of any particular scene is uniform throughout the entire useful area of the mosaic. A number of compensating voltages are used, and the controls are usually described as follows:

Vertical saw	Horizontal saw
Vertical parabola	Horizontal parabola
Vertical sine	Horizontal sine
Vertical sine phase	Horizontal sine phase

All these correction voltages are mixed into a common shading amplifier. The output of the amplifier, in one case, is carried by coaxial cable from the video control room to the studio camera where it is subsequently introduced at the low-level input of the first stage of the video preamplifier. Other systems introduce the shading potentials at high level, sometimes at the input of an intermediate video amplifier in the control room. It should be pointed out that the vertical and horizontal sine phase controls mentioned above are employed for the purpose of changing the phase of the vertical and horizontal sine voltages through 180 deg. continuously. This proves very advantageous in providing complete control.

Proper operation of the controls requires practice on the part of the engineer. It is usually some months before he becomes adept. It is common practice to allow the engineer to shade pictures first during rehearsals. Later he is allowed to shade pictures that are being transmitted, but only after he has become proficient. The amount of time required to train an engineer thoroughly for this operating position varies with the individual. Certainly he must show some aptitude and alertness if he is to qualify for such a position.

4.11 Care Required in Handling and Installation of the Iconoscope. The Iconoscope at best is a very sensitive and delicate device, and the greatest care must be exercised in handling it. When the tube is received from the manufacturer, it must not be removed from its shipping carton under bright illumination. Rather, it should remain in the carton until the average illumination is subdued, and just sufficient lighting is permitted to facilitate proper handling without risk of accidental damage. No direct light must fall upon the sensitized mosaic. Usually, the source of light necessary to permit examination and installation is fixed at a considerable distance from the Iconoscope and camera in which it is to be installed.

It will be seen that the tube, as received from the supplier, is packed in a carton with the neck down. The tube should remain in this position when extracted from the carton to obviate the possibility of foreign elements within the glass envelope falling upon the sensitized mosaic. Most television cameras are so arranged that the tube mount permits the gun section of the Iconoscope to extend downward. This arrangement affords the maximum protection to the mosaic surface. Such a mount, or support, should be rigid. It should also afford some type of shock absorption to prevent mechanical damage to the tube when it is in operation, since the camera is in practically constant motion about the studio floor during the televising of a program sequence.

Care must be exercised to prevent the socket mount from producing undue strain or stress at the gun press and base. Usually, the external leads connecting to an appropriate socket are properly cabled. The socket terminates at the extreme end of this short, flexible cable, and thus, the cable itself absorbs the shock which might otherwise be transmitted to the gun structure and enclosing neck of the tube. The connectors that fit over the caps protruding through the walls of the tube, to permit connection to the mosaic and the collector ring, must be equipped with short flexible leads to eliminate strain at this point.

The large bulb of the Iconoscope may be secured to the camera proper by means of a narrow metal strap about 1 in. wide. This strap, fitted to encircle the tube in the region of the mosaic, is lined with felt to prevent damage to the glass bulb. In one type of installation, one end of the strap is clamped to an upright support at the lower and outer side of the bulb of the tube. If the face of the strap is slotted for a convenient distance from one end, it may be fitted over machine screws which extend from the upright insulating support. The strap is then drawn tight about the bulb of the tube. Just enough tension is applied to clamp the tube firmly in position, after which the machine screws are tightened. Too much tension must not be applied, because this may fracture the glass bulb. The metal strap is at ground potential, but it connects to ground through a lead that holds the ground at the first stage of the preamplifier at the same potential. It is important that no difference of potential exists between grounds.

When the Iconoscope is being fitted in the camera mount and mechanically rotated and adjusted for proper operation, a suitable lightproof hood of cloth should replace the metal hood which has previously been removed from the camera to allow access to the tube mount. The engineer may then make the necessary adjustments without the possibility of extraneous light striking the sensitive mosaic. If too much direct light falls upon the mosaic during this operation, a reduction in the photosensitivity of the target may result. As a matter of fact, no direct light is ever permitted to fall upon the mosaic surface. Only reflected light from the subject being televised is allowed to strike it, and then only through the optical lens system. Actually very little light reflected from a studio scene strikes the mosaic. In one instance the light measured at the surface of a test pattern that was properly illuminated indicated a total of 1,400 ft.-c. The light reflected from this test pattern and measured on a plane equal with that of the lens system was 110 ft.-c. The light measured inside the camera housing with the Iconoscope removed, but at the same position formerly occupied by the mosaic, indicated a light-meter reading of 87 ft.-c. Therefore, it can be readily seen that direct light may prove very injurious, since it compares very unfavorably in intensity with light actually being reflected upon the mosaic through the optical lens system.

It is customary to lightproof the camera-housing interior. The surfaces are coated with Kodalac or some similar nonreflective material, and the lens-barrel interior is also coated with a similar material, so that no reflections occur within its inner walls.

When the Iconoscope has been installed, it must be slightly rotated within the clamping ring until the mosaic is perfectly square with the aperture through which reflected light is admitted. The tube is covered with a lightproof cloth during this procedure, and the optical lens system is removed. Standing in front of the camera, the engineer lines up the mosaic with the window, light from the rim-lighting system furnishing enough illumination under the hood to facilitate the adjustment. The tube is firmly clamped after the operation is completed.

From the preceding discussion of the Iconoscope, it is apparent that five inherent faults are present in the tube. One particularly troublesome defect is the presence of a *spurious shading signal* which causes nonuniform shading of the image to be transmitted. Although this defect may be satisfactorily compensated for through the use of special equipment, it necessarily complicates the transmitting system, and specially trained personnel are required to effect the proper shading correction. A second disadvantage is the *low over-all sensitivity* of the Iconoscope. Owing to the rain of secondary electrons upon the photosensitized mosaic, it is said that the charge reaching the second anode as each picture element is discharged through scanning actually approximates about 25 per cent of the total charge stored at the mosaic. Moreover, because of the extremely low difference of potential that exists between the mosaic and the collector ring, a *space charge is present* between these elements. This space charge serves to reduce further the number of electrons that might otherwise succeed in reaching the collector. Both the rain of secondary electrons upon the sensitized surface of the mosaic and the space charge that exists between the mosaic and collector produce a reduction in the over-all sensitivity of the device.

A fourth disadvantage lies in the *large surface area* of the mosaic. It will be recalled that the output voltage, or the amplitude of the video information prevailing at the tube's output, is in part a function of the area of the photosensitized surface, thus accounting for the large area of the mosaic. In fact, it is considerably larger than that found in either of the other present-day pickup tubes, and it should be borne in mind that the larger the target area, the more expensive the optical lens system that must be employed at the camera. Actually, the cost of a good optical lens system to operate with the Iconoscope approximates the cost of the tube itself.

A fifth disadvantage is the *keystone compensation that is required.* Such correction is necessary because of the beam striking the mosaic at an angle of 30 deg. from the perpendicular and the resulting image, before correction, being keystoned in shape.

4.12 The Orthicon. All the inherent defects and faults ascribed to the Iconoscope have been subsequently corrected in the Orthicon, a pickup device that is a more recent development of R.C.A. Laboratories. An early commercial version of this tube is shown in Fig. 4.11, and a schematic diagram of the device is shown in Fig. 4.12. This pickup tube is largely the work of Albert Rose and Harley Iams of R.C.A. The word "Orthicon" is a simplification of the name "Orthiconoscope," which has been used by these engineers to denote any pickup tube in which the target operates at cathode potential. The Greek prefix *orth* means straight, and it was added to the term Iconoscope to describe the linear relation between light and signal output which obtains in pickup tubes of this type. A later version of this tube, the Image Orthicon, will be subsequently described in the text. The Orthicon type of pickup device, attaining new heights of perfection in the Image Orthi-

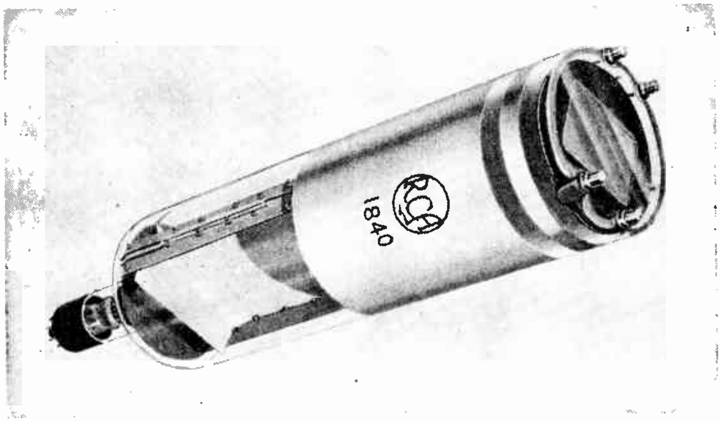


FIG. 4.11 R.C.A. type 1840 Orthicon, an early commercial type of tube which has seen special use as an outdoor pickup device. (Courtesy of Radio Corporation of America, Tube Division.)

con, has replaced the Iconoscope as the preferred type of tube for most pickup applications.

While the Iconoscope employs a high-velocity electron beam for scanning the target, the Orthicon makes use of a low-velocity beam for the

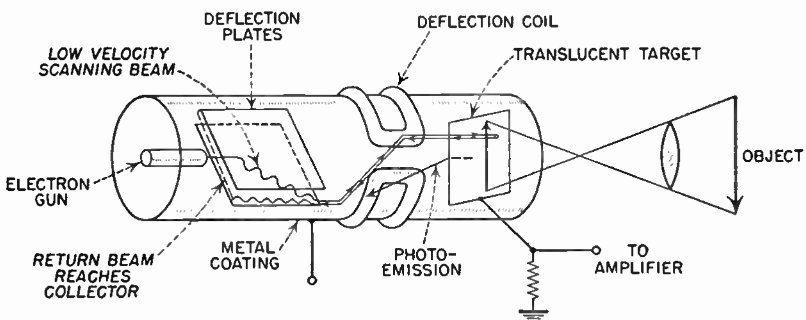


FIG. 4.12 Schematic diagram of R.C.A. type 1840 Orthicon pickup tube.

same purpose. This eliminates the problem of secondary emission which so lowers the over-all efficiency of the Iconoscope. It can be seen that the ideal pickup tube design would have all the emitted photoelectrons drawn away without the introduction of secondary emission in so doing. This may be accomplished by operating the target at the same potential as the cathode or emitting device. It has been shown by A. W. Hull* that the potential of an insulated surface exposed to an electron beam is stable at this potential. Secondary electrons are liberated at the mosaic of the Iconoscope because the high-velocity electron beam impinges upon the target with considerable force The electrons striking

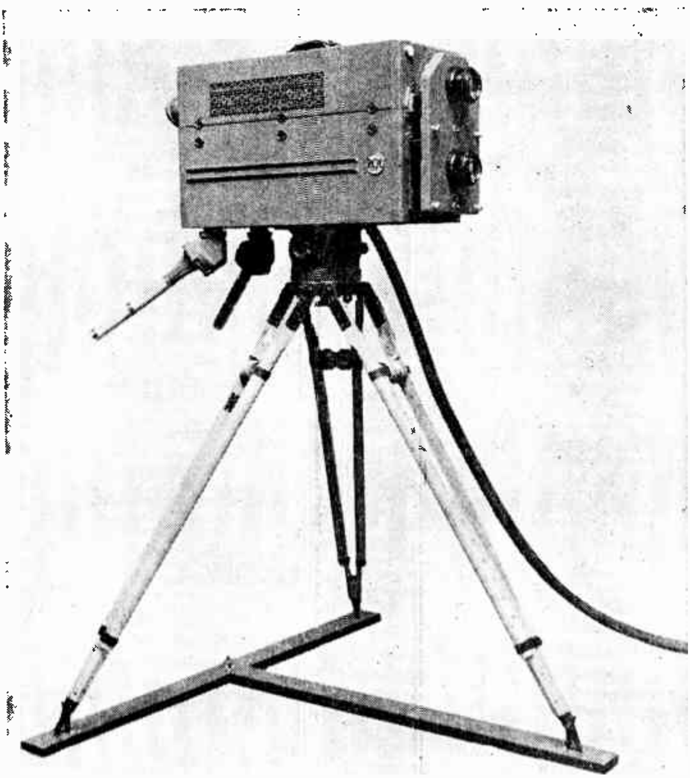


FIG. 4.13 Early R.C.A. field camera for use with the Orthicon pickup tube. (Courtesy of Radio Corporation of America, Tube Division.)

the target develop very high velocity owing to the great potential difference existing between cathode and target.

When a low-velocity beam such as that used in the Orthicon is employed, beam electrons which attempt to land on the target are repelled and retire without ever reaching it. But with photoemission, which occurs when a light image is optically focused upon the target, the target assumes a slight positive potential with reference to the cathode, and the beam electrons impinge without the development of appreciable secondary emission, restoring the target to the potential it

* *Proc. I.R.E.*, Vol. 6, No. 1 (Feb. 1918), p. 5.

held before photoemission developed the slight positive charge. It may be seen, therefore, that the Orthicon, with target operating at cathode potential, is a distinct improvement over the Iconoscope. The improvement is due principally to the absence of secondary emission when the mosaic is lighted and under electron bombardment during scanning.

4.13 The Mosaic of the Orthicon. In any electron tube for image pickup that has thus far been developed, a photosensitized surface is necessary. The reflected light from the scene being televised is imaged upon this sensitized surface by means of an optical lens system that is accessory to the pickup tube. The Orthicon employs such a light-sensitive surface, but it is quite different from that employed in the conventional Iconoscope. The target of the Orthicon is a sheet of thin mica. The surface facing the electron beam is coated with a mosaic of photosensitive elements, but the other surface, the side opposed to the beam, is translucent. Herein lies a principal departure from the target design of the Iconoscope.

The light imaged upon the mosaic must then pass through this translucent signal plate before being imaged upon the photosensitized surface of the mosaic. The geometry of the tube is such that the mosaic is close to the optical glass window at one end of the containing envelope. This closeness results in a reduction in the actual physical difference between the optical lens system and the sensitive target. The position of the mosaic and the translucent signal plate may be clearly seen in Fig. 4.11. With this improved construction, the camera lens may be made very short in focal length, and a short focal length lens may be employed for wide-angle shots. Too, the small target area reduces the required diameter of the optical lens. Because of this, the Orthicon, its lens system, and the camera which houses it may be made much smaller than required for Iconoscope operation. In fact, the tube has had some early use for outdoor or remote pickup work. An Iconoscope camera is too bulky and cumbersome for practical operation in the field. The Image Orthicon is now the principal tube for outdoor use.

The reduction in camera size afforded by the Orthicon results in greater mobility and maneuverability in the field. Since the mosaic operates at approximately cathode potential at all times, no high-voltage power supply mount at the camera dolly or tripod is required. A positive potential of 100 v. sometimes connected to the conductive metal coating of the envelope, is the highest d-c potential ever employed. This coating may also be operated at ground potential, if desired. In the latter case, plus 25 v. d-c is the maximum potential applied. When we consider that 750 to 1,000 v. are required for second-anode potential at the Iconoscope, an additional advantage of the Orthicon can be readily seen. Then too, there is less danger of the operator or cameraman coming in contact with high potentials. It may now be seen why it replaced the Iconoscope as a principal tube for outdoor pickup, at least until the more sensitive Image Orthicon was evolved.

4.14 The Orthicon Electron Gun. The electron gun of the Orthicon is a very simple structure. It comprises a conventional, spirally wound heater coil enclosed in a suitable cathode cylinder. The end of the coil is coated with strontium and barium oxides to reduce the surface potential at which electrons are copiously emitted. Beyond the emissive cathode are two low-voltage anodes. One anode has an aperture diameter of 1 mm.; the second, placed slightly farther along the gun structure and in the direction of the target, has an aperture diameter

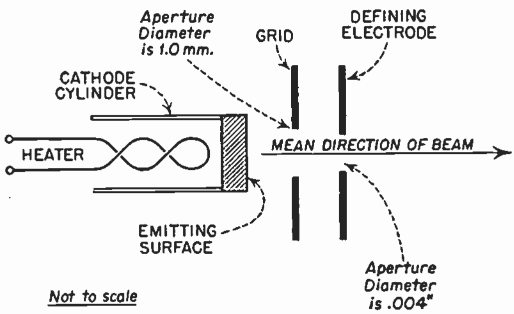


FIG. 4.14 Schematic diagram of Orthicon gun construction.

of 0.004 in. The electron beam leaving the gun structure is thus masked to this latter effective diameter before entering the electrostatic field of the horizontal deflection plates. The cross section of the electron beam is limited to the size of a single picture element by the defining aperture of the last electrode.

The inner surface of the glass envelope enclosing the tube components is suitably coated with a metallic covering, which may be connected to ground. The cathode is operated at 25 v. negative with respect to ground. The signal plate at the target is also connected to ground through the load resistance, across which the signal is developed. The input to the video preamplifier is connected across this load resistance. The electron beam, masked to 0.004 in., reaches the target at approximately the same diameter owing to the presence of the long focus coil employed. The theory of the long focus coil has already been discussed in Chap. 2.

Because the Orthicon is of much smaller physical size than the Iconoscope, the electron beam is less affected by extraneous electrostatic or magnetic fields. The distance through which the beam must travel, cathode to target, is relatively short. Once the beam leaves the gun, it is better assured of traversing a uniform deflection field, and there is less possibility that distortion will be brought about by stray fields in the vicinity of the apparatus.

4.15 Beam Deflection in the Orthicon. The electron beam emerging from the gun structure of the Orthicon possesses both low voltage and low velocity. This eliminates the need of utilizing the type of electrostatic focusing system commonly employed when a high-velocity beam is involved. An important problem in the design of the tube, which employs both an electron gun for beam generation and a target operating at cathode potential, was to deflect the beam without appreciable defocusing. It is a well-known fact that in any tube employing an electron gun only the exact center of the target is normally connected with the emissive cathode by a magnetic line. Therefore, if electrons emitted by the gun are to impinge upon other parts of the total photosensitized area, either the beam must pass over the magnetic lines of the axial field, gun to target, or it must pass or be forced to other areas of the target surface by warping the normal axial magnetic field. Thus, a gun and an axial magnetic field have been employed in the Orthicon of R.C.A. Laboratories to obtain scanning.

The Orthicon is immersed in a uniform magnetic field developed by a long field coil which extends the complete length of the device. High-speed horizontal deflection is obtained through use of a pair of electrostatic deflection plates in addition to the axial magnetic field. With this arrangement, the electron beam is deflected in a plane parallel with the horizontal plates and diverges from the axis only when it is between the plates. It has been shown that the amplitude of deflection is proportional to the electric field and the transit time of the electrons moving between the parallel deflection plates, and that it is inversely proportional to the strength of the axial magnetic field. The deflection plates are made as wide as the target, since the maximum amplitude of deflection is a function of the width of the plates.

If the beam could be conveniently viewed from the gun end of the plates, it would be seen to "wiggle" through in the pattern of a series of cycloids. This is representative of the two-dimensional path of electrons moving in crossed electric and magnetic fields. It was found by R.C.A. engineers that it was entirely possible to ensure that the beam leaving the plates retained none of the transverse velocity acquired in the plates. This was accomplished by suppressing the amplitude of cycloidal motion within the plates, the beam being admitted between the parallel plates through a gradually increasing electric field. The plates are so designed that they flare out at the entrance and exit ends.

It has been pointed out by R.C.A. engineers that two distinctions are noted in comparing electrostatic deflection in the presence of a magnetic field with electrostatic deflection in an ordinary cathode-ray tube. In the cathode-ray tube, the plane of deflection is perpendicular to the plates. In the Orthicon, the plane of deflection has been rotated through 90 deg. into a plane parallel to the deflection plates. Also, in ordinary cathode-ray tube electrostatic deflection the deflection plates impart a transverse velocity to the electron beam. As a result the beam continuously diverges after departing from the plates. In the Orthicon pickup tube, the beam diverges only from the mean axis while between the plates.

The magnetic lines of force are essentially in a straight line from one end of the Orthicon to the other, owing to the presence of the long magnetic coil surrounding the envelope. Thus, if no deflection forces are applied, a beam 0.004 in. in diameter leaving the gun at one end of the

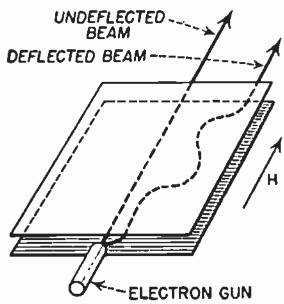


FIG. 4.15 Diagram of the path of an electron beam in electric and magnetic fields. (After A. Rose and H. Iams.)

tube will emerge at the target with its initial diameter. In addition the magnetic field tends to constrain the beam to motion parallel with the axis after it emerges from the plates.

A pair of magnetic coils are used to obtain vertical deflection in the Orthicon because of the low frequency involved. The separation of these coils must be made equal to the height of the mosaic, since the amplitude of deflection is a function of the magnitude and axial length of the axial magnetic field. It can be seen that once the beam leaves both the horizontal and vertical pairs of deflection plates, it is in the same condition as when it left the electron gun, except for displacement from the mean axis through the tube. Moreover, the beam reaches the target at near zero velocity owing to the electric retarding field through which it passes. Thus, secondary emission is practically nonexistent.

When a target is not illuminated by reflected light from the studio, the mosaic is not at positive potential. This last occurs only when the mosaic's photosensitive elements are receiving light from some source. Hence, due to the fact that the cathode and target are at precisely the same potential, the electrons will not impinge upon it. Instead, they will first come to zero motion near it, then will be accelerated in the reverse direction. They eventually return to the collector, just in advance, physically, of the gun structure, passing once again through the deflecting mechanism, but in the reverse direction.

But, should the mosaic be illuminated by light that is reflected upon it from some source, then enough of the beam will impinge upon the target to replace the photoelectrons which have been taken away during the previous time of one frame. Thus, the beam serves to maintain the cathode and target at potential equilibrium and the video signal is produced.

Of course, since the beam reaches the target perpendicularly, no keystone correction of horizontal deflection is necessary. This is a distinct advantage over the Iconoscope type of pickup tube. The absence of keystoning circuits greatly simplifies the television system and, incidentally, reduces the amount of training required to produce a competent operating engineer.

4.16 Characteristics of the Orthicon. As has been shown, no signal is actually developed at the output of the tube when no light image is focused upon the mosaic. But when a lighted scene is imaged upon the target, a signal proportional to the light intensity of each point on the surface and corresponding to light and shade in the scene is carried to the video preamplifier of the camera. The amplitude of beam current limits the maximum signal which may be obtained from the device and a modulated beam current of 1 ma. has been measured in some tubes. This is equivalent to a signal current about 300 times greater than the average noise level encountered in a typical television amplifier. Thus, the snow, or noise, level may be considerably reduced in a television system employing the Orthicon. The quality of the resulting picture is, in part, of course, a direct function of the signal-to-noise ratio.

The conversion of possible photoemission into signal approaches 100 per cent efficiency with the Orthicon, as compared to a maximum of 25 per cent efficiency attributed to the Iconoscope. Since the collector electrodes surrounding the target are at times about 100 v. positive, a saturated photocurrent is obtained under static conditions. During frame time, the photoemission from the target is swept over the collecting elements by the vertical coil fields.

The Orthicon, with a target photosensitivity of 1 ma. per lumen, demonstrates the same operating sensitivity as an Iconoscope that possesses a target sensitivity of 10 ma. per lumen. The Orthicon will demonstrate as much as 600-line resolution in the center of the picture. For a target of the size used in the Orthicon (2.5 in. wide), this means that the scanning beam is capable of resolving elements on the target separated by less than 0.02 in. As will be seen in Fig. 4.4, the tube has the same spectral-response characteristics as those possessed by the Iconoscope.

4.17 The Image Orthicon. A very efficient electron tube for image pickup has been developed by R.C.A. Laboratories. It is called the Image Orthicon and represents a considerable improvement over the early commercial version of the Orthicon previously described. A photograph of a developmental model of the new Image Orthicon is shown in Fig. 4.16, and a schematic of the tube is illustrated in Fig. 4.17.

Physically, the tube is much smaller than the earlier Orthicon. It is, of course, considerably smaller than the Iconoscope. It measures only 15 in. along its greater axis and just 3 in. at its greatest diameter. This small size makes it a very desirable pickup tube for portable-equipment applications, and it has become the principal tube for indoor work as well as for remote pickup work outside the studio. A very small camera housing is required to enclose the device completely.

Problems of lighting become inconsequential because of the extreme sensitivity of the Image Orthicon. The device demonstrates almost unity gamma. Satisfactory results are obtained in scenes illuminated with less than 0.01 c. per sq. ft. The tube incorporates an electron multiplier, and the gain of the multiplier is about 10 at the 0.01-c. level. It increases to about 100 at a 10-c. level. Thus, the image signal is amplified sufficiently to cause the video signal leaving the tube to be above the noise level before it enters external connecting circuits.

Clearer television images under shifting light conditions may be obtained through the use of the Image Orthicon. Satisfactory pictures have been obtained from scenes illuminated by the light of a candle or match. Its sensitivity through the infrared portion of the light spectrum is such that pictures have been obtained in almost total darkness when the infrared rays were focused upon the scene to be televised. This was accomplished through use of the type 2P23 Image Orthicon tube, which possesses greater infrared sensitivity than certain other types. Today, several commercial varieties of the Image Orthicon have been made available for pickup purposes. The type 2P23 is principally adapted to pickup work outside the studio, whereas the type 5655 has been especially developed for studio pickup indoors. Another Image Orthicon tube, which may be used both indoors and outdoors, is the type 5769.

The type 5820 Image Orthicon tube was recently announced. It is particularly suitable for outdoor or field pickup purposes and is unusually stable in performance at all incident-light levels ranging from bright sunlight (several thousand foot-candles) to a deep shadow (1 ft.-c. or less). Pictures of commercial quality are obtainable at incident-light levels greater than approximately 10 ft.-c. The minimum light level

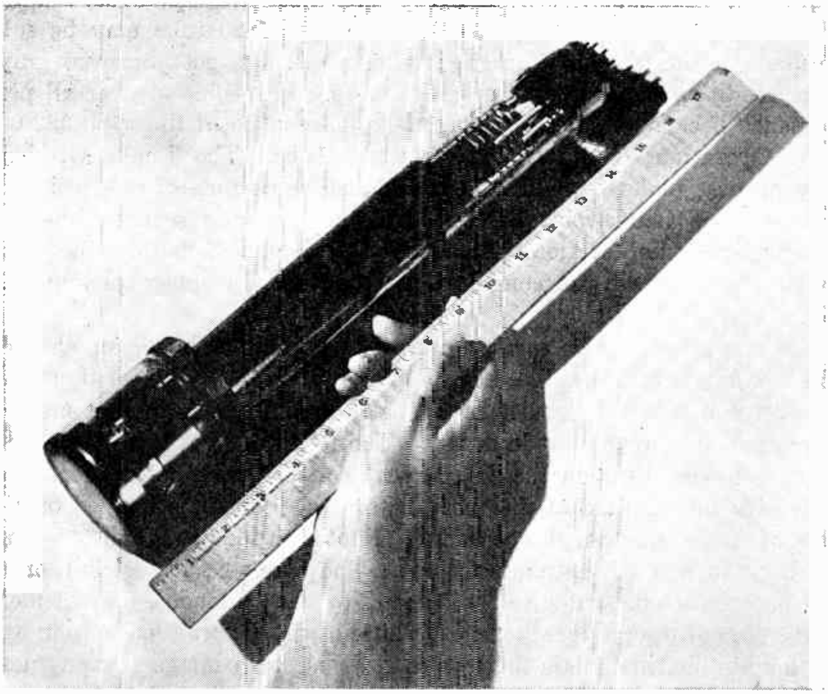


FIG. 4.16 Early commercial version of the Image Orthicon. (Courtesy of Radio Corporation of America, Tube Division.)

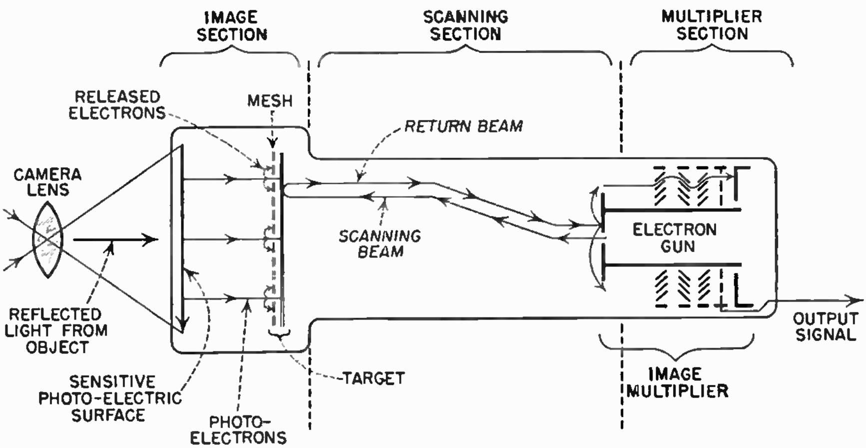


FIG. 4.17 Schematic diagram of the Image Orthicon.

required of this tube is 0.15 of that required for the type 5769, and 0.4 of that required by the type 2P23. The type 5820 tube may be substituted for the type 5655 in the studio in order to get improved gray-scale rendition of color, but not without some sacrifice in over-all performance because of the lower signal-to-noise ratio of the type 5820.

4.18 Operation of the Image Orthicon Tube. The Image Orthicon may be best understood if it is considered to comprise three principal sections: the image-multiplier section, the scanning section, and the electron-multiplier section. All three are combined within the glass envelope to provide the complete electron tube for image pickup (see Fig. 4.18).

The *image-multiplier section* comprises a photocathode, an electron lens system, and a suitable target. The operation of this section is of considerable interest, since it functions in a somewhat different manner from anything previously described. The reflected light from the studio stage is passed through the Image Orthicon camera's optical lens system, with the result that the scene before the camera is imaged on the face of a translucent photocathode. Photoelectrons are emitted from the back surface of the photocathode. The number and distribution of the photoelectrons are directly related to the luminous flux incident at the face of the photocathode. Because of the electron lens action and the longitudinal magnetic field present, an electron image (synonymous with the reflected-light image) obtains at the front surface or face of the target. This target, located just back of the translucent photocathode, is actually a very thin glass plate, in front of which is a screen of fine wire mesh. The mesh for the screen can be made with 1,500 gossamer wires to the linear inch, or 2,250,000 openings to the square inch. It is so fine that an ordinary pinhead will cover 7,000 of the tiny openings. The screen used for commercial purposes is termed "200" and "500 mesh" screen.

The incident photoelectrons are accelerated approximately 400 v. before passing through the fine mesh screen, and secondary electrons are emitted upon their contact with the front surface of the target. The secondary electrons are collected by the mesh and are passed to ground. The result is a charge deficiency on the target which corresponds to the electron emission obtaining at the photocathode of the tube.

A charge pattern several times greater than that at first originating at the photocathode is produced on the target. This amplification is due to the fact that the secondary-emission ratio of the target of the image-multiplier section of the tube is greater than unity. The charge is positive at the points where picture high lights are present in the image.

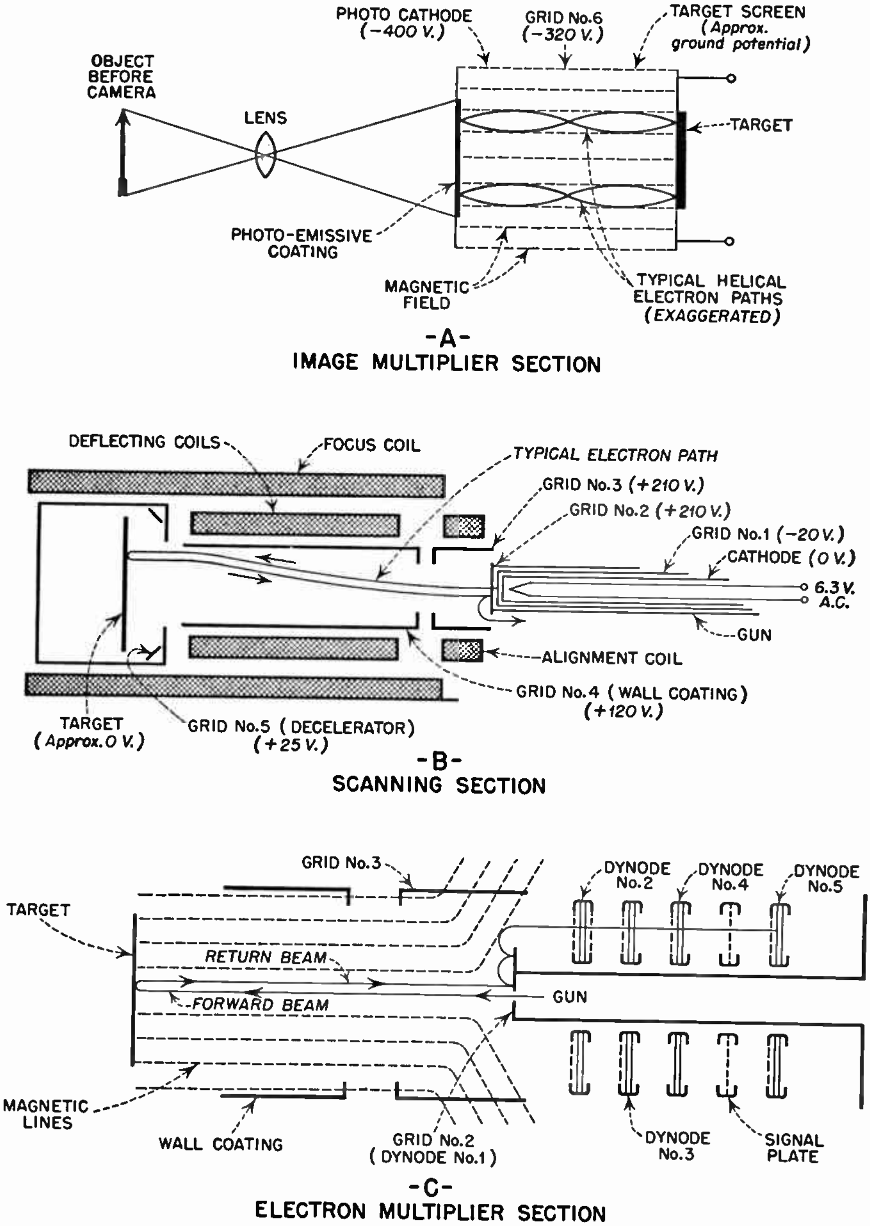


FIG. 4.18 The three important sections of the Image Orthicon tube.

The fine wire mesh screen is utilized for collecting the secondary electrons generated at the surface of the target, thereby preventing their irregular rain and fall back onto the face of the target. The possible development of a spurious shading signal of any consequence is eliminated, and therefore the necessity for special shading circuits at the camera control equipment.

The potential of the wire screen determines the potential of the tube target. When the target potential becomes more positive than the potential present at the mesh screen, the secondary electrons encounter a retarding field which serves to prevent their reaching the screen and obviates the possibility of a further potential rise. The glass target is very thin, and the ratio of its transverse to longitudinal resistivity is therefore sufficiently high, so that the pattern of charge on the face of the target is transmitted to its rear surface without any serious loss of resolution.

The *scanning section* of the tube is also of interest. The electron gun for generation of the required scanning beam is similar to that encountered in other cathode-ray tubes. The potential at grid 2 (G-2) determines the velocity with which the generated electrons are fired by the gun. The potential at grid 1 (G-1) serves to limit the beam current. Grids 2, 4, and 5 (G-2, G-4, and G-5) combine with the longitudinal magnetic focusing field and cause the electron beam to be focused upon the rear surface of the target. Grid 3 (G-3) has negligible effect during the forward travel of the electron beam.

It should be noted here that the scanning section is physically situated to the rear of the image-multiplier section, and that the image-multiplier section is located at the front of the tube. It is important to keep this arrangement in mind as the description continues, so as to coordinate the entire structure.

The target mesh is operated at ground potential, or slightly negative. Therefore, in the absence of a positive charge on the target, electrons will never reach the target of the tube. Instead, they will reverse their direction and return to the electron gun. This return beam eventually determines the character of the output video signal of the tube.

When reflected light from the scene being televised is focused upon the front surface of the photocathode, photoelectrons are emitted. These are accelerated down the tube and finally reach the target. Owing to the characteristic of the target, each photoelectron that impinges at the target causes several secondary electrons to be emitted. These secondary electrons are collected by the mesh screen, as already described. The over-all effect is to leave those portions of the target which correspond to picture high lights at greater positive potential with respect to the mesh than those parts of the target which correspond to darker portions of the original scene. The charge pattern, therefore, corresponding to light and shade in the original scene before the television camera is transferred with inconsequential alteration to the rear of the target. This rear side of the target is the surface that is scanned.

Through proper adjustment of the potential applied to the target mesh, the electron beam arriving from the gun may be compelled to approach the target at such velocity that the major portion of the beam will be repelled by those sections of the target which correspond to black portions of the original scene. The beam will supply electrons to neutralize the charge deficiency at those parts of the target which correspond to whites, or high lights, in the original scene before the camera.

Therefore, as the electron beam is deflected over the target in the scanning process, a portion of the original beam will be reversed in direction and will be accelerated back toward the gun from which it was originally fired. The magnitude of the electron current in the return beam at a given instant will be a function of the charge on the part of the target of the tube that is being scanned at that instant. The current variation in the return beam is such that maximum current relates to the black picture, and the minimum relates to the whites.

Scanning at the Image Orthicon pickup tube is brought about by passing saw-toothed deflection currents through sets of horizontal and vertical deflection coils, which are located within a long focus coil. The latter produces the longitudinal magnetic field in which the scanning and image sections of the tube are immersed. It will be noted that the scanning fields penetrating to the image section would result in distortion of the resulting image. This distortion is the result of displacement of the photoelectrons. A metal shield is placed about the target end of the tube to obviate the possibility of such an occurrence. Eddy-current effects due to the presence of the metal shield reduce the scanning field in the image section of the Image Orthicon tube.

The portion of the target that has just been scanned possesses no remaining charge of a positive character and is in a state identical with a part of the target corresponding to black information in the picture. Thus, it is important that the beam be prevented from striking the target during the horizontal and vertical retrace intervals. The value of the return beam current is related to the magnitude of the luminous flux. Thus, when the target potential is properly adjusted, the pulse introduced into the picture by target blanking produces a definite black-picture reference level.

The third important section of the tube is the *electron-multiplier section.* When the return beam from the target passes the wall coating and enters the influence of grid 3 (G-3), the focus field is fringing. The result is that the beam has a tendency to diverge. It, therefore, comes into actual contact with grid 3, which is also known as the "No. 1 dynode." This dynode surface is coated with a substance that improves its secondary emission characteristic. Thus, each beam electron striking the dynode results in the emission of several secondary electrons.

The secondary electrons find their way into the space separating grid 2 and grid 3. They come within the influence of the accelerating field of the No. 2 dynode, since it is operated at about 500 v. potential. The secondaries pass through a screen into the dynode vanes. The G-3 potential is adjusted for best picture and serves to control electrons falling upon the No. 2 dynode. The vanes of the dynode are flat, radiating from the center of the tube close to the gun structure in wheel fashion. The vanes are inclined 45 deg. with reference to the principal axis of the tube. They are of such physical shape and size that any electron entering the structure on a path perpendicular to its plane must come into contact with one of the vanes, because the arrangement of the vanes along the principal axis of the tube at this point is continuous.

When an electron impinges upon the vane, it brings about additional secondary emission, which produces signal multiplication. Some of the secondary electrons come into contact with the lower surface of an adjacent vane at high velocity, producing added amplification. The secondary electrons are then accelerated to dynode 3, the presence of the screen eliminating the possibility of distortion of the electrostatic field by the vanes.

The process just described keeps repeating in each of the dynode structures, the current being continually multiplied to a greater and greater extent. The final current is passed to a load resistor, and constitutes the output video signal. It is passed to the control grid of the first tube of the video preamplifier. The output current is in the order of a few microamperes, and a black negative picture results at the tube output.

In later chapters (9 and 11) of the text, the operating characteristics of typical Image Orthicon electron tubes for image pickup will be given, as well as practical operating procedures for obtaining the optimum picture under conditions encountered in the field and in the studio.

4.19 The Farnsworth Image Dissector. The Farnsworth Image Dissector is a development of Philo T. Farnsworth. It is an electron tube for image pickup in which electronic scanning is employed and possesses no light-storage characteristic whatsoever. Unlike the Iconoscope, where light storage is responsible in part for the tube sensitivity, the Image Dissector employs a cascaded 11-stage electron multiplier to increase the amplitude of the signal that it delivers to the load circuit. This increased amplitude produces adequate sensitivity for motion-picture film scanning. Photoelectrons from the sensitized cathode are passed through this multistage electron multiplier, having a gain per stage of approximately 3.4 when a potential of 200 v. per stage is applied. Thus, the over-all gain is about 10^6, resulting in output current of 0.1 ma. for those parts of the optical surface illuminated at a light level of 40 ft.-c.

The Dissector is fundamentally a motion-picture film pickup device. It has the advantage of no shading signal, which makes it particularly suited to this application. With motion-picture film being projected many frames per second, it is not possible to shade up a scene properly before transmission. Therefore, the use of a pickup tube that demonstrates no spurious-shading signal results in improved motion-picture film scanning and transmission in television. Also, in televising motion-picture film, the sensitivity to light is not of great advantage in the pickup tube, since the area to be scanned is relatively small, and ample illumination is available at the projection lamp. The Image Dissector has low sensitivity compared with the Iconoscope or Orthicon. Of great advantage in motion-picture film scanning are linearity of response and freedom from spurious-shading signal.

Two sets of standards have been followed by Farnsworth in manufacturing these tubes. Although the standard diameter is 4.5 in. $\pm$ 3⁄16 in., two over-all lengths are available: 9.5 in. $\pm$ ¼ in. or 13 in. $\pm$ ¼ in. Multiplier apertures can be supplied on center or about 1.5 in. off center, so as to remove the multiplier section from the light path of the projector with which it is associated. The tubes have also been made available with spectral response curves of the daylight type with peaks in the green region of the light spectrum, or of the infrared type. The latter tube is peaked at about 8,000 A. Typical response curves are shown in Fig. 4.21.

4.20 Construction and Operation of the Image Dissector. Figure 4.19 illustrates the tube in its present form, and Fig. 4.20 shows a schematic of the structure of the device.

The photosensitized element of this tube is a cup of pure spun silver, having dimensions of 4⅛ in. diameter and a rim that extends at right angles to its plane and in the direction of the opposite end of the tube to a distance of ¾ in. In the construction of this cup, its bottom is first polished to a mirror finish. Then it is etched by raising its temperature in air to approximately 500°C. by means of a hydrogen flame. It is afterward sensitized with caesium, with the result that the finished product appears as a caesium-oxide-silver photosensitized cathode.

This sensitized cathode is physically arranged in a highly evacuated glass envelope of suitable shape so that its photosensitized surface is opposite an optical window at the far end of the tube. The bundle of light rays from the motion-picture projector is admitted through this window and focused upon the sensitized surface of the prepared cathode.

The 11-stage electron multiplier is just inside the optical window. Its position may be clearly seen by examining Fig. 4.19. The aperture

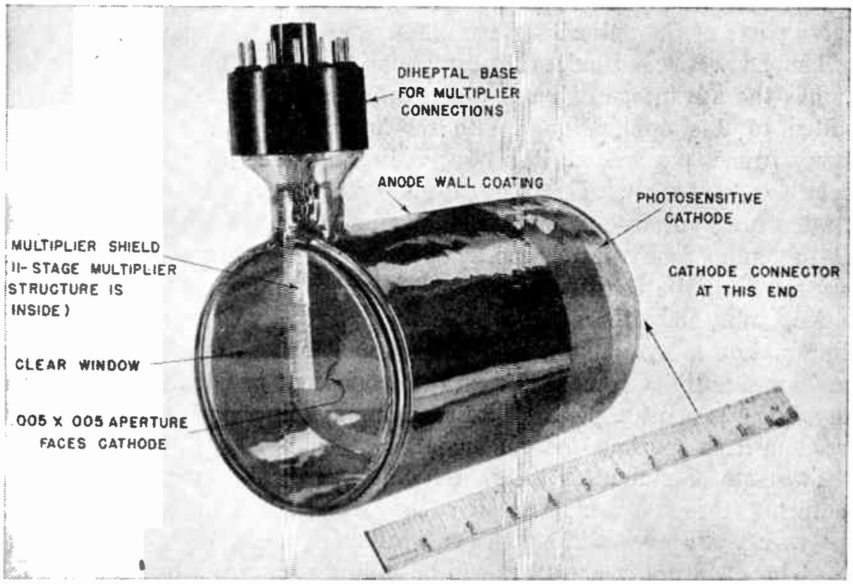


FIG. 4.19 Farnsworth Image Dissector. Location of the photosensitive cathode and the electron multiplier within the large containing glass envelope is indicated. It is an excellent tube for motion-picture film scanning. (Courtesy of Farnsworth Television and Radio Corp.)

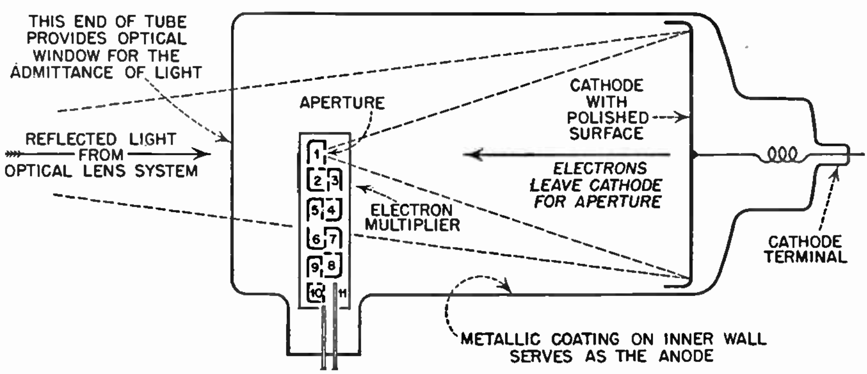


FIG. 4.20 Simplified schematic diagram of the Farnsworth Image Dissector.

of this multiplier is square, with dimensions of approximately 0.005 in. per side for high-definition television work. In the face of the housing, parallel with the cathode and directly in front of the first electron-multiplier stage, is located this square aperture which is die-punched in

0.002 in. nickel foil that covers the entrance of the first multiplier stage. The magnification of the electron image, cathode to aperture, is related to the size of this aperture. Once it leaves the cathode, the electron image diverges and, under influence of the magnetic focusing field, can be enlarged 2.5 times. A longitudinal field parallel to the mean axis of the Dissector focuses the electron image in the plane of the aperture, which is a part of the multiplier. The scanning potentials, which are admitted to horizontal and vertical deflection coils, develop the magnetic fields that bring about deflection of the cathode image across the aperture.

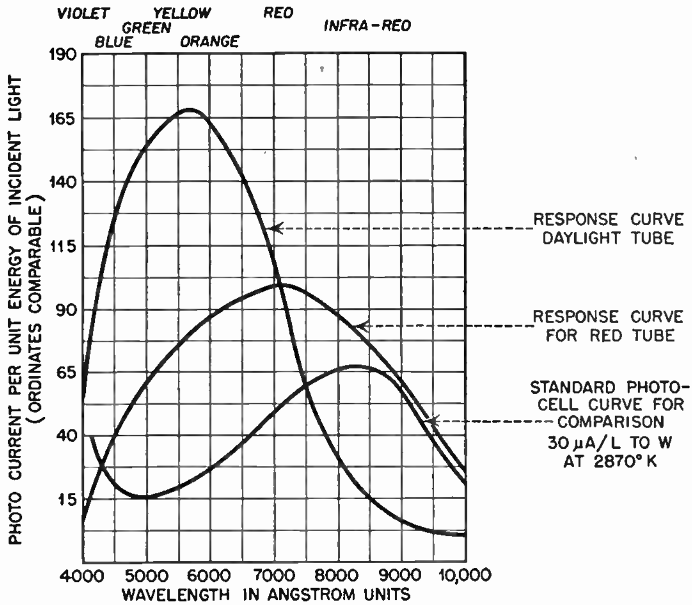


FIG. 4.21 Spectral response curves for Farnsworth Image Dissector.

A centering coil permits positioning of the image. An important point is the fact that the cathode image is deflected across the aperture. By means of these magnetic-deflection fields the entire electron image is made to pass before the aperture in a fixed scanning pattern. Therefore, electrons from every part of the cathode surface are systematically and consecutively collected by the target. In this way the cathode image is dissected. From this characteristic the device gets its name.

The Image Dissector is immersed in a uniform magnetic field developed by a focus coil that completely surrounds the envelope. It is a short-focus coil of the type previously described in the chapter dealing with the cathode-ray tube. Thus, the electrons originating at the cathode of the tube are made to travel to the opposite end of the tube in a pattern in all respects identical to that which obtains at the cathode.

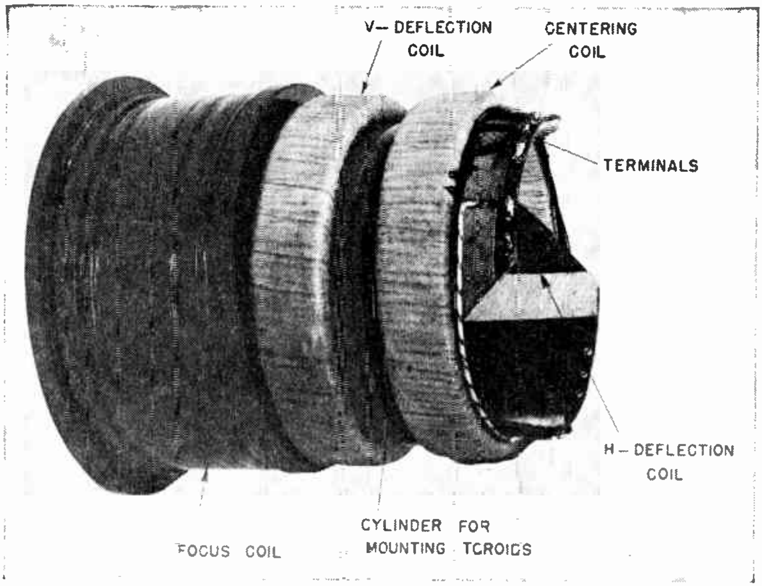


FIG. 4.22 Deflection-coil assembly associated with the Farnsworth Image Dissector. (Courtesy of Farnsworth Television and Radio Corp.)

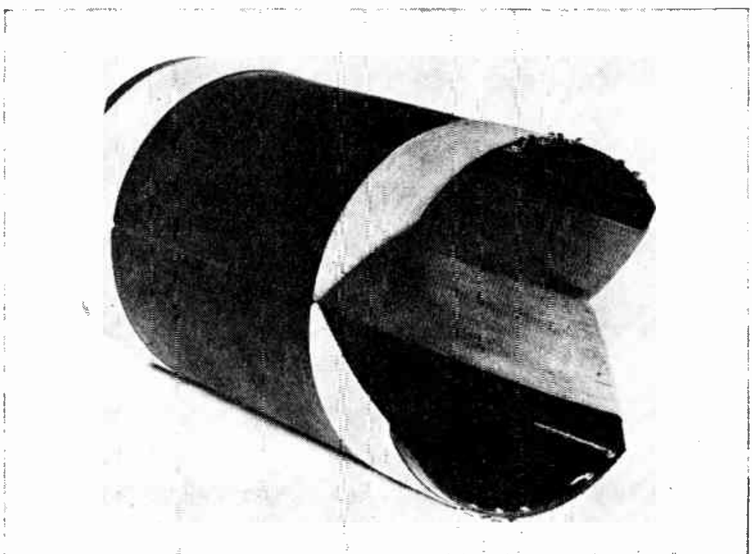


FIG. 4.23 Horizontal deflection coil used with the Farnsworth Image Dissector. The unique construction results in excellent horizontal scanning. (Courtesy of Farnsworth Television and Radio Corp.)

The anode of this pickup tube is in the form of a metallic coating which covers the inner wall of the envelope. It begins 1.5 in. beyond the rim of the cathode and covers the inner walls and the extreme end exclusive of an optical window through which the image is projected. Photoelectrons are emitted by the cathode when bundles of light rays fall upon it. These photoelectrons are accelerated to the previously described anode because of the positive potential applied to it. The potential difference is of such magnitude that it results in saturation current. The illuminated scene projected upon the cathode is electron-imaged upon the anode.

As the extended image is scanned across the aperture, that portion of the extended space current entering the multiplier is proportional at any instant to that part of the extended image current density at which the aperture is looking. The aperture current is proportional to the area of the aperture, the photosensitivity of the cathode, and the amount of light projected upon the cathode surface. The photosensitivity of the device is said to be 20 ma. per lumen, and approximately 10^{-10} amp. enters the aperture at any instant that cathode illumination amounts to 40 ft.-c. of light.

In summarizing, we may say that the aperture of the Image Dissector tube is stationary and the electron image from the sensitized cathode is focused upon the anode end of the tube. When scanning takes place, the electron image is moved or displaced progressively across the window or aperture so that electrons entering the aperture during any time interval represent the emission from a certain part of the illuminated cathode at that same time interval. Magnetostatic deflection is employed. Two pairs of coils, one pair for horizontal and one pair for vertical deflection, are used. A third coil is used for centering or positioning.

No shading is produced in regular motion-picture operation, for which the tube is recommended. In studio pickup work a wide-angle lens must be employed. This results in reflected images from the wall coating of the pickup tube producing optical shading, which is as troublesome as electronic shading in Iconoscope operation. In motion-picture operation, a 1.5- by 2-in. image is projected directly upon the sensitized target surface and no difficulty is experienced. No keystoning is ever required with the Image Dissector, since the axial magnetic field that produces focusing causes all portions of the electron image that depart from the cathode to arrive at the aperture perpendicular to the end of the device. In scanning, the electron image is simply displaced horizontally and vertically in moving it across the aperture, the lengths of the electron paths being practically equivalent for all portions of the image. Normal video output of the tube is about 1 v. with 40 ft.-c. of illumination at the cathode.

When the Image Dissector is used with a still or motion-picture projector, the average illumination recommended is 50 ft.-c. This produces an image relatively free from noise or snow, provided that the infrared components are filtered out. If a Dissector of the red-sensitive type is employed, approximately 20 to 25 ft.-c. of illumination derived from a 2,870-w. source is satisfactory for monochromatic pictures, and infrared filters are not required. The response curves shown are typical of both the daylight and the red sensitive tubes.

It is believed that more extensive use will be made of the Farnsworth Image Dissector in the scanning of motion-picture film, particularly since commercial operation of television stations necessitates a greater ratio of film to live talent telecasts owing to extended schedules of operation.

BIBLIOGRAPHY

1. Zworykin, V. K., "The Iconoscope," *Proc. I.R.E.*, Vol. 22 (January, 1934), pp. 16–32.
2. Farnsworth, P. T., "Television by Electron Image Scanning," *J. Franklin Inst.*, Vol. 218 (October, 1934), pp. 411–444.
3. Zworykin, V. K., "The Iconoscope—A Modern Version of the Electric Eye," *Proc. I.R.E.*, Vol. 22 (January, 1936), pp. 16–32.
4. Krasovsky, V. I., "On Light Storing Devices," *Trans. Illum. Eng. Soc. (N.Y.)*, (February, 1936), pp. 24–34.
5. Zworykin, V. K., "Iconoscopes and Kinescopes in Television," *R.C.A. Review*, July, 1936.
6. Urtel, R., "The Operation of Electron Beam Scanning Devices with Storage," *Z. Hockfreq. Elektroakust*, Vol. 48 (November, 1936), pp. 150–155.
7. McGee, J. D., and H. G. Lubszyuski, "EMI Cathode-Ray Television Tubes," *J. Am. Inst. Elec. Engrs.*, Vol. 84 (April, 1937), pp. 468–475.
8. Iams, H., and A. Rose, "Television Pickup Tubes with Cathode Ray Beams," *Proc. I.R.E.*, Vol. 25 (August, 1937), pp. 1048–1070.
9. Zworykin, V. K., G. A. Morton, and L. E. Flory, "Theory and Performance of the Iconoscope," *Proc. I.R.E.*, Vol. 25 (August, 1937), pp. 1071–1092.
10. Burnett, C. E., "The Monoscope," *R.C.A. Review*, Vol. 2 (April, 1938), pp. 414–420.
11. Heimann, W., and K. Wemheuer, "Operation of the Electron Beam Picture Scanner," *Elek. Nach. Tech.*, Vol. 15 (June, 1938), pp. 1–9.
12. Iams, H., G. A. Morton, and V. K. Zworykin, "The Image Iconoscope," *Proc. I.R.E.*, Vol. 27 (September, 1939), pp. 541–547.
13. Janes, R. B., and W. H. Hickock, "Recent Improvements in the Design and Characteristics of the Iconoscope," *Proc. I.R.E.*, Vol. 27 (September, 1939), pp. 535–540.
14. Rose, A., and H. Iams, "Television Pickup Tubes Using Low-Velocity Electron Beam Scanning," *Proc. I.R.E.*, Vol. 27 (September, 1939), pp. 547–555.

15. ROSE, A., and H. IAMS, "The Orthicon, A Television Pickup Tube," *R.C.A. Review*, October, 1939.
16. ZWORYKIN, V. K., and G. A. MORTON, "Television—The Electronics of Image Transmission," John Wiley & Sons, Inc., New York, 1940.
17. CAWEIN, MADISON, "The Farnsworth Image Dissector," Farnsworth Television and Radio Corporation, Fort Wayne, Ind., 1944.
18. WINNER, LEWIS, "A Report on the Technical Progress at the TBA Conference," *Communications*, January, 1945.
19. "Sensitive Television Camera Tube," *Electronics*, December, 1945, p. 330.
20. WINNER, LEWIS, "Design and Application Features of 5820 Image Orthicon," *Communications*, September, 1949.

REVIEW QUESTIONS

4-1. Describe the operation of the Iconoscope camera tube.

4-2. (a) What is meant by "activation"? (b) Explain why caesium is introduced into the envelope of an Iconoscope during the manufacturing process.

4-3. Name the principal elements of the Iconoscope, and describe the function of each.

4-4. Describe the type 1840 Orthicon in detail.

4-5. Why is the operation of the Iconoscope different from that of the type 1840 Orthicon?

4-6. (a) What are the advantages of using a low-velocity electron beam in camera pickup tubes? (b) What is meant by "secondary emission" in the Iconoscope? (c) What is "shading"?

4-7. (a) Describe the Farnsworth Image Dissector. (b) What are its advantages for use in motion-picture film scanning?

4-8. Give a detailed description of the Image Orthicon, and state its advantages over other types.

4-9. (a) What is meant by "electron multiplier"? (b) Explain the use of the electron multiplier in the Image Orthicon tube.

4-10. Discuss the advantages and disadvantages of the following: (a) Iconoscope; (b) type 1840 Orthicon; (c) Farnsworth Image Dissector; and (d) the Image Orthicon.

4-11. How is the electron beam deflected in the Image Orthicon pickup tube?

4-12. Describe the electron gun of the Iconoscope.

CHAPTER 5

THE SYNCHRONIZING GENERATOR—TIMING, SHAPING, AND DEFLECTION CIRCUITS

5.1 Introduction. The synchronizing generator is the heart of the modern high-definition all-electronic television system. Its purpose is to generate the various synchronizing and blanking or pedestal signals to which the picture signal, already produced and amplified elsewhere in the system, is added, or mixed, to produce a complete, composite TV signal suitable for transmission. Of necessity, the synchronizing generator includes an imposing array of equipment and circuits, all carefully interlocked and timed to satisfy the precise standards promulgated by the Federal Communications Commission.

It is within this unit that the various driving impulses for the television system are generated. In order to trace out a picture line by line at the receiver viewing tube, the electron beam of the cathode-ray tube must be in exact position to sweep out the information contained in each horizontal line. The position of the electron beam at the receiver viewing screen at any given instant is a function of the voltage amplitude along the forward slope of the saw-toothed waveform, since the saw-toothed potential, when applied to the receiver cathode-ray tube deflection system, actually controls the position of the electron beam and the spot at any given instant. The saw-toothed waves providing both horizontal and vertical deflection of the beam at the receiver are produced by the saw-toothed oscillators of the receiver, and the timing of these oscillators is effected by means of synchronizing impulses transmitted as a part of the composite signal radiated by the television transmitter. It is the synchronizing generator which develops the basic signals from which the synchronizing signals are formed. The horizontal positioning of the beam at the television receiver is controlled indirectly by the horizontal synchronizing impulses sent out as a part of the radiated signal, while the vertical positioning of the beam is controlled by the vertical synchronizing impulses. Whichever synchronizing impulse we consider, it functions to trigger off an oscillator in the receiver. This oscillator provides the saw-toothed waveform which, when applied to the receiver cathode-ray tube deflection system, controls the position of the spot along the fluorescent screen of the tube.

The horizontal synchronizing impulse triggers the horizontal oscillator of the receiver and causes the beam to move from the right-hand side of the screen to the left. When the electron beam reaches the left-hand side of the screen, the horizontal oscillator is no longer under control of the horizontal synchronizing impulse, and the forward slope of the saw-toothed waveform of the oscillator is utilized to sweep the beam across the screen from left to right to scan another horizontal line in the picture structure. It should be noted, therefore, that each horizontal synchronizing impulse precedes the tracing out of each horizontal line of picture information and accurately times the start of the scan. A succeeding horizontal synchronizing impulse is transmitted when the electron beam at the television receiver has concluded the scanning of one horizontal line and has reached the right-hand side of the raster.

The F.C.C. has adopted standards that specify a picture structure involving 525 lines per frame, each frame being made up of two fields. Thus, each field includes 262.5 horizontal lines, the two fields being interlaced to construct one 525-line frame. Since 30 frames are transmitted per second, one frame is transmitted in $\frac{1}{30}$ sec. We may conclude that 15,750 horizontal lines of picture information are transmitted per second, and 15,750 horizontal synchronizing impulses are required of the synchronizing generator per second. It follows that the frequency required of the horizontal synchronizing impulse is 15,750 pulses per second (p.p.s.), since one impulse takes control of the receiver horizontal oscillator at the conclusion of each horizontal scan. The horizontal line interval occurs in 63.5 μsec. Expressed as H, this is the time from the start of one line to the start of the next line.

Thus far, we have considered only in a broad manner the horizontal synchronizing impulse required of the synchronizing generator. Other impulses are required to be generated by this unit. The licensing authority has specified interlaced scanning, so that not only are driving impulses at the line frequency (15,750 p.p.s.) required, but also synchronizing impulses at the field frequency of 60 p.p.s. (to produce 60 vertical fields per second). In order to adhere faithfully to the standard set-up, the timing of the vertical scan must, of necessity, be very accurately related to that of the horizontal scan. In order that the two frequencies, line and field, may be precisely maintained, the synchronizing generator, in itself, is a precision device.

The accuracy with which the two frequencies are timed determines whether 60-c.p.s. pickup interference can be made ineffectual. Unless the 60-c.p.s. vertical scanning frequency is perfectly synchronized with the 60-c.p.s. power line that energizes the system, hum developing anywhere in the entire television system will slowly drift vertically across all viewing and monitoring cathode-ray tube screens.

When interlaced scanning is employed in the television system, as is required by present standards, it is extremely important that the return of the beam from the lower edge to the top edge of the picture takes place at exactly the proper instant. To accomplish this a *vertical synchronizing impulse* must be transmitted as well as a *horizontal synchronizing impulse.* Even though the timing has been adjusted for proper interlacing of the two vertical fields (one occurring each $\frac{1}{60}$ sec.), a slight change in relative phase between the line and field frequency will result in two sets of horizontal lines (one set of 262.5 lines for each field) pulling together, or twinning, thus completely destroying the interlace.

In order to eliminate the possibility of hum patterns drifting across viewing screens in the system, brought about by poor synchronization of the line and field frequencies, a common master oscillator provides the basic signal of 31,500 c.p.s., from which the line and field frequencies are derived, and an automatic frequency-control system is employed in the synchronizing generator to maintain the master oscillator in phase at all times with the standard power-line frequency. This frequency-control system also ensures that the horizontal and vertical scanning voltages are harmonically related, and that they are precisely controlled in relative phase position. It has been shown that even a slight shift in timing of the vertical scan by an interval equivalent to 0.5 horizontal line will totally destroy the interlace. The interlace must be maintained so precisely that the maximum unbalance between adjacent horizontal line spacing that may be tolerated must not exceed 40 to 60 per cent. To keep within these limits, timing precision must be held to 0.1 line, or to 1/5,250 line, in a standard 525-line high-definition system.

As has been stated, the vertical synchronizing impulses, which must be transmitted along with the picture signal and other impulses comprising the composite video signal, are employed to time accurately the return of the electron beam from the lower to top edge of the picture at the start of each field. Since with interlaced scanning each field consumes $\frac{1}{60}$ sec. it follows that the frequency with which the vertical synchronizing impulse is transmitted must be 60 times per second. That is, one impulse occurs in the composite signal each $\frac{1}{60}$ sec., and the frequency of the impulse is 60 p.p.s. It should be noted here that the line frequency of 15,750 c.p.s. is far removed from the field frequency of 60 c.p.s. This difference facilitates the separation of the two synchronizing impulses from the composite TV signal at the receiver, so that one pulse may be used to time the horizontal oscillator and the other to time the vertical oscillator. These two oscillators provide the two saw-toothed voltage waveforms required for horizontal and vertical beam deflection at the cathode-ray tube.

The reader should now have a basic knowledge of the horizontal and vertical synchronizing impulses, their relation to each other, and their purpose in the complete television system. A discussion of the *complete composite TV signal*, which includes the synchronizing impulses just described, may now be undertaken. One horizontal line of the television image, together with the blanking voltages and horizontal synchronizing impulses, is shown in Fig. 5.1. It is customary to transmit 25 per cent sync and 75 per cent video in making up the total composite signal amplitude (100 per cent peak to peak). This signal level is maintained by china-marking, or calibrating, the screen of a cathode-ray tube, this tube being operated in a suitable oscillograph, the Y-axis input of which is connected in shunt with the output of the line amplifier of the system.

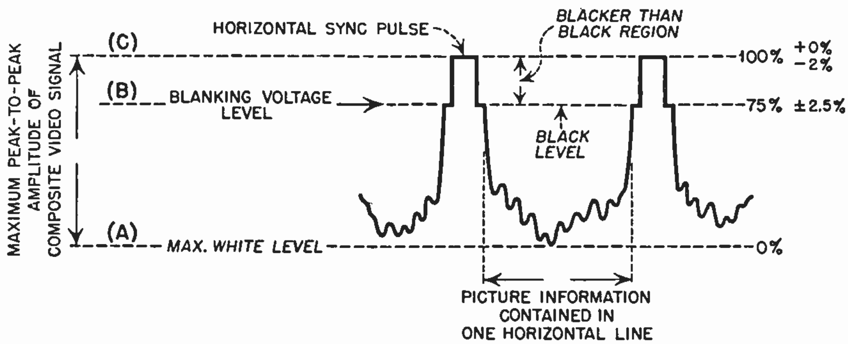


FIG. 5.1 The composite TV signal as interpreted in one line of horizontal picture information, with blanking voltage level and horizontal synchronizing impulses indicated.

In some instances a separate cathode follower is provided at the line-amplifier output. This cathode follower supplies the signal to the oscillograph, since no impedance discontinuity then obtains at the line-amplifier output. The main objective, of course, is the provision of some means of monitoring the signal at the line-amplifier output.

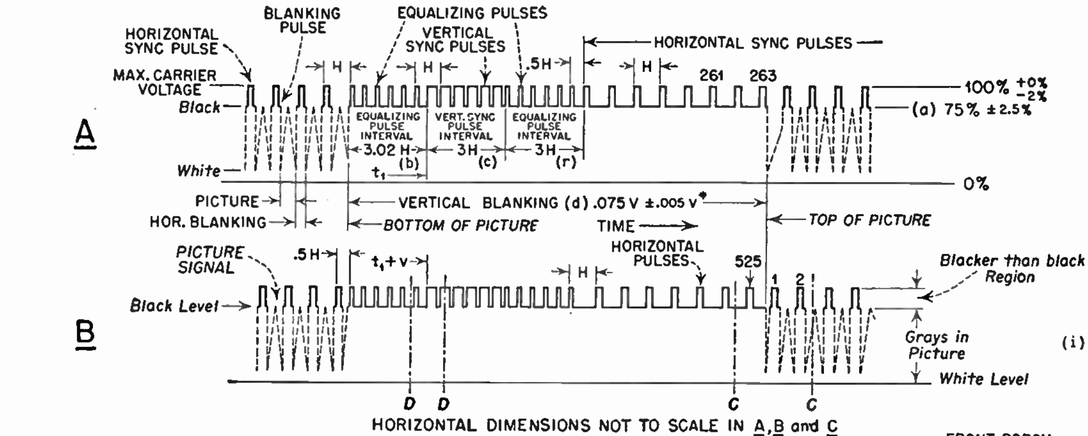
Thus, if 1.5 v. (peak to peak) of composite TV signal are required at the line-amplifier output to drive the transmitter to 100 per cent modulation, then one horizontal line is china-marked across the screen at A and another at C. These two lines thus indicate the maximum signal level (peak to peak) to be tolerated in effecting 100 per cent or complete modulation of the video transmitter. A third line is china-marked across the screen of the cathode-ray tube at B. This line indicates the maximum peak to peak amplitude of the horizontal sync pulse above C which can be tolerated to result in sync occupying 25 per cent of the total peak-to-peak amplitude of the required 1.5-v. composite TV signal. The sync level is adjusted until the horizontal sync pulse just extends from C to B. Of course, this separation must just equal 25 per cent of the total separation between A and C. The video signal, which varies in amplitude as the scene changes, must not be allowed to exceed the china-marked line A. It, therefore, can be held to a maximum of 75 per cent of the total composite signal (peak to peak).

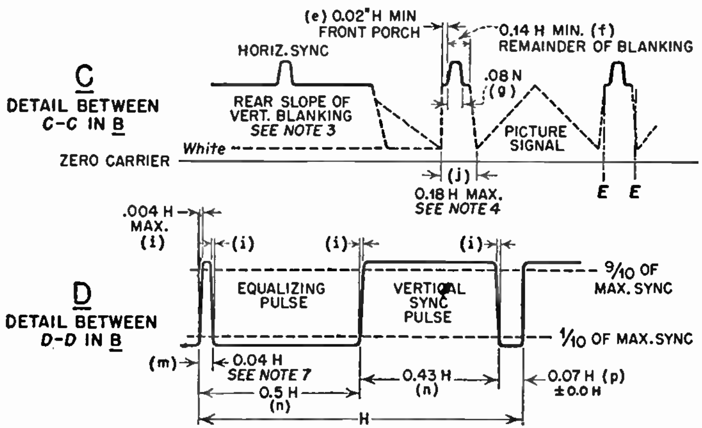
To so monitor the composite signal amplitude at the line-amplifier output, the screen of the oscillograph must be calibrated in terms of peak voltage. On most commercial instruments, a binding post is provided on the front panel from which a standard source of voltage for purposes of calibration may be obtained. A calibrated translucent screen is placed over the face of the cathode-ray tube and the screen calibrated against this reference voltage, which is introduced into the Y-axis input of the oscillograph.

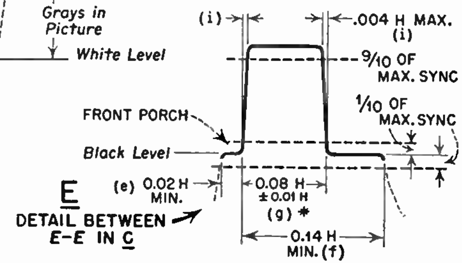
In examining Fig. 5.1, it should be noted that the blanking voltage, which blanks out the return trace of the horizontal saw tooth in receiver scanning, maintains control over the receiver cathode-ray tube grid for a short time interval before and after each synchronizing impulse. This control assures that the return trace of the beam, sweeping the receiver cathode-ray tube screen will be completely invisible to the viewer. It will be seen that as soon as the blanking voltage loses control of the cathode-ray tube grid, the construction of another line of picture information begins. Note that the amplitude of the picture information varies throughout the scanning of one line, which is due to the variation of light and shade in the image reaching the mosaic of the pickup tube in the camera.

Thus far we have discussed the information contained in one line of the television image. When one complete field (262.5 lines) has been scanned, it becomes necessary to transmit a vertical synchronizing impulse for the purpose of deflecting the beam back to the top of the screen once more, so that a succeeding field (60 per second) may be scanned (see Fig. 5.2). Bear in mind that the vertical synchronizing impulse is transmitted only at the conclusion of a field. However, to obviate the possibility of the horizontal generator losing synchronism during the transmission of the vertical impulse, both are transmitted simultaneously during the time of the vertical sync-pulse transmission.

At the lower edge of the field and after the last picture line in the field has been scanned, a long vertical pulse is transmitted. This results in the vertical synchronizing oscillator of the television receiver deflecting the beam to the upper edge of the screen. To prevent the horizontal oscillator at the receiver from losing control of the beam during transmission of the vertical sync impulse, the latter impulse is divided into a train of impulses occurring at shorter intervals of time. This allows both horizontal and vertical sync impulses to be transmitted at one and the same time, the horizontal synchronizing oscillator at the receiver maintaining







FCC STANDARD PICTURE WAVE-FORM

Fig. 5.2

NOTES—

1—H = TIME FROM START OF ONE LINE TO START OF NEXT LINE.

2—V = TIME FROM START OF ONE FIELD TO START OF NEXT FIELD.

3—LEADING AND TRAILING EDGES OF VERTICAL BLANKING SHOULD BE COMPLETE IN LESS THAN 0.1 H.

4—LEADING AND TRAILING SLOPES OF HORIZONTAL BLANKING MUST BE STEEP ENOUGH TO PRESERVE MIN. AND MAX. VALUES (e & f) AND (j) UNDER ALL CONDITIONS OF PICTURE CONTENT.

5—* DIMENSIONS MARKED WITH AN ASTERISK INDICATE THAT TOLERANCES GIVEN ARE PERMITTED ONLY FOR LONG TIME VARIATIONS AND NOT FOR SUCCESSIVE CYCLES.

6—FOR RECEIVER DESIGN, VERTICAL RETRACE SHALL BE COMPLETE IN 0.07 V.

7—EQUALIZING PULSE AREA SHALL BE BETWEEN 0.45 AND 0.5 OF THE AREA OF A HORIZONTAL SYNCH PULSE.

control. The vertical impulse, broken up into smaller intervals, is known as a "serrated" vertical impulse.

The serration of the vertical impulse does not alter the effect of the vertical synchronizing impulse, and the horizontal synchronizing impulses are allowed to be transmitted without interruption, thereby maintaining proper horizontal synchronization at television receivers in the field.

As stated before, the F.C.C. has specified interlaced scanning. Because of this requirement, it becomes necessary to modify the form of the video signal just before transmission of the serrated vertical impulse. It should be noted that the beam must be stopped before completing the 263d line, at one half the traverse across the screen. It is at this point that the vertical synchronizing impulse is transmitted. Thus the beam moves to a position where the scanning of the second field continues line by line until the complete field has been scanned. The beam is returned from the bottom to the top of the raster to begin the scan of another field. Since it is necessary that the vertical pulse be transmitted when a horizontal line is half scanned (for one field), the construction of the video signal must be altered just before transmission of the vertical impulse.

The vertical synchronizing oscillator of the receiver must be actuated by an impulse at the same instant upon the conclusion of each field. Thus, a train of six equalizing impulses are inserted as a part of the composite signal immediately preceding and succeeding the long serrated vertical synchronizing impulses. These equalizing impulses do not affect the operation of the horizontal and vertical synchronizing oscillators of the receiver, but are employed to ensure that the vertical impulse occurs at precisely the same instant at the conclusion of each field.

If the cathode-ray tube monitor is operated at half speed vertically, the monitor being supplied with composite signal, the equalizing impulses preceding and succeeding the long vertical serrated impulses can be seen. Three impulses will be noted immediately preceding and succeeding the vertical impulses, since the monitor screen is driven at half speed vertically (see Fig. 5.3). Of course, the control affecting brilliance of the monitor screen must be so adjusted that blanking is visible. This adjustment provides a convenient method of roughly checking the long serrated vertical and equalizing impulses contained in the complete composite television signal. It must be borne in mind that one vertical synchronizing impulse succeeds each field transmitted, while one horizontal impulse occurs at the conclusion of the scan of one line of picture information.

Thus far, only the function of the synchronizing generator in supplying synchronizing impulses for transmission, particularly as they are employed to hold the receiver in synchronism, has been discussed. The synchronizing generator must also supply impulses for driving the camera chains at the studio, and this function must also be considered by the reader.

The various impulses and waveforms developed by the synchronizing generator must take the form of narrow impulses, the leading and trailing edges of which occupy a definite and fixed part of the standard television signal. This signal is illustrated at Fig. 5.2. The reason for the very

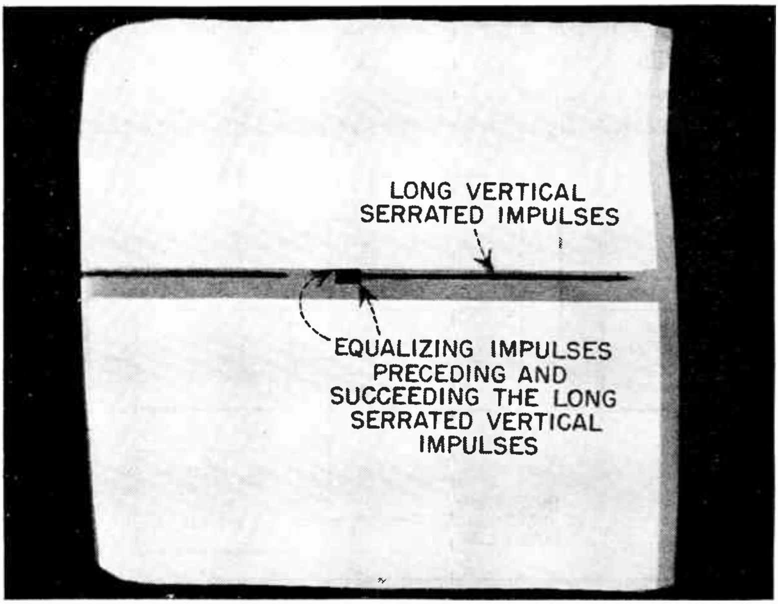


FIG. 5.3

accurate timing of these various impulses lies in the fact that they are generated, for the most part, to drive additional voltage generators throughout the complete system. To develop the standard television signal, all components of which are precisely interrelated, it is at once evident that the timing accuracy of the individual impulses is of paramount importance. The impulses developed by the generator are employed to key special circuits which, in turn, develop saw-toothed deflection, pedestal, blanking, and synchronizing voltages. Each generated voltage must satisfy a special requirement in building up the complete signal required by the F.C.C. standards. The short time interval during which one field or frame is transmitted dictates the use of impulses rather than waves to drive the various circuits, the impulse form of voltage having the required steep leading and trailing edges and consuming time in the order of microseconds.

To grasp the complexities of the synchronizing generator and associated wave-shaping circuits, a general knowledge is required of free-running oscillators, multivibrators, blocking-tube oscillators, counter-type dividing or timing circuits, and a.f.c. systems. To impart such knowledge, each of these circuits and systems will be discussed in some detail before a complete description of the synchronizing generator is undertaken.

5.2 The Frequency-Divider System. The fundamental requirements of a television synchronizing generator are shown in the block schematic in Fig. 5.4. The complete system includes a free-running high-frequency master sine-wave oscillator, a frequency-divider chain, the circuits that generate the various signal components required, and the circuits required

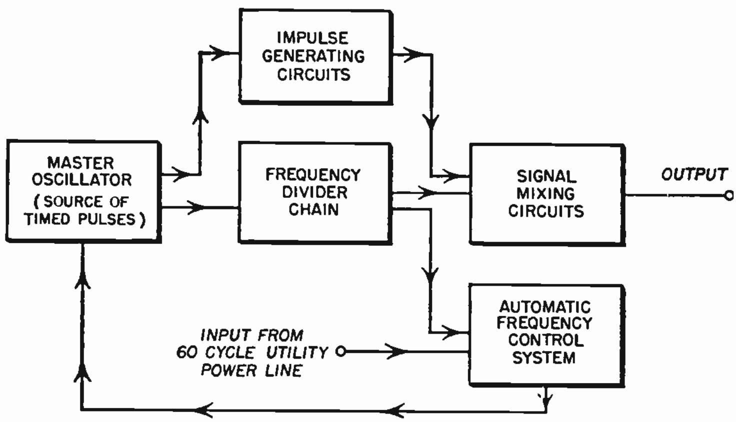


FIG. 5.4 Simplified block schematic of a typical synchronizing generator.

for mixing these components into what is termed the "standard" television signal. It has been stated that the relation between the vertical field and the horizontal line frequencies must be precisely maintained. To make this relationship possible and to ensure that the proper accuracy is maintained, the licensing authority, upon recommendation of those closely identified with the science, has specified a line structure which facilitates frequency-divider design. In other words, the line structure has been so constructed that the master oscillator frequency can be divided by multivibrators, blocking-tube oscillators, or counter-type dividers into impulse voltages possessing the necessary frequencies required in timing and driving the associated wave-shaping, timing, and related generating circuits.

The frequency-division ratio required to relate the vertical scan properly and accurately to the second harmonic of the horizontal scan is always a function of the number of lines. Therefore, for practical

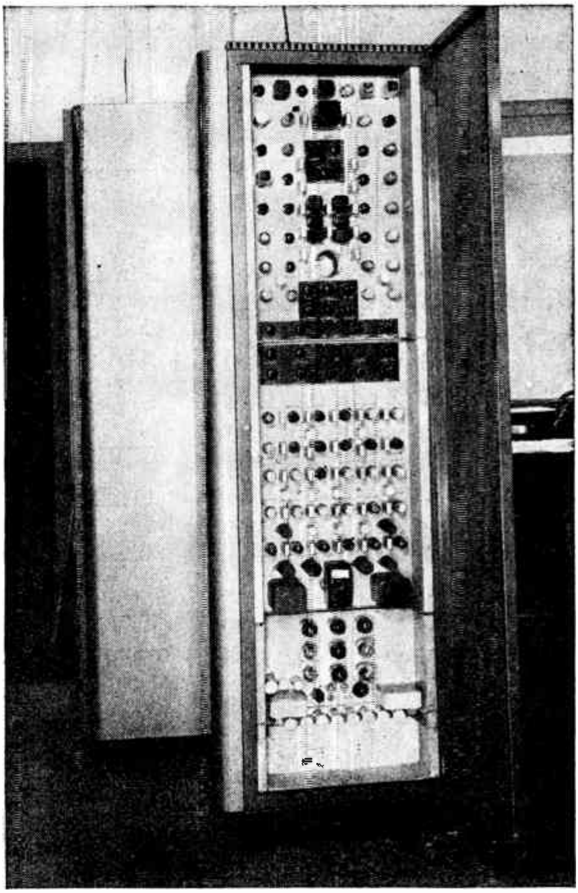


FIG. 5.5 The R.C.A. synchronizing generator (Type TG-1A) shown here is the "Brain Center" of television equipment. The unit supplies the fundamental timing and synchronizing impulses essential for operation of the R.M.A. standard 525-line, 30-frame interlaced television scanning system. The unit is complete with a built-in regulated power supply and is assembled in a standard type rack. It supplies both the television cameras and transmitters with necessary blanking and other signal impulses. The synchronizing generator is also an integral unit of the test equipment used on television receiver and transmitter assembly lines. (Courtesy of R.C.A.-Victor Div., Radio Corporation of America.)

frequency-divider design, the number of lines per frame must be a number which may be easily broken into several small prime factors. The F.C.C.

standard of 525 lines per frame may be broken down as follows:

$$\begin{aligned} 525 &= 7 \times 5 \times 5 \times 3 \\ &= 5 \times 5 \times 7 \times 3 \\ &= 5 \times 3 \times 7 \times 5 \\ &= 7 \times 5 \times 3 \times 5 \\ &= 3 \times 5 \times 5 \times 7, \\ &\quad \text{and so on} \end{aligned}$$

Consequently, any frequency-divider chain will usually comprise four individual dividers, each capable of dividing the master oscillator output frequency by 7, 5, or 3 and in one of the factoring arrangements shown above, so that the master oscillator frequency is eventually brought down to 60 c.p.s., the utility power-line frequency. For convenience, and for other reasons just stated, the master oscillator frequency is standardized at 31,500 c.p.s. Multiplying the number of lines per frame by the number of frames per second and by the interlace ratio yields this value. Thus, $525 \times 30 \times 2 = 31{,}500$.

Therefore, if 31,500 c.p.s. is divided by 7, by 5, by 5, and then by 3, the result is 60 c.p.s. Dividing the master oscillator frequency by 2 results in the line frequency; i.e., $31{,}500 \div 2$ equals 15,750. This is the frequency at which the horizontal scan takes place. From this discussion it may be seen how interrelated and how interdependent the complete system is.

Actually, there are two reasons why the frequency of 31,500 c.p.s. has been chosen as the master oscillator frequency in the synchronizing generator. One reason is the necessity for providing 31,500-c.p.s. signal components in the synchronizing signal. These are the equalizing impulses (already described) and are usually provided by the master oscillator through a multivibrator. Also, vertical synchronizing blocks at this frequency are required and are timed by the equalizing impulses. The choice of the 31,500-c.p.s. standard master oscillator frequency is also dictated by the whole-number-plus-one-half relationship between the horizontal and vertical scanning frequencies. The frequency of 15,750 c.p.s. cannot be readily factored or divided down to 60 c.p.s. because of the one half factor. On the other hand, the chosen frequency of 31,500 c.p.s. can be readily factored down to 60 c.p.s., since it bears a simple whole-number relationship to the field or vertical scanning frequency of 60 c.p.s., which, in turn, is equivalent to the power-line frequency common to both television transmitter and receiver.

In order to link the vertical scanning frequency to the second harmonic of the horizontal scanning frequency, the frequency-divider chain becomes a very important part of the synchronizing generator. To achieve this necessary frequency division, several types of circuits may be utilized to provide the four links in the frequency-divider chain. These may be multivibrators of several types, blocking-tube oscillators, or counter circuits. All are in practical use.

5.3 The Multivibrator. Essentially, the multivibrator is a type of relaxation oscillator. It comprises two RC-coupled amplifier stages in cascade, the output of the second stage being fed back to the input of the first stage to produce the oscillations. There are many types of multivibrators in general use today, the type selected depending upon the application. They all fall into two general classifications, those designated as "free running oscillators" and those described as "driven oscillators," the latter having its operation as well as its frequency controlled by a synchronizing or triggering impulse applied from some source external to the multivibrator circuit. This latter type is the one of principal concern in television.

The frequency of oscillation of the multivibrator is a function of the time constants of the coupling networks, the characteristics of the tubes employed in the circuit, the power-supply voltage, plate resistance, and the amplitude of the driving voltage impulse in the case of the driven type of multivibrator. The output of the multivibrator is practically rectangular in shape, owing to the fact that the output is rich in harmonic content, and is responsible for the almost vertical waveform of the output voltage. A wide frequency range is possible with standard circuits. This range, with careful design, may be made to extend from 1 c.p.m. to well above 100 kc. per sec. The stability of the multivibrator is such that its use as a frequency divider for factors in excess of 3 : 1 has been discouraged. For this reason, counter circuit timers and blocking-tube oscillators are more applicable for frequency-division purposes in television systems, since divisions in the order of 7 : 1 and 5 : 1 are required. These division ratios are too great for the conventional multivibrator to handle, though it is common to find multivibrators yielding excellent service throughout the television system where a 2 : 1 division is required.

Various methods have been devised to increase the degree of stability. Stable types of multivibrators will be encountered in the text as the more complex circuits in the system are discussed.

5.4 Eccles-Jordan Flip-Flop Circuit. To understand more thoroughly the operation of the multivibrator, the reader should first familiarize himself with the Eccles-Jordan trigger circuit, developed by W. H. Eccles and F. W. Jordan. The inherent operation of this circuit is such that a first insight into its performance allows a clearer conception of multivibrator operation. The circuit is similar to that of a multivibrator, except that it has two stable limiting conditions instead of two unstable limiting conditions as are found in the conventional free-running multivibrator, and it cannot be considered essentially as an oscillator. It is a convenient circuit by means of which to explain the trigger action, that action employed in synchronizing the multivibrator or other frequency-divider circuit. It will be noted in Fig. 5.6 that direct coupling is commonly employed between the plates and control grids of the two tubes employed in the circuit.

The circuit demonstrates two conditions of stable equilibrium. One such condition obtains when the first tube is conducting, the second tube being at cutoff. The other condition obtains when the second tube is conducting, the first tube being at cutoff. One or the other of these two conditions is maintained, with no variations in plate, grid, or cathode

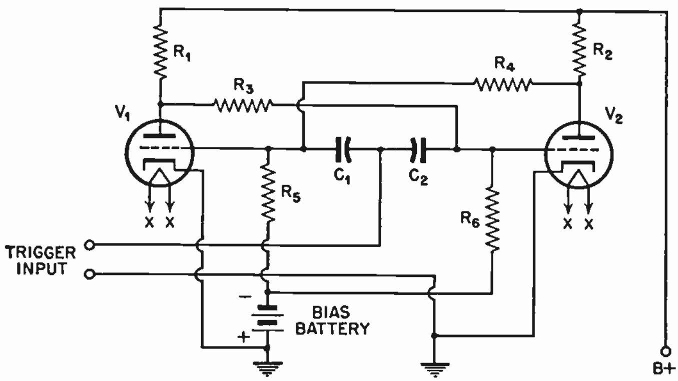


FIG. 5.6 Eccles-Jordan "flip-flop" circuit.

potentials or plate current, until some action is introduced that compels the nonconducting tube to conduct. When this action occurs, the tubes reverse their operation and the operation remains altered so long as no plate current flows in the tube that is cut off.

The instantaneous change from one state of equilibrium to the other has resulted in the circuit being described as the Eccles-Jordan "flip-flop," or trigger, circuit.

To understand the operation of this trigger circuit, let us consider the action that takes place when positive plate potential is instantaneously and simultaneously applied to both V_1 and V_2 (see Fig. 5.6). Assuming that both tubes possess identical characteristics and that all circuit elements are identical as well, the current flowing in each plate circuit would be of equivalent amplitude. This condition, however, could be only theoretical, since a perfect balance of tube characteristics is hardly conceivable. Owing to the dissimilarity of the two tubes and the circuits, one tube would most assuredly begin to conduct current an instant before the second tube. For purposes of circuit analysis it may be assumed that V_1 conducts before V_2, and that the conduction is heavier.

The vacuum tube V_1 will pass greater current than V_2 when conduction occurs, resulting in the IR drop across the plate resistor R_1 being of greater magnitude than the drop across R_2, the plate resistor associated with V_2. Because of the greater drop across R_1, the voltage actually obtaining at the plate of V_1 will be less than that which occurs at the plate of V_2. This reduced plate voltage is transferred to the control grid of V_2 through R_3, the coupling resistor. There is a further reduction in plate current through the second tube V_2, due to this negative-going reduction of grid potential; i.e., the positive voltage from the plate of V_1 through R_3, when combined with the negative bias voltage at the control grid of V_2, serves to decrease the negative voltage at the grid of this tube. The reduction in plate current at V_2 results in increased plate voltage at V_2. This voltage is passed, in turn, to the control grid of V_1 through the coupling resistance R_4. Because of the positive voltage added to the grid of V_1, additional plate current flows in the plate circuit of V_1, thereby further reducing the voltage at the plate of the tube. The action builds up, and the resulting amplitude of voltage across V_1 is eventually much less than the bias voltage E_c. At this moment, the potential across R_6 is made greatly negative, enough to cut off V_2.

When this condition obtains, the circuit arrives at a state of equilibrium, V_2 being cut off, while V_1 conducts heavily. The circuit will remain in this condition until a trigger voltage is applied at the trigger input terminals, the application of which will result in the nonconducting tube V_2 being made to conduct.

A positive impulse from some outside source may be injected to the grids of both V_1 and V_2 through capacitors C_1 and C_2. As V_1 is already passing a heavy current, the positive impulse on its grid will have negligible effect on the flow of current through the tube. Such is not the case at V_2. This tube is operating at cutoff. If the positive impulse reaching its grid is of sufficient magnitude, it will instantaneously remove the high negative bias. The result is current flow in its plate circuit, and the rise in plate current causes a reduction in plate voltage. The reduction in plate voltage is applied to the grid of V_1 through R_4. The amplitude of plate current through the plate resistor R_1 decreases, and the plate voltage increases accordingly. The increased plate potential reaches the control grid of V_2 through R_3, which serves to increase the plate current further. It will be seen that the action is now the opposite to that originally existing. The action continues until V_2 is conducting a heavy current and V_1 is again cut off. The flopping from one state of equilibrium to another takes place almost instantaneously. The transfer is extremely rapid.

From the foregoing discussion it is seen that the introduction of external positive impulses reverses the tubes by forcing the nonconducting tube to conduct. Introduction of a negative triggering impulse will act on the conducting tube to cause an instantaneous reduction in plate current and a consequent rise in plate voltage. This increase is transferred to the cutoff tube, bringing about a flow of plate current in its plate circuit, which starts the action discussed above. In either case, whether a positive or a negative impulse is introduced, one alternation occurs for each trigger impulse. Two impulses must be introduced to bring about a complete cycle. The circuit has been modified, however, so that a single impulse will bring about a complete cycle.

5.5 The Modified Eccles-Jordan Multivibrator. A single positive impulse is introduced into the modified Eccles-Jordan Multivibrator of Fig. 5.7 to result in a complete cycle. The waveforms throughout the circuit are also shown for clarity. Essentially, this multivibrator com-

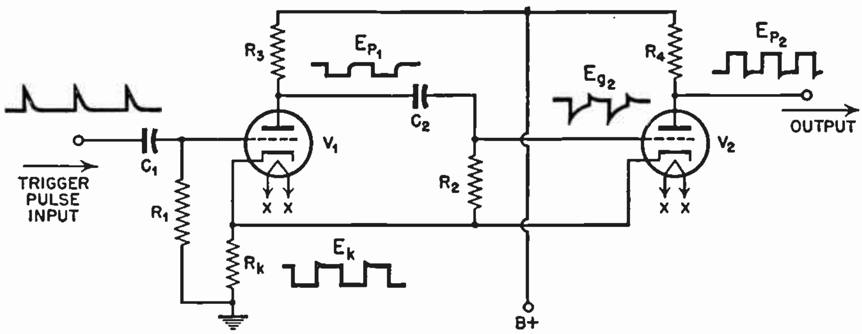


FIG. 5.7 Modified Eccles-Jordan multivibrator circuit.

prises a two-stage *RC*-coupled amplifier with one tube biased to cutoff, the other tube conducting. Biasing of the two tubes is responsible for the balanced-circuit condition. The control grid of the second tube V_2 is connected to its cathode by virtue of R_2 in the circuit. There is no current flow through R_2, so the grid bias at V_2 is normally at zero potential. Owing to the circuit arrangement, it will be seen that the plate current of V_2 must flow through the cathode resistor R_K at V_1. The plate-current flow through R_K results in V_1 being biased to cutoff. When V_2 is not conducting, it is impossible to cut off V_1 because of the self-bias developed across R_K.

The operation of the circuit is quite simple. The vacuum tube V_1 is cut off by the *IR* drop across the cathode resistance R_K, the current flowing through this resistance being due to the plate current I_p of V_2. The second tube V_2 is heavily conducting since its grid is at cathode potential. When the first positive impulse is admitted through C_1, it has sufficient magnitude to increase the grid of V_1 beyond cutoff. It is fed to the control grid of V_1. Upon application of the positive impulse, V_1 begins to conduct, while the voltage at its plate decreases. The reduction in plate voltage passes through C_2, since the voltage across C_2 cannot be changed instantaneously, and appears at the grid of V_2 as a negative voltage. This results, in turn, in the plate current of V_2 decreasing. Accordingly, the voltage across R_K suffers a reduction, since this voltage drop is equivalent to I_pR_K, and more current flows through V_1, owing to the decreased bias. As a result, the plate

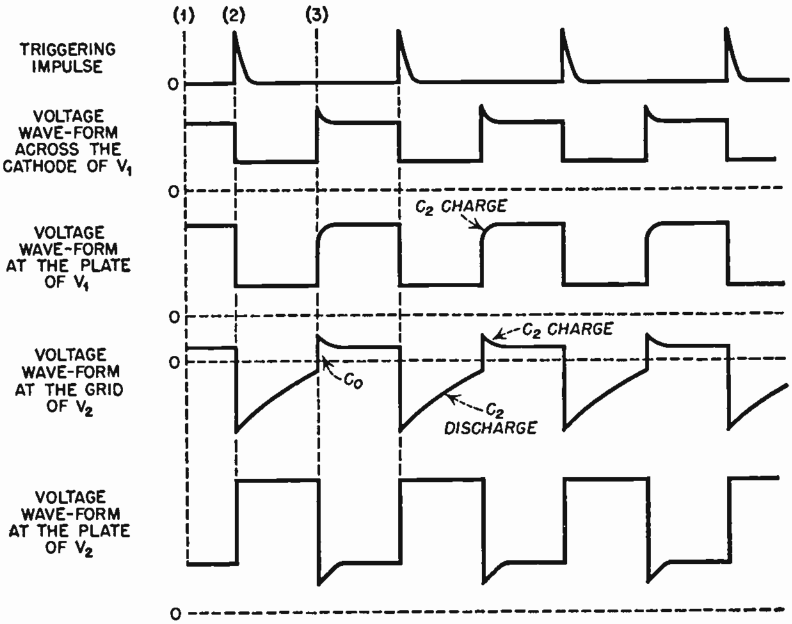


FIG. 5.8 Waveforms present in the one-shot multivibrator.

current at V_1 suffers a further reduction, and in turn, the grid of V_2 becomes more negative. This train of action is repeated until V_2 is completely cut off while V_1 is conducting, although the entire cycle is so rapid as to prove almost instantaneous.

The vacuum tube V_1 continues to conduct, and V_2 is operated at cutoff during the time interval 2–3 in Fig. 5.8. The capacitor C_2, which serves as a coupling capacitor between the two tubes, discharges enough in the direction of the reduced value of plate voltage of V_1 to permit the control grid of V_1 to increase from its most negative value of grid voltage. When this condition obtains, V_2 begins to conduct (3) (Fig. 5.8), the plate current of V_2 increases the drop across the cathode resistor R_K, thereby reducing the plate current of V_1. The plate voltage of V_1 increases as a result of the reduced plate current. The increase in plate voltage is coupled to the grid of V_2, which serves to increase further the plate current of V_2. The action just described is repeated until V_1 is cut off while V_2 is heavily conducting. The circuit is once more in its state of equilibrium and will so operate until the next impulse arrives to result in V_1 conducting once more.

This multivibrator circuit operates so that each positive trigger impulse that is fed into the input circuit results in a large positive-impulse output from the plate circuit of the second tube. The time duration of the positive-impulse output, or the width of the top of the impulse, is principally determined by the time constant developed by the product of C_2R_2. The larger the values are made and, hence, the greater the product, the greater the length of the positive-impulse output. A positive-impulse output is generated for each positive input-trigger impulse, regardless of the frequency of occurrence. This discussion should afford some idea of how impulses, which are applied to the multivibrator as triggering impulses, result in the production of impulses at the output circuit. An understanding of the operation of such a circuit is essential

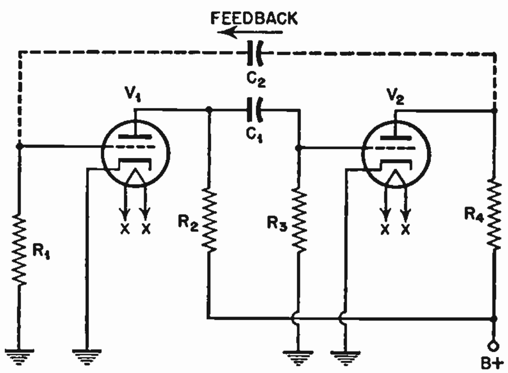


FIG. 5.9 Basic circuit-free running multivibrator.

in acquiring a knowledge of the more complex frequency-divider circuits employed in the synchronizing generator of the television system.

5.6 Plate-Coupled Multivibrator. The multivibrator illustrated in Fig. 5.9 is of the free-running type. When the circuit is analyzed, it will be found that it too comprises a two-stage RC-coupled amplifier, the output being coupled back to the input or to the control grid of the first tube by means of a coupling capacitance. Oscillations take place since the output voltage is in phase with the input; i.e., if we consider the voltage at the grid of the first tube as negative, then it is positive at the plate of the first tube, positive at the grid of the second stage, and negative at the plate or output of the second stage. Actually, the circuit indicates a two-stage RC-coupled amplifier with feedback from output to input, C_2 representing the feedback capacitance in the circuit arrangement.

Figure 5.10 indicates a basic multivibrator circuit with sine-wave synchronizing voltage applied to the grid. The frequency of the multivibrator in television applications is always controlled by a driving impulse, the frequency of which is an even or odd multiple of the frequency desired at the multivibrator output except in special cases. Application of the synchronizing voltage to the grid results in this voltage adding to the normal grid voltage. Without the synchronizing voltage the multivibrator would be classified as "free-running." The waveform is that shown at 1–2 in Fig. 5.10. The synchronizing signal is admitted just before time (2), but, because of grid limiting, it is ineffective until V_1 cuts off at (2). Between (3) and (4) the synchronizing frequency is greater than the natural frequency of the multivibrator, and the distorted curve achieves cutoff more rapidly than curve (5–6).

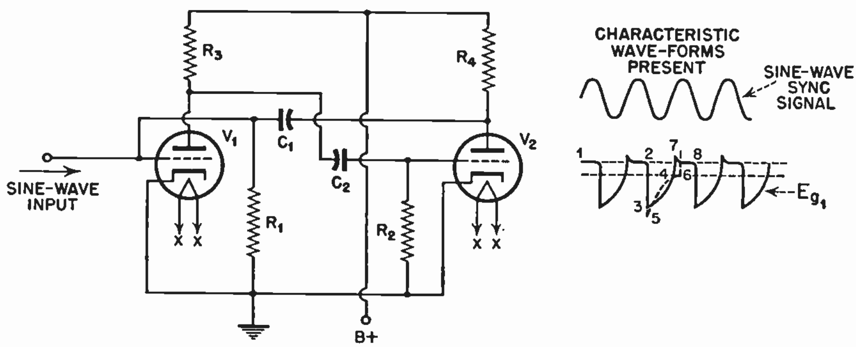


Fig. 5.10 Simple multivibrator synchronized with sine-wave signal.

Grid limiting takes place when V_1 is conducting during the interval of time shown between (7) and (8). The synchronizing voltage is thus prevented from adding to the grid voltage. As the synchronizing impulse voltage decreases below zero voltage and starts to lower the voltage on the grid, the multivibrator regenerative action promptly cuts off V_1. This action occurs at (8) at the identical instant during each cycle of synchronizing signal, and the multivibrator is thus forced to operate at the synchronizing frequency. This action takes place only when the frequency of the synchronizing impulse is greater than the natural frequency of the multivibrator. Multivibrators are more satisfactorily synchronized by the use of short positive or negative trigger impulses. In television the multivibrator may be synchronized to a submultiple of the frequency of the trigger impulse in frequency-divider design. If the multivibrator is assumed to divide by five, then every fifth triggering impulse may be made to switch the multivibrator. Hence, the repetition frequency of the multivibrator is made one fifth of the triggering impulse, and the frequency of the multivibrator can be precisely controlled by a higher frequency that is some multiple of the controlled frequency. Thus, some standard frequency can lock into step a submultiple frequency. In the circuit shown in Fig. 5.11, the synchronizing voltage is applied to the cathode.

The frequency of operation of a conventional multivibrator is largely

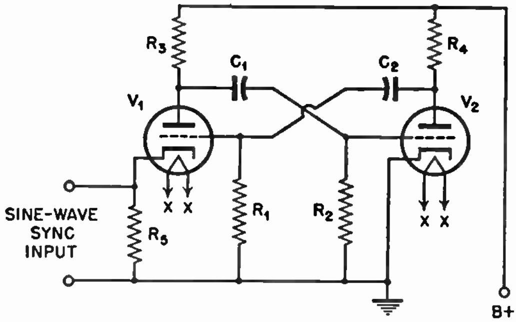


FIG. 5.11 Multivibrator in which the sine-wave synchronizing voltage is applied to the cathode.

a function of the circuit constants, it being assured that the plate potential is maintained constant. In the circuit shown in Fig. 5.12, the frequency is roughly determined by the values chosen for the components

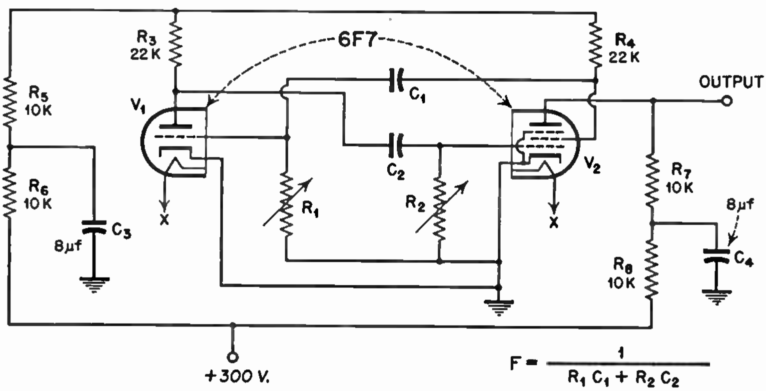


FIG. 5.12 Simple multivibrator circuit.

R_1C_1 and R_2C_2. The operating frequency is determined by the equation

$$F = \frac{1}{R_1C_1 + R_2C_2}$$

where R is in ohms and C in farads.

In commercial design, both R_1 and R_2 are made variable. This condition permits accurate adjustment to the precise desired frequency and affords some compensation for changes in the capacitance of C_1C_2. Under operating conditions it is sometimes found that ambient gradient will affect the values of the circuit constants, and this possibility must be taken into consideration by the design engineer.

5.7 The Blocking-Tube Oscillator. Although the multivibrator will be found in use as a frequency-dividing device in a number of frequency-divider circuits of standard television synchronizing generators, its inherent instability is such that the blocking-tube oscillator and counter circuit timer have almost entirely replaced it, except in instances where a frequency division of not more than 2 : 1 is desired. One such application is where the sine-wave output of the master oscillator is made to trigger a multivibrator affording 2 : 1 division, the pulse type of output providing 15,750 impulses at the line frequency for driving a horizontal scanning generator.

The blocking-tube oscillator is a much more satisfactory type of circuit, primarily because of the substitution of a stable transformer for

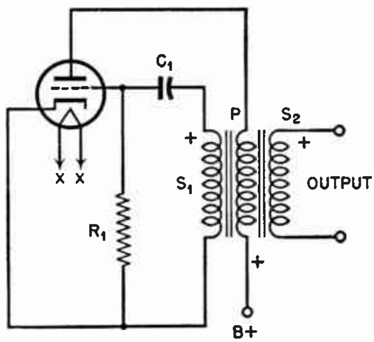


FIG. 5.13 Fundamental circuit of a blocking-tube oscillator.

one of the tubes employed in the multivibrator. While demonstrating increased stability, it too is subject to some frequency variation with respect to changes in power-supply potential, with changes in the amplitude of the pulses driving it, and the circuit is dependent to a great extent upon the characteristics of the vacuum tubes employed in the circuit. This condition is apparent to the engineer who has discovered that the failure of a tube in the circuit requires readjustment of the circuit when a replacement tube is installed. It is very important that the power supply that provides d-c plate potential to the blocking-tube oscillator be of the regulated type, and the amplitude of the triggering impulse must be held closely to the required amplitude.

The blocking-tube oscillator is a device that operates to cut itself off after one or more cycles because of the accumulation of a negative charge on the capacitor in series with the control grid of the vacuum tube employed. The basic circuit of a single-swing blocking-tube oscillator is shown in Fig. 5.13. In any oscillator in which the grid swings positive, electrons are attracted toward the grid. They accumulate on the plate or conducting surface of the grid capacitor nearest the control grid. The electrons cannot return to the cathode through the tube, but must choose a path through the grid-leak resistor. The electrons will accumulate at the grid capacitor faster than the grid resistor will permit them to return to the cathode, provided that the grid resistor is of large value. Therefore, a negative charge accumulates at the grid which can bias the tube to plate current cutoff if the grid swing is high enough. Once the tube is cut off, it permits no additional electrons to reach the grid capacitor. When cutoff occurs, however, accumulated electrons at the grid capacitor continue to flow through the grid leak, reducing the negative grid potential. This results in the tube again conducting. The product of C_1 and R_1 determines the rate at which the operation occurs, i.e., the time constant of the grid circuit. Therefore, the greater R_1 or C_1 is made, the greater the time duration of one cycle of operation (see Fig. 5.13).

There are two general types of blocking-tube oscillators. One type is known as the "single-swing" blocking-tube oscillator, the second as a "self-pulsing" blocking-tube oscillator. In the first type, the tube reaches cutoff before the completion of one cycle of operation. In the self-pulsing type each cycle of oscillation results in the grid becoming progressively more negative until a point of operation is obtained where the tube is biased to plate-current cutoff.

The wave shape developed by the blocking-tube oscillator is principally a function of the transformer design. Leakage inductance and tightness of coupling are responsible for rise and decay time. In order to ensure tight coupling, the only separation allowed between windings is that due to the insulation about the wire itself of which the coils are formed. In some instances primary and secondary turns are interlaced, so that they both comprise a single winding. Blocking-oscillator transformers have a turns ratio which is step-up into the grid circuit. This permits sufficient grid drive and reduces plate overshoot.

It is desirable that the transformer Q (X_L/R) be kept low to reduce the possibility of oscillation developing because of overshoot. Low Q is sometimes obtained through the use of resistance damping; i.e., a resistor is placed in shunt with the winding to increase the ratio r/X_L. In conventional blocking tube oscillator design, a core material of very high permeability is made use of, and laminations are held to approximately 2.5 mils thickness. A layer of varnish insulation between adjacent laminations serves to increase the permeability.

5.8 The Blocking-Tube Oscillator with Resonant Stabilizer. In order to increase the frequency stability of the blocking-tube oscillator, when employed in the frequency-divider chain of a television synchronizing generator, a resonant stabilizer is sometimes connected in series with the oscillator grid circuit, as shown in Fig. 5.14. This resonant stabilizer is, in effect, a parallel resonant circuit and results in frequency division being determined by the resonant frequency of the tuned circuit.

Shock excitation of the resonant stabilizer is obtained by the impulse of grid current that passes through the tuned circuit during the positive grid portion of each cycle. The potential developed across the resonant stabilizer is a damped transient oscillation, the period of which is a function of the tuning of the parallel resonant circuit added. Each time a pulse of oscillator-grid current flows, a transient voltage is developed across the resonant stabilizer-tuned circuit. This potential adds to the exponential capacitor-discharge voltage and to the series of

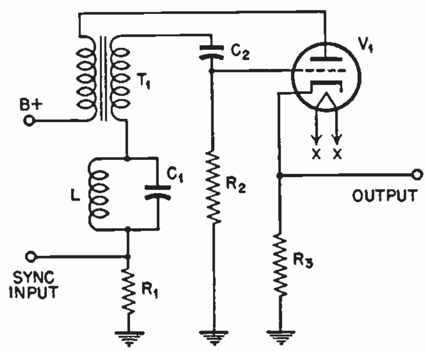


FIG. 5.14 Blocking-tube oscillator employing resonant stabilizer.

driving impulses to produce the composite oscillator-grid signal. The stabilizer LC circuit is adjusted to about 1.5 times the frequency desired at the blocking-tube oscillator output. When the resonant stabilizer is tuned to this frequency, the transient oscillation will extend the desired driving pulse to a greater amplitude than others, resulting in synchronization of the blocking-tube oscillator on the driving impulse that is sought. Furthermore, the oscillator will synchronize on this impulse regardless of variation in power-supply potential, the amplitude of the driving pulses, or variations in tube characteristics.

It has been shown that the amplitude of the stabilizing signal is a function of the magnitude and waveform of the grid-current impulse providing excitation, as well as by the $Q(\omega L/R)$ and R/C ratio of the stabilizer. In practice, the Q of the stabilizer circuit should be made as high as possible. The final magnitude of the stabilizing signal is set by adjustment of the R/C ratio.

Two frequency-divider chains employing stabilized blocking-tube oscillators are shown in Figs. 5.15 and 5.16. This modification of the conventional type of circuit results in a stable divider that may be used successfully in the frequency-divider chain of the television synchronizing generator. It possesses none of the limitations previously described as inherent in the ordinary circuit arrangement used in the past.

The cathode-stabilized blocking-tube oscillator (Fig. 5.17) is sometimes employed in commercial equipment to ensure greater stability of

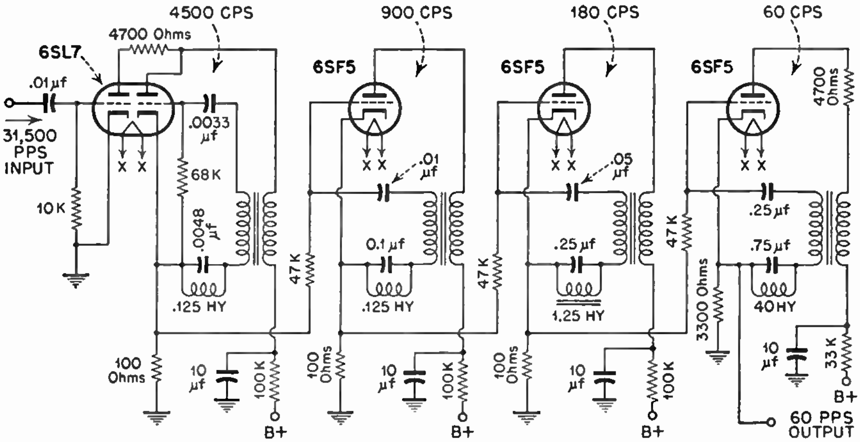


FIG. 5.15 Frequency-divider chain employing stabilized blocking-tube oscillators.

operation. When this oscillator is fired, a surge of current flows through the cathode circuit, which is tuned to a frequency one half that of the trigger repetition rate. This brings about a "ringing" of the tuned cir-

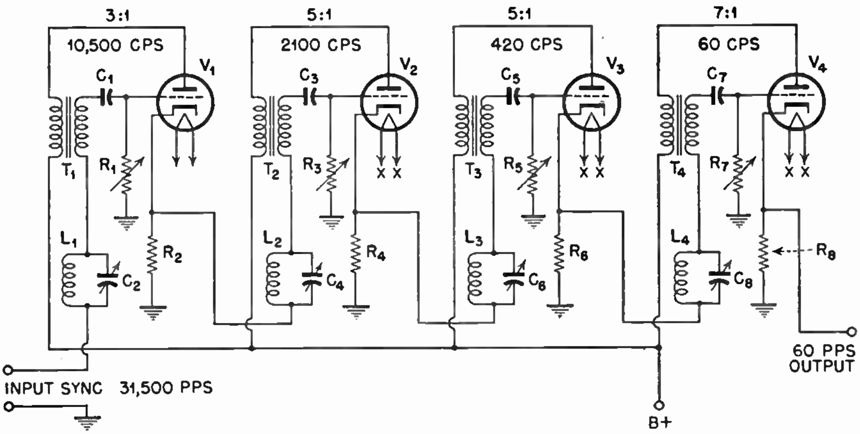


FIG. 5.16 Sychronizing-generator frequency-divider chain making use of stabilized blocking-tube oscillators.

cuit due to its Q. The cathode-voltage waveform is essentially a damped wave; it is in fact a sine-wave persisting for 2.5 c.p.s. (for a 5 : 1 count-down) before the blocking-tube oscillator fires again. Discrimination through use of the cathode-stabilized blocking-tube oscillator is excellent against all frequencies except that producing the proper or intended frequency division.

Either grid- or cathode-stabilized blocking-tube oscillators are much to be preferred over other types for television applications.

5.9 Pulse-Counting Circuits. The pulse-counting circuit developed

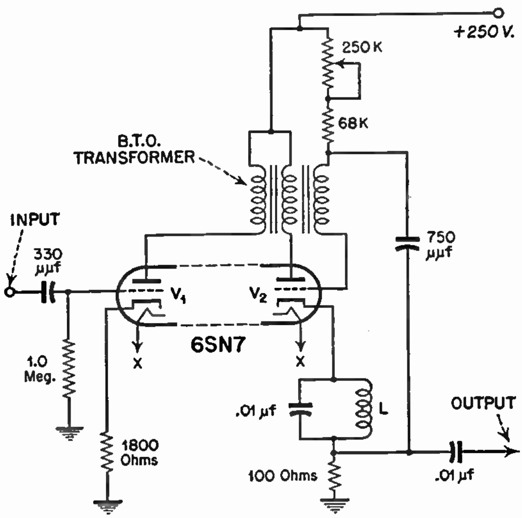
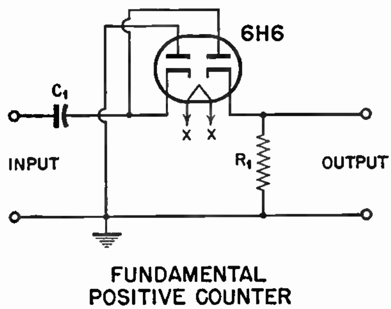


FIG. 5.17 Cathode-stabilized blocking-tube oscillator, as used in the timing unit of a Du Mont synchronizing generator.

by the R.C.A. License Division Laboratory is a preferred circuit for use in the frequency-divider chain of a television synchronizing generator. An elementary diagram of this counter circuit is shown in Fig.

FIG. 5.18



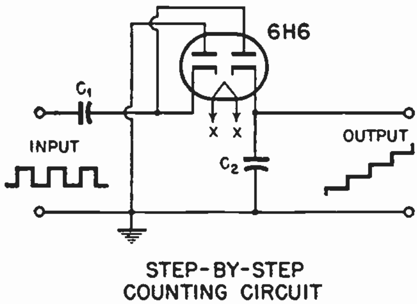
5.18. The counter-circuit timer comprises, in most fully developed arrangements, a conventional blocking-tube oscillator in which the grid-leak resistors are replaced by a pair of diodes. The counter does not have a definite period of its own and hence possesses greater inherent stability. Since the multivibrator and also simple forms of blocking-tube oscillators possess natural frequencies of their own, they must be specifically designed to operate near this frequency. The counter circuit may be arranged to operate so as to provide any frequency division within reasonable limits through very simple adjustments of circuit constants. It provides more positive locking than do other types of frequency-divider circuits, and since reasonable variations of plate potential do not materially result in frequency drift, the regulated power supply need not be as critical of adjustment as one associated with a multivibrator or blocking-tube oscillator.

The driving signal, or impulse, is applied to the oscillator grid through a diode, in the fully developed circuit which results in the voltage being built up in a series of steps. The circuit may be fundamentally referred to as a "capacitor-charging" circuit, in that the charge on the capacitor IX_C is built up to a predetermined value by a selected number of cycles of charging potential. The discharge circuit is adjusted so that the desired firing impulse results in the blocking-tube oscillator always firing on top of the step, thereby discharging the grid capacitor to complete the cycle. Fundamentally, frequency is not a factor in circuit operation. For this reason the counter-circuit timer is a very flexible arrangement for use in the synchronizing generator. Thus, a counter-circuit timer is developed to divide 31,500 c.p.s. by 7 to produce 4,500 p.p.s., and the identical timer circuit can be used to divide 4,500 p.p.s. by 5 to obtain 900 p.p.s. with only a slight change in circuit adjustment. The same timer can also be used to divide 900 p.p.s. by 5 to obtain 180 p.p.s., or to divide 180 p.p.s. into 60 p.p.s. With a chain of counter-circuit timers incorporated in the synchronizing-generator design, it only becomes essential to hold the top frequency constant, i.e., the frequency of the triggering pulse at the input of the first timer in the chain. The counter-circuit timers succeeding the first can be adjusted to provide the required frequency division, no matter what the sequence of division ratios or in what order they are chosen.

To obtain some knowledge of the action which takes place in counting circuits, the reader is referred to the fundamental diagram in Fig. 5.18. This diagram describes a positive counter circuit. If positive square waves of constant amplitude are introduced into the input of this circuit, the charge on capacitor C_1 cannot change instantaneously as the positive leading edge of the firing impulse is applied. Because of this, the plate of the second-diode section assumes a positive potential, and conduction occurs. The result is a charging current that flows through R_1 during the pulse time, a small charge being developed on C_1. At the conclusion of the pulse the reduction in potential places the diode side of the capacitor at a negative potential equal to the charge developed on C_1. It is impossible for the second diode section to conduct, because the plate is negative with respect to the cathode. But, since the first diode section conducts, discharging the small charge accumulated by the capacitor, which would otherwise build up during each successive positive impulse, this condition eventually causes the circuit to become insensitive to the applied square-wave impulses.

Since a definite amount of current flows through resistor R_1 as each impulse is applied, then an average current flows, which tends to increase as the impulse frequency increases, and the average current indicates a reduction as the frequency decreases. The *IR* drop developed across R_1 can be made useful in controlling a succeeding stage.

FIG. 5.19



A step-by-step counting circuit is shown in Fig. 5.19. It may be seen that a capacitor C_2 replaces R_1. A step potential is produced across the output of this circuit, since the charge on the capacitor shunting the output is increased by a slight amount each time a positive impulse passes into the input. The steps decrease in size exponentially as the potential across the output capacitance reaches the final value. The rate of decrease is a function of the output impedance of the driving circuit. The voltage across the output capacitor continues to increase with each impulse until the voltage is equal to the amplitude of the applied impulse. When this condition obtains, the cathode of the second-diode section is held at a positive potential equal to that on the plate during the impulse time, and the tube does not conduct.

To use the step-by-step counter as a frequency divider, a single-swing blocking-tube oscillator is connected to the output of the double diode, shown in Fig. 5.20. The blocking-tube oscillator is triggered into functioning when the potential across C_2 reaches a value sufficiently positive to raise the grid of V_2 to cutoff. The blocking oscillator demonstrates a regenerative effect, and the grid swings positive with respect to the cathode, once conduction starts. Consequently, the capacitor C_2 is discharged back to ground potential. The blocking-oscillator transformer is so wound that similar polarities are present at certain points in the circuit. These points are indicated by the plus signs. Therefore, a positive impulse recurs at a submultiple of the input-pulse recurrent frequency and is produced across the output. The desired submultiple frequency is determined through the simple adjustment of R_1.

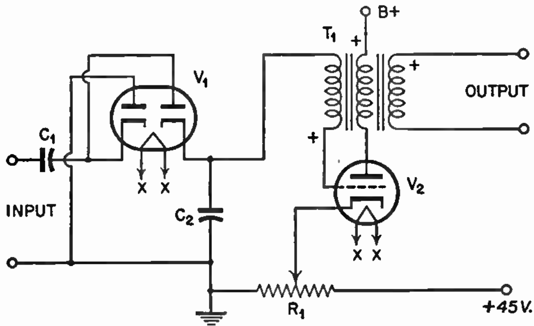


FIG. 5.20 Blocking-tube oscillator triggered by counter circuit.

The effect is to choose the bias voltage applied to the cathode of the blocking-oscillator section, thereby determining the point on the operating curve (Fig. 5.21) at which the tube begins to conduct. Therefore, the input impulse may have a frequency of 31,500 p.p.s., and the output may be adjusted to one seventh this frequency, to 4,500 p.p.s.

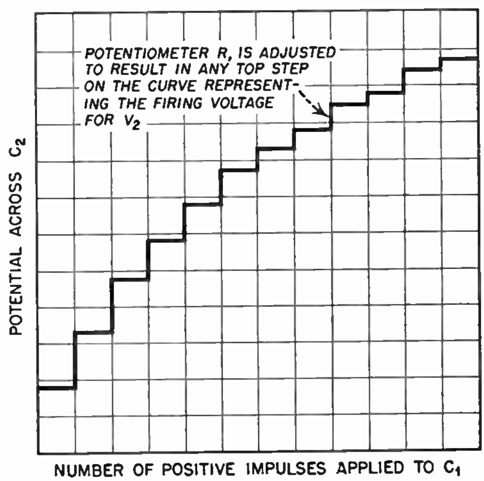


FIG. 5.21

The counter may be operated with low-impedance cathode-coupled output through an isolation amplifier as shown in Fig. 5.22. This circuit eliminates the necessity for the tertiary winding at the transformer, and this is the most desirable method for obtaining the output potential. A commercial frequency-divider chain employing counter-circuit timers is shown in Fig. 5.22. This divider chain is incorporated in the syn-

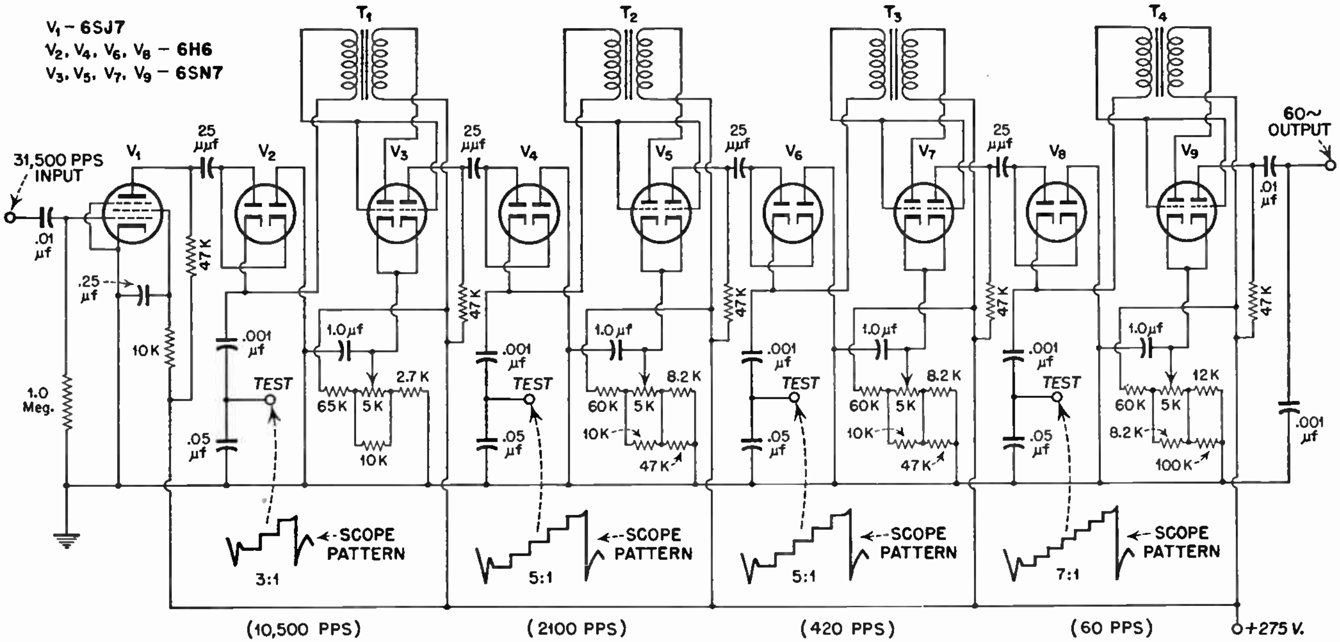


FIG. 5.22 Frequency-divider chain employing counter circuit timers.

chronizing generator used by one of the leading networks at its television station in New York City.

In this frequency-divider chain, vacuum tube V_1 is employed as a pulse amplifier. It is followed by V_2, the first counter, where a frequency division of 3 : 1 is obtained. The third tube, V_3, is a blocking-tube oscillator and is followed by V_4, which effects a count-down of 5 : 1. The vacuum tube V_5 is a blocking-tube oscillator. The 31,500-p.p.s. input has now been divided by 3 and by 5, so that the frequency rate of the pulse applied to V_6 is at 2,100 p.p.s. A further 5 : 1 count-down is taken at V_6, so that the frequency is now 420 p.p.s. The tube V_6

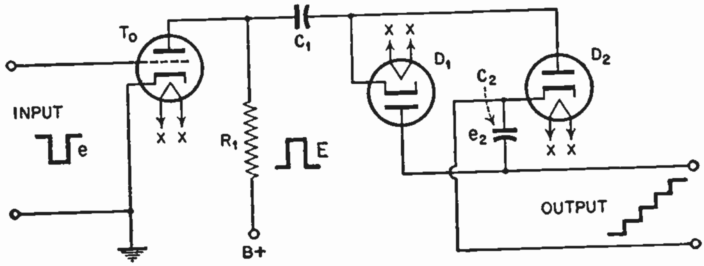


FIG. 5.23 Conventional counter of frequency-divider system.

is followed by another blocking-tube oscillator V_7. The final counter-circuit timer, V_8, effects a frequency division of 7 : 1. The tube V_9 is the final blocking-tube oscillator. The output frequency, due to the final 7 : 1 count-down, is therefore 60 p.p.s. This is the required pulse for application to the a.f.c. system of the synchronizing generator.

Recently an improved counter-circuit timer for television synchronizing generator application has been described by C. E. Hallmark of Farnsworth Television and Radio Corporation.* In the usual form of counter-circuit timer (Fig. 5.23), the potential e_2 increases exponentially, owing to the d-c restorer action of the diode D_1, and returns the potential of one plate of capacitor C_1 to zero during the time interval when the signal E makes a negative excursion. With the typical counter-circuit timer there is a definite limitation in the possible count down ratio.

The modified counter is shown in Fig. 5.24. It will be seen that the diode restorer has been eliminated and that a cathode follower T_1 supplants it. The reference potential to which capacitor C_1 is returned is no longer zero, but instead is dependent upon the number in the pulse-counting sequence. As a result, a staircase voltage function prevails, the potential rising linearly within the limit of distortion of the cathode follower T_1.

* Paper delivered at the 1947 I.R.E. National Convention.

It requires about 2 v. to trigger the blocking-tube oscillator and to maintain reasonable stability. The count-down ratio can be made 200 : 1 with this circuit, depending upon adjustment of the ratio C_2/C_1. The counter is stable when counting down in the order of

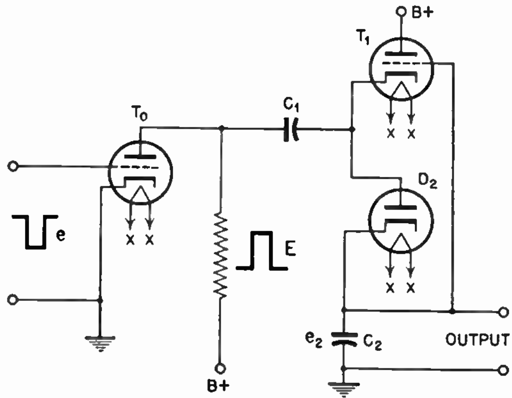


Fig. 5.24 Modified linear counter providing a ratio of 200:1.

200 : 1. By increasing the negative bias potential, this ratio can be increased, the limit to which the count-down ratio can be extended being a function of permissible grid bias. In a commercial version of this counter-circuit timer, two such counters were employed to achieve a

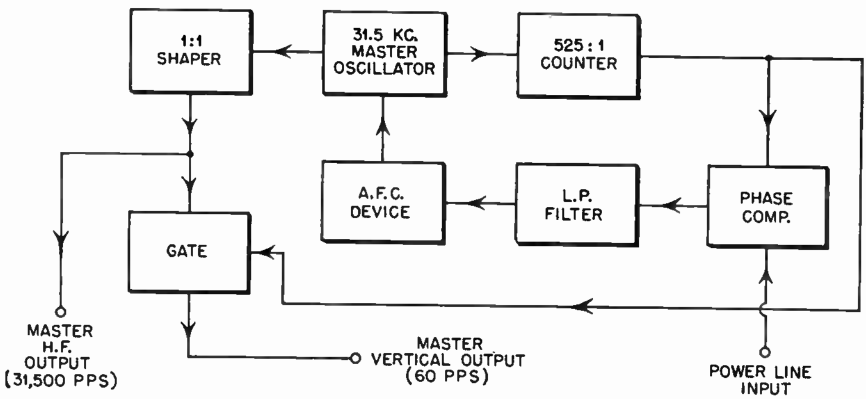


Fig. 5.25 Block diagram of suggested timer using the Hallmark counter.

count-down ratio of 525 : 1, and was of sufficient stability to operate over 10 per cent variations in line and plate voltages.

The manner in which this counter is utilized in a television synchronizing generator is shown in Fig. 5.25. It is seen that a master oscillator provides the basic 31,500 c.p.s. wave. This is passed through a 1 : 1 shaper to provide the proper impulse shape at the equalizing impulse frequency. The output of the master oscillator is also conducted through the two-stage counter-circuit timer, which is incorporated in the system described by Hallmark. It provides a 60-p.p.s. output signal which is gated to produce the master vertical output impulse of 60 p.p.s. The timer output is also admitted to the discriminator, to which also is introduced the power-line voltage at 60 c.p.s. The a.f.c. circuit maintains the master-oscillator frequency at the prescribed frequency of 31,500 c.p.s.

5.10 A.F.C. Circuit. In the typical synchronizing generator, the master oscillator is of the sine-wave type and is adjusted to the basic frequency of 31,500 c.p.s. It is ordinarily of the free-running type, i.e., a tuned circuit determining the operating frequency, with L and C in this circuit being selected in the design procedure to result in the desired operating frequency. The inductance in the tuned circuit is ordinarily made fixed and the capacitance variable through a small range either side of F_R. This arrangement facilitates making compensations for slight frequency drift due to ambient gradient and the aging of tuned circuit components, slight changes in applied operating potentials, and so on. Since the master oscillator must control all the driving impulses required in the system, it must, of necessity, be a very stable device. The stability is to some extent assured through judicious design, use of components possessing close tolerances, and selection of a tube that is notably stable.

At first sight it may appear that frequency stability within the oscillator circuit itself is not of great importance, since its frequency is under control by a reactance tube. Practical experience in synchronizing-generator operation has indicated the fallacy of such reasoning. The reactance tube will control the frequency within certain limits either side of the basic master oscillator frequency; but the more stable the master oscillator can be made, the more stable the basic frequency about which the reactance tube must exercise control. In any precision device, the more stable all the circuits can be made, the more generally satisfactory will be the entire operation.

Master-oscillator circuits that have been used in synchronizing generators have included the Colpitts circuit in modified form, the electron-coupled oscillator, and the transitron oscillator. The latter, possessing inherently greater circuit stability, circuit simplicity, and ease of adjustment, has proved to be a preferred arrangement. To provide television images with straight vertical sides, a high degree of cycle-to-cycle regularity is required of the master oscillator. This regularity is difficult to achieve in relaxation-type oscillators, and they are, therefore, never employed in master-oscillator design.

An automatic-frequency-control (hereafter abbreviated a.f.c.) system and master oscillator are shown in Fig. 5.26. It includes, in addition to the transitron master oscillator, an a.f.c. reactance tube, an a.f.c. discriminator, an amplifier for increasing the amplitude of the 60-c.p.s. pulse applied to the discriminator, and an equalizing pulse multivibrator. The reason for automatic frequency control of the master oscillator lies in the fact that some 60-c.p.s. hum pickup is always present in video circuits. This hum pattern will be in motion vertically and can be observed on all screens of cathode-ray tube monitors and the viewing tubes of receivers, unless the frequency of the timing generator is accurately and precisely synchronized with the 60-c.p.s. power-line frequency.

The operation of the a.f.c. system is quite simple. The 60-c.p.s. pulse from the vertical blanking oscillator output, controlled as to frequency

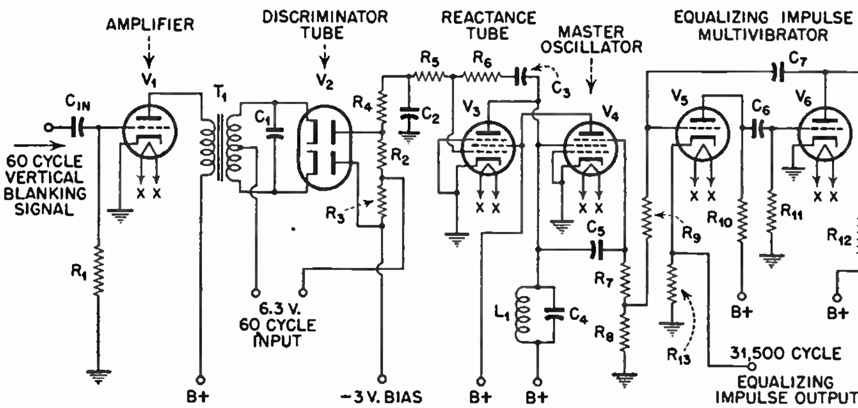


FIG. 5.26 Automatic-frequency-control system of a television synchronizing generator and the equalizing impulse multivibrator.

by the 60-c.p.s. output of the final frequency divider of the frequency-divider chain—and hence controlled by the master oscillator—is amplified and applied across the primary of transformer T_1. If the master oscillator is operating at 31,500 c.p.s., and provided that the frequency-divider chain is precisely adjusted for step-by-step division of this frequency to 60 c.p.s., then the signal applied across the primary of T_1 will be at this precise frequency.

A component from the 60-c.p.s. power line, with which the television system must be synchronized, is obtained by means of a step-down transformer which reduces the normal 110-v. 60-c.p.s. potential to 6.3 v. A filament transformer of high quality is usually employed for the purpose. The secondary voltage of this transformer must be coupled to the discriminator circuit at the connection between resistors R_2 and R_3, the other end of the secondary winding being connected at the center tap of the secondary winding of T_1. Thus, these two voltages—the first taken from the 60-c.p.s. vertical blanking oscillator, the other from the 60-c.p.s. power line—are now 90 deg. out of phase. If the two voltages are in exactly the same phase relationship, i.e., at the same frequency, then the rectified output of the discriminator will appear equal but opposite in polarity in the balanced network in the plate circuit, the resulting output being zero. If the frequency of the voltage being delivered to the discriminator by the 60-c.p.s. vertical blanking oscillator should change, then the output voltage of the discriminator may become negative or positive, depending upon the shift in phase from 90 deg. This voltage is filtered at R_4, R_5, and C_2, after which it is applied to the grid of V_3, the a.f.c. reactance tube. This tube and associated circuit is capable of changing the capacity reactance of the resonant-tuned circuit of the master oscillator. It is seen that the plate of the reactance tube is connected directly to the control grid of the transitron oscillator and also to one end of the tank tuning capacitance C_4. Across the oscillator-tuned circuit is connected C_5 and R_7 and R_8 to ground. The current, which is leading, will flow through the oscillator-tank capacitance C_4 and also through R_6 and C_3 of the reactance circuit, the amount of lead depending upon the series reactance. Thus, if the reactance is changed, then the resonant frequency F_R of the oscillator-tank circuit is also changed. Therefore the output of the discriminator controls the frequency of the 31,500-c.p.s. master oscillator, which, in turn, controls the frequency of the 60-p.p.s. vertical blanking oscillator responsible for the original drift or change in frequency.

The reactance-tube circuit employs a resistance-capacitance network connected between grid and plate (R_6C_3) to provide grid excitation shifted precisely 90 deg. in phase from the plate potential supplied to V_3. The time constant of the a.f.c. circuit must be sufficiently high to obviate the possibility of instantaneous power-line fluctuations affecting the master-oscillator frequency. The 60-c.p.s. vertical blanking oscillator output is used to drive the a.f.c. circuit since it is the widest 60-c.p.s. pulse employed as a component part of the composite synchronizing and pedestal signal. This wide vertical blanking pulse (pedestal) is amplified in passing through V_1 before being passed through transformer T_1. It is partly shaped into a sine wave by the resonant secondary of T_1.

In some a.f.c. systems employed in television synchronizing generators, a somewhat different arrangement is made use of. The circuit is shown in Fig. 5.27. It is seen that the power-line voltage at 60-c.p.s. frequency is admitted to the discriminator in much the same manner as was the 60-p.p.s. output of the vertical blanking oscillator in the system previously described. A transformer T_1 is used to obtain 6.3 v. from the 110-v. power line. It will be noted that a variable-phase shifting network is connected across the secondary of this transformer. This network includes a 50,000-ohm potentiometer of logarithmic taper in series with a 0.5-μf. fixed capacitor. Since $\tan^{-1} = 2\pi FRC$, precise phasing can be obtained through adjustment of the potentiometer. This arrangement enables the engineer to shift the phase of the timer-circuit

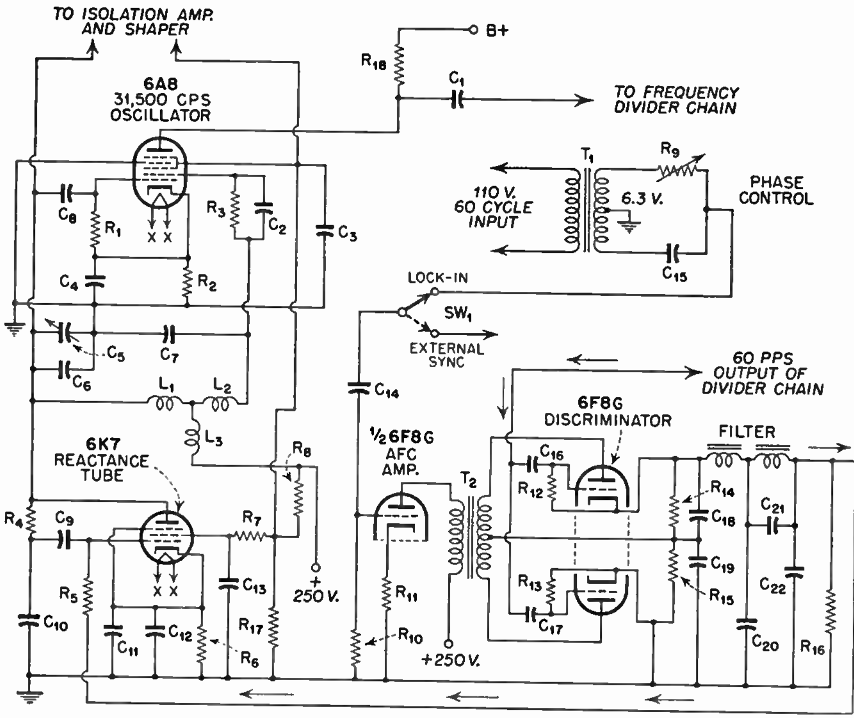


FIG. 5.27 Automatic-frequency-control system as used in a commercial synchronizing generator.

output as desired to reduce the effect of power-line hum interference on the image. An isolation amplifier is provided, through which the 60-c.p.s. current is passed before introduction to the discriminator.

To the two plates of the discriminator is fed the 60-c.p.s. component from the power line, the output load of the isolation amplifier being the secondary of the coupling transformer, i.e., the transformer coupling the amplifier to the discriminator. The transformer secondary is center-tapped, and this center tap connects to the mid-point of a balanced-resistance network feeding the low-pass filter. The output of the timer, or frequency-divider system supplying the 60-p.p.s., is fed directly to the control grids of a type 6F8G vacuum tube. This tube is employed as a discriminator, the output load of which takes the form of the transformer secondary. Since this secondary provides the load for the 60-c.p.s. isolation amplifier through which the power-line component is fed, the output voltages in the two halves of the transformer winding cancel out, and the voltage to the low-pass filter is zero; i.e., the component of voltage from the power line is mixed in the transformer with the 60-p.p.s. output of the last timer or frequency divider in the frequency-divider chain. When the utility power-line voltage and the timer output voltage are exactly in phase, the voltage delivered to the filter is zero, since they are 90 deg. phase displaced with each other. But if either the 60-p.p.s. output of the timer or the 60-c.p.s. power-line frequency drifts, a correction voltage to the grid of the 6K7 reactance tube is applied, and the resonant frequency of the master oscillator is

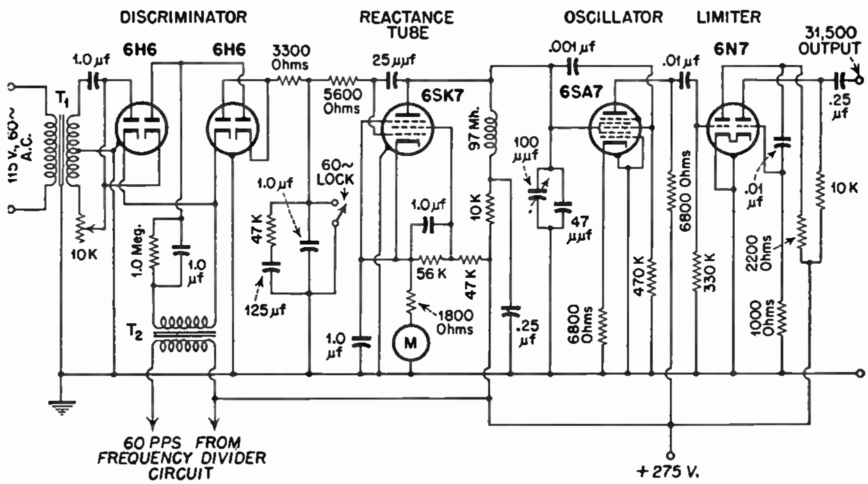


Fig. 5.28 Oscillator and a.f.c. circuits of a commercial synchronizing generator.

corrected. Thus, the free-running oscillator is always under control of the reactance tube, which is in turn under control of the discriminator. An additional type of synchronizing generator utilizes an oscillator and a.f.c. system as indicated in Fig. 5.28.

In adjusting the synchronizing generator, the frequency of the master oscillator is first adjusted precisely to 31,500 c.p.s. The adjustment can be best accomplished by beating the output of the oscillator with that of a reliable signal generator or beat-frequency oscillator, some form of detector being used to indicate zero beat between the signal generator and the master-oscillator output. Next, the frequency-divider chain is adjusted by means of an oscillograph so that each divider in proper sequence provides the specified frequency division. The oscillator-tuned circuit is then slightly readjusted until the 60-p.p.s. output of the divider chain appears stationary on the screen of the oscillograph, the 60-c.p.s. power line being employed as the horizontal sweep voltage for the oscillograph. The lock-in switch of the synchronizing generator is then closed, resulting in the complete circuit locking in step with the power line. In other words, the reactance tube then assumes control over the master-oscillator tuned circuit, which, in turn, is subject to the discriminator output voltage. By the means previously described, the discriminator output voltage assumes control whenever a phase difference between the power-line voltage and the 60-p.p.s. input from the output of the timer exists.

Should the synchronizing generator suddenly drop out of step during operation, the application of an oscillograph is recommended in determining which divider or timer is responsible or whether some other circuit fault exists. In rapidly examining the output of each divider or timer with the oscillograph probe by taking a sample voltage from the cathode of each divider stage, the difficulty can usually be definitely isolated in a few minutes' time. By the same means the difficulty can be isolated to some other component circuit of the complete generator should it not be found to exist in the divider network. If the examination of sample voltages at the various cathodes of tubes in the divider stage indicates that one of the timers has "dropped out of step," a slight readjustment of the control in the timer circuit will correct the difficulty. It is highly important that a well-regulated power supply having low internal impedance be employed to supply all d-c operating potentials to the synchronizing generator. This power supply must be regulated at the prescribed d-c output potential at which the timers have been adjusted for proper operation. The circuit diagram of such a supply is indicated in Fig. 5.29. This particular power supply has seen long service in an existing television installation as a source of d-c operating potential for the synchronizing generator in this specific installation.

Care must be exercised in circuit design to make sure that no cross coupling exists between circuits, particularly throughout the divider stages. Otherwise, extraneous voltages may be coupled into the divider circuits and result in a tendency for them to provide synchronization at frequencies other than those dictated by the design. Ordinarily, a slight readjustment of tuning is necessary when vacuum tubes are replaced in the divider chain, particularly where blocking-tube oscillators or multivibrator circuits are made use of. Circuit adjustments should only be undertaken after a warming-up period of 15 min. to ½ hr.

Because of the possibility that an ambient gradient may affect the tuned circuits, the chassis, or rack, in which the generator is located must be well ventilated. One manufacturer employs a small motor-driven blower in the chassis supporting a small portable synchronizing generator to ensure proper circulation of air about the various components. This arrangement tends to hold the ambient temperature constant during periods of extended operation, since some temperature rise is expected owing to the operation of tubes in the generator. The provision of the blower has proved to be a necessary accessory because it insures that timers will not drop out of step during the transmission of programs, the result of which is to cause the pictures to "roll." Proper shielding of all conductors carrying high-level signal voltages is also

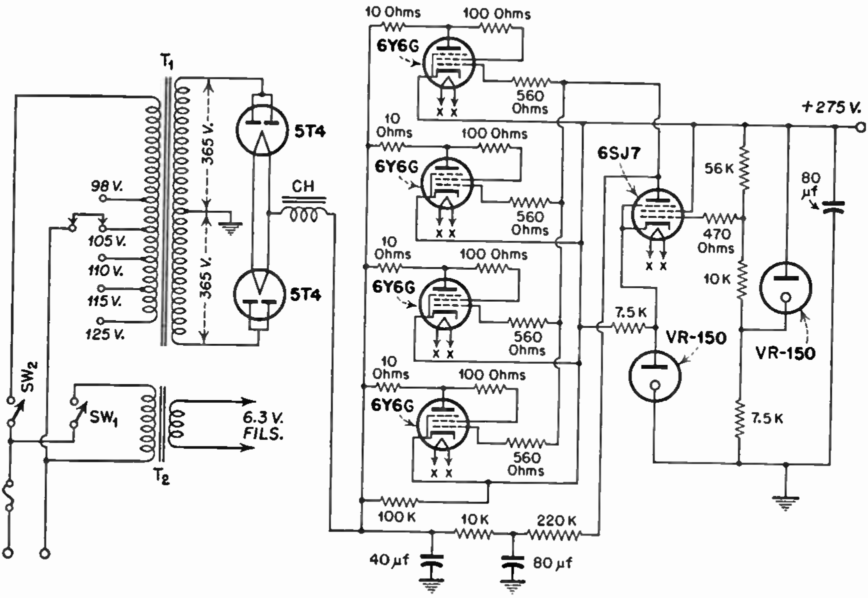


FIG. 5.29 Regulated power supply providing d-c potential to a portable television synchronizing generator.

important in synchronizing-generator design, particularly when such conductors pass through or near adjacent circuits which might be affected by spurious coupling of undesired voltages.

5.11 Wave-Shaping Circuits. The F.C.C. has established definite standards regarding the component waveforms included in the standard television signal. This standard television signal, shown in Fig. 5.2, includes five separate waveforms in addition to the actual picture signal. These waveforms require definite and distinct wave shapes, each occurring at fixed and precise time intervals. The five signal components needed in developing the complete composite signal are produced individually as complete trains of pulses. They are later combined to produce the standard television signal.

A wave-shaping circuit essentially converts a sinusoidal voltage into a square or rectangular pulse of definite shape. The shaping circuit is also employed to narrow a square pulse to the prescribed width, maintaining steep leading and trailing edges of the wave. Another purpose of the shaping circuit is to delay a pulse so that it may be fed into a circuit at the desired instant to combine properly with other generated pulses that have been also precisely timed. The shaping circuit may also be utilized to clip the amplitude of a pulse and to key or gate pulses in and out to satisfy certain requirements of timing.

The synchronizing and pedestal signals are essentially waveforms of rectangular shape joined together by constant voltage-time intervals. Some of the required signal components, i.e., the component signals required to produce the standard television signal, are generated by multivibrators that are timed by the synchronizing generator in order that the pulse width may be definitely under control by a constant timing source, and the intervals during which desired waves occur may be precisely and accurately timed. The multivibrator possesses the required stability for use in wave-shaping systems, provided that it is not called upon to divide frequencies at a greater ratio than 3 : 1.

In order to gain a good understanding of shaping circuits, it is necessary to know something of the fundamental circuit functions involved, the fundamental circuits being combined to achieve the required wave shapes. One such circuit function is that termed "clipping."

5.12 Clipping or Limiting Circuits. The term "clipping," or "limiting," refers to the removal of one extremity or the other of an input wave. The circuit which performs this function is termed a "clipper," or "limiter." Clippers are used in television systems to square off the extremities of an applied sinusoid or of a semisinusoidal signal. In other words, a sine wave may be applied to a clipper circuit to produce a rectangular wave of suitable shape at the output of the clipper. Likewise, a peaked wave may be introduced to a clipper, or limiter, for the purpose of eliminating either the positive or negative "tips" of the peaks of the wave.

Clipping, or limiting, may be brought about by driving the grid of a tube negative to beyond plate current cutoff, or by applying the input signal in positive polarity to a grid that is biased beyond cutoff. The following tabulation lists some of the methods employed in clipping, or limiting, all of which are in common use:

1. Series diode limiting
2. Parallel diode limiting
3. Grid limiting
4. Saturation limiting
5. Cutoff limiting

Some of the more important clipping circuits will be briefly described.

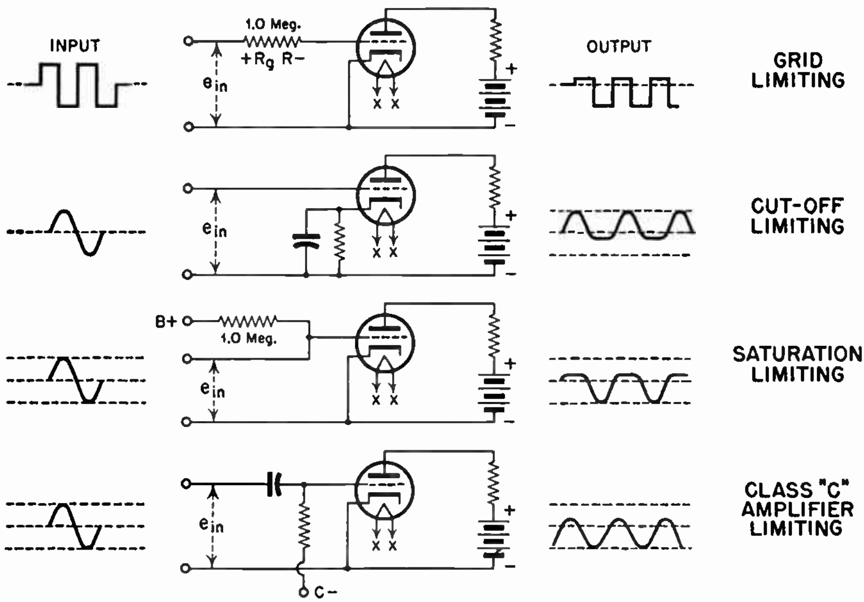


FIG. 5.30 Four types of limiting, or clipping, circuits.

Grid Limiting. The grid of a triode is normally held at zero bias, but in series with the grid it has a high value of resistance; i.e., there exists a grid-leak resistance. The positive portion of the square wave introduced into this circuit tends to drive the grid far into the positive region. But since the impedance of the grid suddenly becomes low in value, a much larger portion of the total voltage drop appears across the grid resistor, thus opposing the applied positive voltage. Accordingly, the final voltage on the grid is very small. The negative portion of the wave, however, is passed through the amplifier and appears in the output in magnified form.

Cutoff Limiting. Electron current can flow through a vacuum tube only from cathode to plate—never from plate to cathode. Thus, plate current cannot become a negative value. When the grid of the tube is driven to cutoff, the plate current is reduced to zero and remains at zero for the time the plate is driven beyond cutoff. The input wave does not result in cutoff current, the wave going up to plate current saturation. The real result is that the portion of the wave rising to the point of plate-current saturation is clipped off.

Saturation Limiting. When a large value of series limiting resistor is employed in the grid circuit of a vacuum tube, the grid cannot be driven to an appreciable positive potential, and despite the positive amplitude of the input voltage, the maximum plate current that flows is that determined by the plate-supply voltage and the resistance of the plate circuit at zero bias. Therefore, the minimum plate voltage is a function of the limiting action of the grid circuit. The grid-limiting resistor can be eliminated from the circuit if the input voltage is taken from a low-impedance high-power source, limiting in the plate circuit still being realized. This is the result of plate-current saturation. The action is sometimes referred to as "saturation limiting," or "saturation clipping."

5.13 Differentiating Circuits. The square- and rectangular-shaped signals required in television circuits must have flat tops and steep sides, i.e., leading and trailing edges. To obtain such waveforms both low

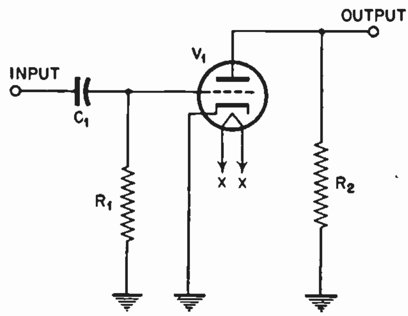


FIG. 5.31 *CR* differentiator circuit. It narrows the pulse, since *C* acts to discriminate against the low frequencies.

and high frequencies are required, the low-frequency component of the signal resulting in the flat top, and the higher—particularly the harmonic—frequencies being responsible for the straight vertical sides of the wave. A wave is narrowed by passing it through a differentiating circuit. Such a circuit discriminates against the low-frequency component of the wave. It is shown in Fig. 5.31. The small capacity and low value of resistance at the input of the vacuum tube serves to attenuate the low frequencies, while allowing the high-frequency components of the wave to be transmitted with negligible attenuation. This is due to the high reactance of the small series capacitance at the low-frequency components of the wave.

The more the value of *C* is reduced, the greater the differentiation or narrowing of the pulse with reference to time. The output pulse, after differentiation, will have considerably greater positive amplitude than had the square wave when introduced.

After differentiation, this pulse may be introduced to a clipper, or limiter, the limiting tube being biased beyond plate-current cutoff. It may then be clipped at the required amplitude, resulting in the requisite narrow pulse with steep leading and trailing edges. Of course, any type of limiting may be used.

After clipping, the wave will be of negative polarity since the polarity of the wave is reversed by virtue of having passed through the limiter. It may then be introduced into a second limiter, or clipper. At the output of the second clipper the wave will again be of positive polarity, but it will have a flat top and sharp leading and trailing edges.

The width of the final pulse is a function of C and R at the clipper input, i.e., the time constant present at the input circuit. It is also a function of the point along the grid voltage—plate current curve at which clipping takes place, or the point beyond plate current cutoff at which the limiter is biased. As the time constant CR is reduced, the resultant pulse will become narrower. Conversely, as the product of CR in the grid circuit is increased, the pulse can be made wider. This

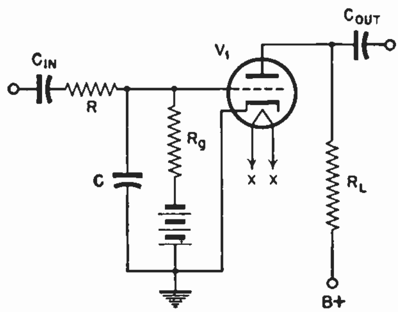
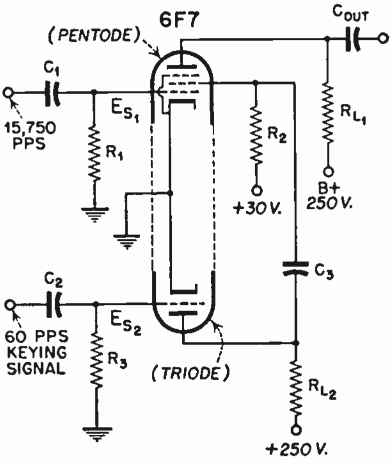


FIG. 5.32 Integrating, or delaying, circuit.

is the usual adjustment procedure, the point along the grid voltage—plate voltage curve at which clipping occurs being fixed through grid-bias adjustment and through the adjustment of the grid-circuit time constant until the required wave shape is obtained. Late-type Du Mont and R.C.A. oscillographs are available which permit the introduction of marker pulses timed in microseconds. These marker pulses are apparent along the trace of the wave as viewed on the fluorescent screen of the cathode-ray tube of the instrument. Thus, the square or rectangular wave under adjustment may be viewed on the cathode-ray tube screen, the marker pulses being superimposed, and the value of CR in the differentiating circuit adjusted for the proper pulse width in microseconds that is required of the particular wave. At the same time, the degree of clipping may be adjusted through adjustment of the associated clipper circuit.

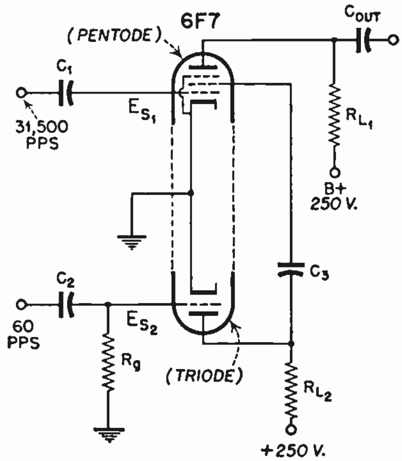
5.14 Integrating Circuits. An integrating, or delay, circuit is used in shaping component television signals for the purpose of affording discrimination against the high-frequency components of the wave. In simple form, such a circuit comprises a series resistance followed by a shunt capacitance (see Fig. 5.32). Since the vertical leading and trailing edges of a square or rectangular wave are determined by the tive over that period of time and keying in the 31,500-p.p.s. signal at the line frequency.

In practice the outputs of the keying-in and keying-out circuits would be combined in a common load resistor. Therefore, signal synthesis occurs, the required super-sync signal being developed through mixing the signals. In this manner various wave shapes, all properly timed and gated, are combined to result eventually in the standard television signal.



KEYING OUT CIRCUIT

FIG. 5.34



KEYING IN CIRCUIT

FIG. 5.35

5.16 The Equalizing Pulse Signal. A part of the composite synchronizing signal includes two groups of accurately timed pulses. Each group includes six pulses having one half the width of the horizontal sync pulses. They are spaced at intervals of one half horizontal line. One group of six narrow pulses is transmitted just before the transmission of the long serrated vertical synchronizing signal. The second group, also containing six narrow pulses, each one half the width of the horizontal synchronizing pulses, are transmitted immediately succeeding the vertical synchronizing signal. Of course, these two groups of signals have a definite purpose in the system. They are developed for the purpose of *equalizing* the two sets of alternate fields, each including 262.5 horizontal lines and the two fields making up one complete picture frame. The pulses are separated by one half horizontal line in order to develop the required interlace and are, therefore, made identical for a short time interval just prior to and succeeding the vertical synchronizing signal. The short time interval for each pulse permits the use of very simple integrating circuits in the television receiver to separate the vertical synchronizing signal from the composite video signal.

Such an integrating circuit in the television receiver is sometimes referred to as a "sync separator."

The master oscillator incorporated in the synchronizing generator has a sine-wave output of 31,500 c.p.s. The equalizing pulses are at a frequency of 31,500 p.p.s. In pulse-generator design it is common practice, therefore, to employ a stable multivibrator following the master oscillator. This stable multivibrator supplies the train of accurately timed narrow equalizing impulses. One circuit arrangement is shown in Fig. 5.36. The master oscillator drives the multivibrator at 31,500 c.p.s., the multivibrator output developing the required narrow

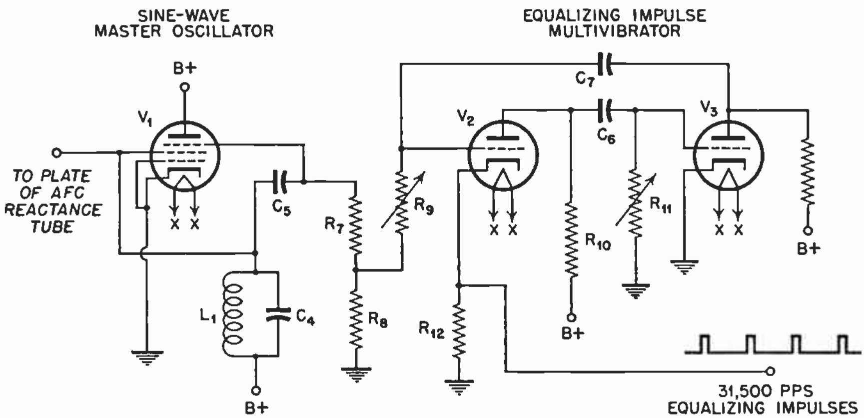


FIG. 5.36 Sine wave master oscillator and the equalizing impulse multivibrator.

pulses whose width is controlled by the circuit component R_{11}. The value of resistor R_9 is then adjusted for precise synchronizing with the master oscillator of the synchronizing generator.

The same equalizing pulse multivibrator may be employed for driving the frequency-divider chain of the generator, regardless of the type of divider employed in the chain. In fact, it is desirable to do so, since then a common source of pulses accurately times both equalizing pulses and the 60-p.p.s. output of the divider chain. The equalizing multivibrator may also be employed, and is so employed in one system, to drive the horizontal pedestal or blanking oscillator, i.e., the synchronizing-pulse oscillator that is used to reduce 31,500 p.p.s. to 15,750 p.p.s. It may be used to provide the leading edge for all the requisite synchronizing signal components. These services are all in addition to the development of the equalizing pulses.

It should be noted here that multivibrators may be employed to produce the pulses referred to, since no frequency division greater than 2 : 1 is required (see Fig. 5.37). The multivibrator will demonstrate ample stability where such a low order of frequency division is necessary.

For greater division ratios either a blocking-tube oscillator or a counter-circuit timer would be employed.

5.17 The Horizontal Pedestal Signal. One of the component signals required in developing the complete television signal is called the "horizontal pedestal signal." It is also commonly referred to as the "blanking signal." It is generated for the express purpose of blanking out the screen of the television receiver during the flyback time, or during the return time of the horizontal saw tooth employed in sequential scanning. After each horizontal line is scanned from left to right, the blanking signal is inserted to extinguish the electron beam of the receiver cathode-ray tube, preventing it from reaching the fluorescent screen of the tube. Thus, the person viewing the reproduced television image does

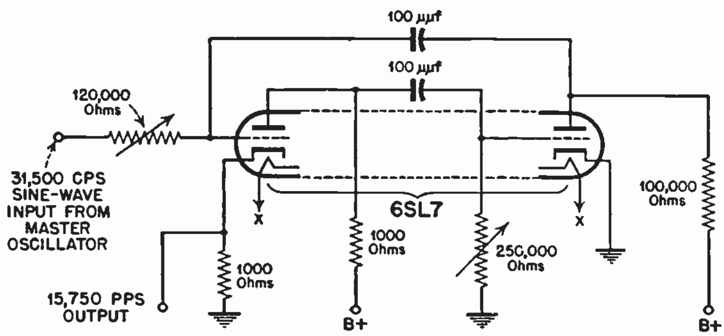


FIG. 5.37 Equalizing impulse multivibrator.

not see the retrace. During the blanking interval, i.e., during the time the horizontal blanking signal is transmitted, the horizontal synchronizing signal is also transmitted. Thus, the horizontal deflection system of the television receiver can reposition the beam from the right edge to the left edge of the raster. After the repositioning, the blanking signal relinquishes its control of the cathode-ray tube beam, and the next line is scanned. This process is repeated until 525 lines are scanned, i.e., for each standard television frame.

The horizontal pedestal, or blanking, signal is not to be confused with the vertical blanking signal which will be described later in the text. The horizontal pedestal signal blanks out the horizontal retrace, or fly-back, and the vertical blanking signal blanks out the vertical or low-frequency flyback, or retrace. The two signals are interrelated with respect to time and accomplish similar action, but are independent as to the services that they perform.

The horizontal blanking signal, sometimes described as the "pedestal signal," is the base, or pedestal, upon which the horizontal sync signal is constructed. Since in our high-definition system 30 frames per second are transmitted, each frame consisting of 525 horizontal lines, it follows that the frequency of the horizontal blanking signal is 15,750 p.p.s. In other words, if 15,750 horizontal lines are included per second, then the return trace incidental to the scanning of each line must be blanked out. The horizontal blanking interval is equivalent to 10.16 μsec. (0.16H.) (H. = 63.5 μsec.).

In the television receiver it is necessary to separate the synchronizing signals from the picture signal, since the synchronizing signals must drive certain receiver circuits to obtain scanning at the viewing tube that is identical with the scanning that has already occurred at the pickup tube in the television studio camera. The horizontal synchronizing impulses are made more narrow than the horizontal blanking, or pedestal, signals, above which they are superimposed. Thus, the leading edge of the horizontal sync pulse is made to follow the leading edge of the horizontal pedestal impulse by a small time interval. This interval is

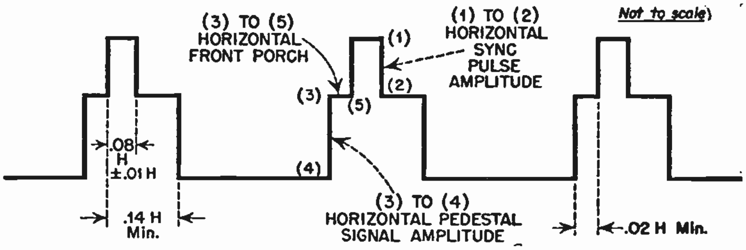


FIG. 5.38 Horizontal pedestal and synchronizing signal.

called the "horizontal front porch." If we examine the horizontal pedestal and horizontal synchronizing signal, as illustrated in Fig. 5.38, it will be seen that the amplitude of the horizontal synchronizing signal extends along the trailing edge (1) to (2). The amplitude of the horizontal blanking, or pedestal, signal extends from (3) to (4). It will also be noted that the leading edge of the horizontal pedestal signal precedes the leading edge of the horizontal synchronizing signal by the time interval (3) to (5) which is equivalent to 1.27 μsec. (0.02 H.). This separation constitutes the "horizontal front porch." Both the horizontal front and back porches are shown in Fig. 5.39. The horizontal back-porch time is approximately 3.81 μsec. minimum.

The horizontal equalizing pulses establish the source from which the horizontal blanking pulses are derived; that is, the equalizing impulses drive the pedestal multivibrator, which, in turn, generates the horizontal blanking impulses. The firing of the horizontal pedestal multivibrator in relation to the leading edges of the equalizing impulses that drive it is delayed by passing first through a time-delay circuit. The firing is delayed by a time interval equivalent to slightly less than one half line, or the time interval existing between equalizing impulses.

A. R. Applegarth* has described a method for accomplishing the delay in firing, and the required circuit is shown in Fig. 5.40.

The 60-c.p.s. nine-line keying signal, which is employed to time accurately the keying of the equalizing group, is utilized to drive a pulse

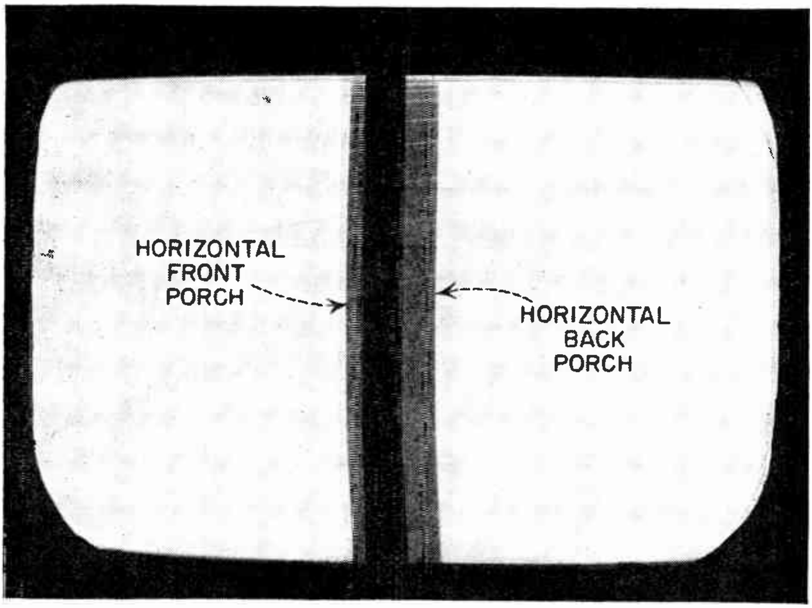


FIG. 5.39

of current through a resonant circuit. This application causes it to generate two trains of damped sinusoidal oscillations, one following each pulse edge. The resonant circuit is tuned, and the second half cycle of the damped oscillations follows the excitation produced by the leading edge of the 60-c.p.s. nine-line signal. The use of the second half cycle for pulse selection results in a gain in pulse selectivity of about 300 per cent, as compared with the possible use of the first half cycle. This is because the frequency to which the resonant circuit must be tuned is three times as great when the desired time interval is three quarters of a cycle as compared with one quarter of a cycle.

The second half cycle of a highly damped transient oscillation is much reduced in effective amplitude as compared to the first half cycle.

* Applegarth, A. R., "Synchronizing Generators for Electronic Television," *Proc. I.R.E.*, March, 1946.

Therefore, if the polarity of the transient signal is chosen to cause the second half cycle of the initial damped oscillation, which is excited by the *leading edge* of the 60-c.p.s. nine-line pulse, to reinforce the desired equalizing pulse, the first half cycle of the second train of damped oscillations, which is excited by the *trailing edge* of the 60-c.p.s. nine-line pulse, will be greater in amplitude than the desired reinforcement signal and will most likely result in erroneous synchronization. The resistance component of the inductor, which is part of the tuned circuit in Fig. 5.40, adds a voltage component of the same wave form as the 60-c.p.s. nine-line

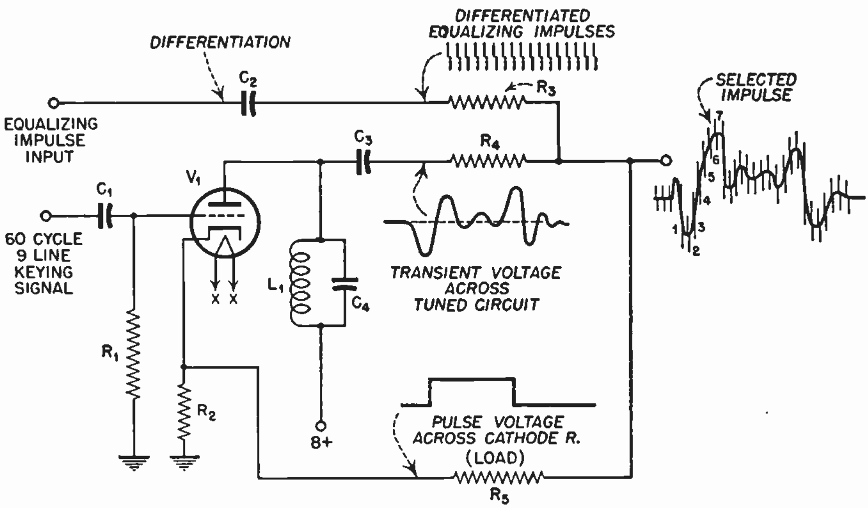


FIG. 5.40 Applegarth's precision time-delay system.

pulse. This voltage component brings about a further accentuation of the undesired reinforcement. According to Applegarth, these factors may be overcome by mixing with the transient oscillations and differentiated equalizing impulses a third component comprising a 60-c.p.s. nine-line pulse of proper polarity to elevate the initial transient with respect to the second one. The result of adding the three components is to produce a precise synchronizing signal for the 60-c.p.s. three-line oscillator, which is accurate to approximately 1 part in 25,000, and without the requirement of any particularly critical circuits. The tuning of the resonant circuit is the only adjustment, its tolerance being approximately plus or minus 10 per cent in resonant frequency.

In some systems, the horizontal pedestal is assured of starting ahead of the other horizontal signals by delaying all horizontal signals except the pedestal signal by the desired time interval. The other impulses are passed through delay networks. In some cases, these delay networks take the form of composite filters, each designed to afford just the proper time delay for each of the requisite horizontal signals. Such a delay network is shown in Fig. 5.41. This horizontal delay network is employed to delay the horizontal signal that is transmitted to the Iconoscope driving system of a film pickup camera.

A multivibrator employed as a pedestal oscillator is shown in Fig. 5.42. First, a saw-toothed wave is developed through integration of the

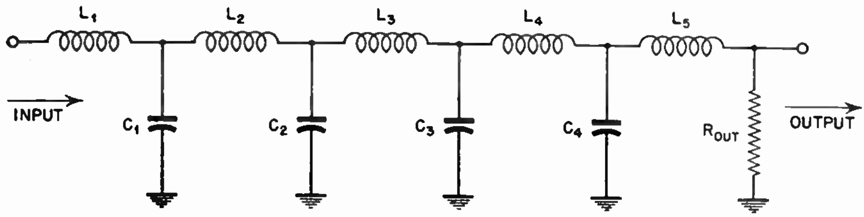


FIG. 5.41 Multisection low-pass filter used as a time-delay network in the television system.

equalizing impulses. A part of this signal is used to fire the horizontal pedestal multivibrator. The front-porch interval (equivalent to 0.02 H., or 1.27 μsec.) is set by adjusting resistor R_4, and the pulse width is set by R_8. Once the time interval is set, the values of resistance may be included in the circuit as fixed values, although it is sometimes convenient

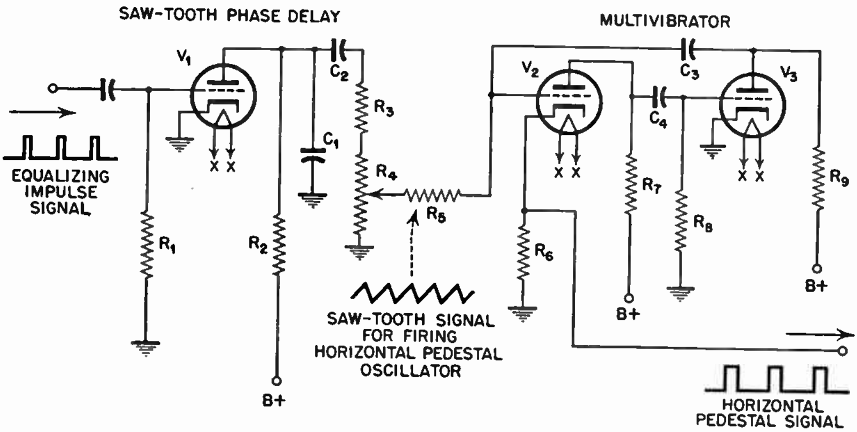


FIG. 5.42 Horizontal pedestal multivibrator system of a synchronizing generator.

to have the front-porch width adjustable under actual operating conditions. The pedestal oscillator in this system consists of a conventional multivibrator that supplies the train of required horizontal pedestal impulses at a frequency of 15,750 p.p.s.

The leading and trailing slopes of horizontal blanking must be sufficiently steep to preserve the minimum and maximum values expressed in the standard television signal waveform for the front-porch interval

(0.02 H., or 1.27 μsec.), and for the remainder of the blanking signal (after the front-porch interval), which is equivalent to 0.14 H., or 8.89 μsec. They must also preserve the minimum and maximum values established for the slope of the leading and trailing edges of the horizontal synchronizing waveform. In the latter case, the time interval between a point taken at nine tenths of the maximum sync amplitude and a point taken at one tenth of maximum sync amplitude is given as 0.004 H., or 2.54 μsec., maximum. The time interval given above for the front-porch interval and for the remainder of the blanking signal is the minimum requirement.

5.18 The Horizontal Synchronizing Impulse. In order to ensure that the horizontal scanning system of the television receiver is perfectly synchronized with respect to the horizontal scanning system employed at the point of transmission, it is necessary that suitable control impulses be transmitted as a part of the composite television signal. These impulses, which control horizontal scanning at the television receiver, are termed "horizontal synchronizing impulses." They are not transmitted during the restricted time intervals consumed in transmitting the narrow equalizing impulses and the wide vertical synchronizing signals. Each pulse must be precisely formed and timed to make certain that each horizontal scan at the receiver starts and ends at the proper instant and in synchronism with an identical horizontal scan taking place at the pickup tube in the television camera in the studio. Thus, a train of 15,750 horizontal synchronizing impulses must be transmitted each second, since 30 complete frames, each including 525 horizontal lines, are transmitted each single second of transmission.

It follows that these impulses may be accurately timed by the equalizing impulses. The horizontal pedestal impulses, upon which the horizontal synchronizing impulses are constructed, are closely related. Thus, both are timed by the equalizing pulses, although the equalizing pulses that time the pedestal impulses are delayed in order to provide the necessary front porch. Therefore, the two signals are synchronized separately, but by an identical timing source. Care must be exercised to make certain that the two horizontal signal components are not synchronized on alternate equalizing impulses.

Because the leading edge of the horizontal pedestal impulse occurs before the leading edge of the horizontal synchronizing impulse, it is entirely possible to utilize the horizontal pedestal impulses to fire a multivibrator that produces the horizontal synchronizing impulses. A time-delay network is employed to defer firing of the horizontal pedestal multivibrator. In order that the front-porch time delay may be adjustable over a reasonable range without affecting the timing of the horizontal synchronizing impulses, it is better to employ an alternate equalizing impulse selector, so that the horizontal-pedestal oscillator will select the desired set of alternate equalizing pulses necessary to synchronize the horizontal pedestal multivibrator properly. Such a method of handling the problem is shown in Fig. 5.43, as described by A. R. Applegarth.* The various signals which occur throughout the circuit are shown.

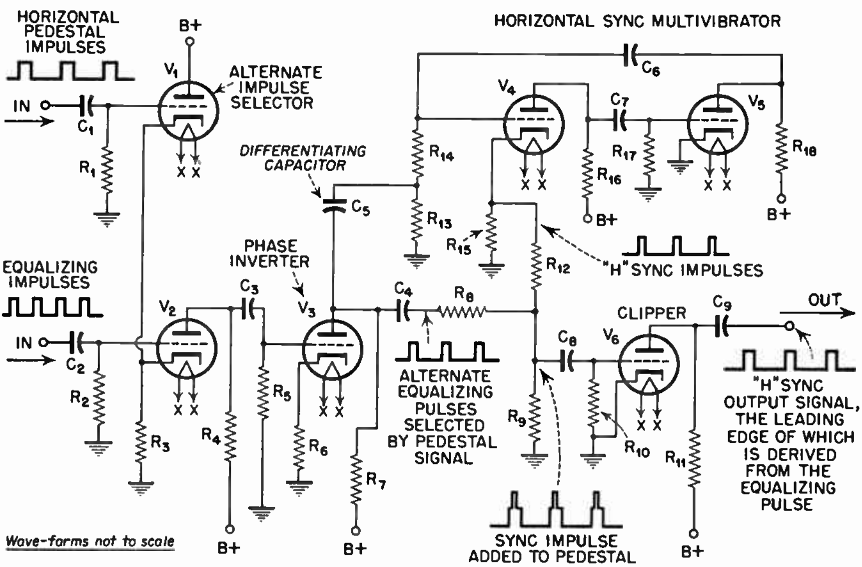


FIG. 5.43 System employed to generate the horizontal synchronizing impulse.

5.19 Vertical Scanning-System Synchronization. The composite synchronization signal contains a component comprising a series of six wide impulses known as "vertical synchronizing blocks." In order to synchronize the vertical scanning system of the television receiver properly, these six impulses are integrated. There are two fields making up one frame in the modern high-definition television system, the images being transmitted at 30 frames per second. One field, therefore, occurs each $\frac{1}{60}$ sec. The groups of six wide vertical synchronizing impulses generated must be identical for each field to ensure that the two fields are properly interlaced to produce one picture frame. The equalizing impulses at 31,500 p.p.s. precede and follow the series of vertical synchronizing impulses and effectively serve to bring about proper and satisfactory interlacing. So as not to create interference with the horizontal timing system during the transmission of the vertical synchronizing signal, this latter component is split up or serrated into blocks.

It is convenient to employ wave-shaping circuits to re-form the equalizing impulses into vertical synchronizing blocks. Employing the

* *Ibid.*

equalizing impulses as a source of signals for construction of the vertical synchronizing blocks leads to much better stability in the complete composite TV signal, since all impulses are under direct control of the master oscillator that drives the complete synchronizing system. A separate oscillator is sometimes provided to generate the vertical synchronizing signal, but such practice is not recommended.

Figure 5.44 shows a circuit recommended for re-forming the equalizing impulses. It is evident that the train of equalizing impulses are admitted at the input of the system, that they are converted into saw-toothed impulses and are clipped twice, and that they pass out of the system as correctly timed vertical synchronizing blocks.

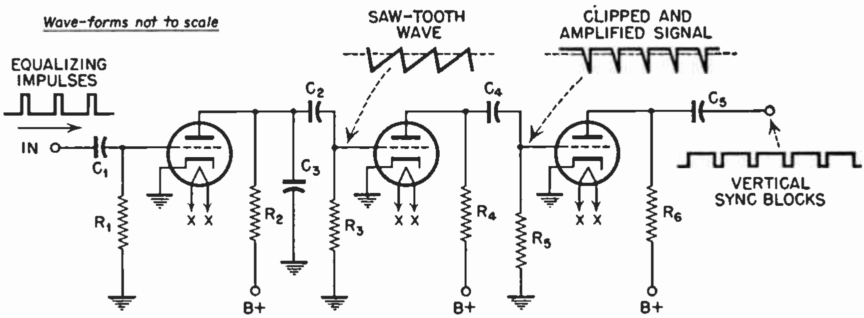


FIG. 5.44 Circuit used in generating and shaping the vertical synchronizing blocks.

5.20 The 60-C.P.S. Keying Signals. In making up the composite synchronizing signal two 60-c.p.s. keying signals are required. One of these signals must be generated for the purpose of keying out nine consecutive horizontal synchronizing impulses from an otherwise continuous train of these impulses and, in their stead, substituting a series of 18 equalizing impulses. A second keying signal at 60 c.p.s. is employed to key in a train of six vertical synchronizing impulses to the center six equalizing impulses of the above selected group. This is the 60-c.p.s. three-line keying signal. It is possible to utilize the output of the last blocking-tube oscillator of the frequency-divider chain as the 60-c.p.s. nine-line keying signal, with this oscillator so designed as to generate an impulse of the requisite pulse width.

Ordinarily, a carefully designed blocking-tube oscillator is used to produce the 60-c.p.s. three-line keying signal, although a multivibrator of the requisite stability may be used instead. It is also possible to use the 60-c.p.s. nine-line keying signal, but this signal must be reshaped for the purpose. It is best to retrigger the blocking-tube oscillator that is generating the three-line signal from the leading edge of an equalizing impulse, since the timing of the 60-c.p.s. three-line signal must be held within the time interval equivalent to the width of an equalizing impulse.

Synchronizing on the leading edge of an equalizing impulse is accomplished in one method by electrical differentiation of the equalizing impulse prior to the instant that it is used to trigger the 60-c.p.s. three-line blocking-tube oscillator.

In some synchronizing systems the 60-c.p.s. nine-line keying signal employed to time the keying of the equalizing-pulse signals is made to force a pulse of current through a parallel resonant circuit. The result is the creation of two trains of damped sinusoidal oscillations. The LC product of the parallel resonant circuit is so selected that its resonant frequency results in the second alternation of the damped oscillation after the excitation developed by the forward edge of the 60-c.p.s. nine-line signal served as the pedestal to elevate the seventh equalizing impulse succeeding the forward edge of the 60-c.p.s. nine-line signal. A. R. Applegarth,* who describes the system, states that using the second alternation of the damped wave rather than the first brings about a gain in pulse selectivity of about 300 per cent, as compared with the use of the first damped wave. This gain is the result, he states, of the frequency to which the parallel resonant circuit is tuned being three times as great when the desired time interval is three quarters of a cycle as compared with one quarter of a cycle. This has been shown in Fig. 5.40.

In the system described, the transient oscillations, differentiated equalizing impulses, and a 60-c.p.s. nine-line pulse of requisite polarity are mixed to elevate the initial or first pulse to the same amplitude as the second. The result is a highly accurate 60-c.p.s. three-line oscillator, which is said to possess an accuracy of one part in 25,000.

5.21 Vertical Blanking Signal. In reviewing the scanning system of a high-definition television system, it will be recalled that saw-toothed waveforms are used. One, a 15,750-c.p.s. saw-toothed waveform, is used for the horizontal scan; and a second, a 60-c.p.s. saw-toothed waveform, is used in drawing the beam to the bottom and returning the scanning beam to the top of the raster at the conclusion of each field. Both saw-toothed waveforms are interrelated. It follows that since only the forward slope of each saw-toothed waveform is utilized in scanning, the return trace of each must be blanked out; otherwise, these traces would appear in the received image. The horizontal pedestal or blanking signal has already been discussed. It is also necessary to black out, or blank out, the screen of the television-receiver cathode-ray tube during the vertical fly-back. The signal required for this purpose is termed the "vertical blanking signal." It is often referred to also as the "vertical pedestal signal," since it may be compared to the horizontal pedestal signal in some respects. It does not, however, serve as a base upon which the horizontal sync signal is constructed. That function rests entirely

* *Ibid.*

with the already described horizontal pedestal signal. The vertical blanking signal serves only to black out the retrace of the vertical saw-toothed waveform.

The horizontal pedestal signal must be very accurately timed, but this condition does not apply to the vertical blanking signal. For the vertical synchronizing signal timing within a line or two is all that is required. A multivibrator is often utilized to provide the vertical blanking signal, since it develops a wide pulse at a frequency of 60 c.p.s. The multivibrator providing the wide 60-c.p.s. pulse for this purpose may be synchronized from the leading edge of the 60-c.p.s. nine-line keying signal. The output of the multivibrator providing the vertical blanking signal may also be introduced into the discriminator for a.f.c. control of the master oscillator of the synchronizing generator.

5.22 Signal-Mixing, or Synthesis, Circuits. In constructing the composite signal from the various component signals generated—each developed to definite standards as to waveform, waveshape, timing, and amplitude—it is necessary to key out one signal during an accurately timed interval, other signals being keyed in during the same period of time. The method of signal mixing, or synthesis, that is followed become essential in mixing or synthesizing the various signal components.

The simplest method of combining several developed signal voltages in order to obtain a composite signal is to apply each of the several component signals to the grid of a vacuum tube, the plates of the several tubes operating into a common load resistor. This method is illustrated in Fig. 5.45.

In the development of such a mixer circuit, the value of R_L is made one third the value that would be required for one tube, assuming that all tubes with plates parallel-connected are of the same type. Should two tubes be used in such a mixer circuit, then the value of R_1 would be made equal to one half the value dictated for one tube, and so on. The main point is that the various signals would combine, or mix, in the common load resistor, and the signal coupled out of the common plate circuit would constitute a composite signal, since it is synthesized from all the component signals introduced at the several control grids.

Accurate timing of the various component signals in relation to one another is highly important. The leading edges of the several signals intended for mixing must be very accurately timed. The leading edges of the three signals produced to synchronize the horizontal scanning system at successive time intervals are of the greatest importance. Failure to provide accurate timing in this respect will result in a received image that lacks straight vertical sides and tightly locked horizontal synchronization. Likewise, if there is a delay in the regular and orderly procession of the leading edges of the equalizing impulses or vertical synchronizing blocks by only 1 μsec. with respect to the timing of the horizontal synchronizing impulses, there may be a displacement of several horizontal lines at the upper edge of the image. This is the result of a transient disturbance produced in the horizontal scanning system of the television receiver.

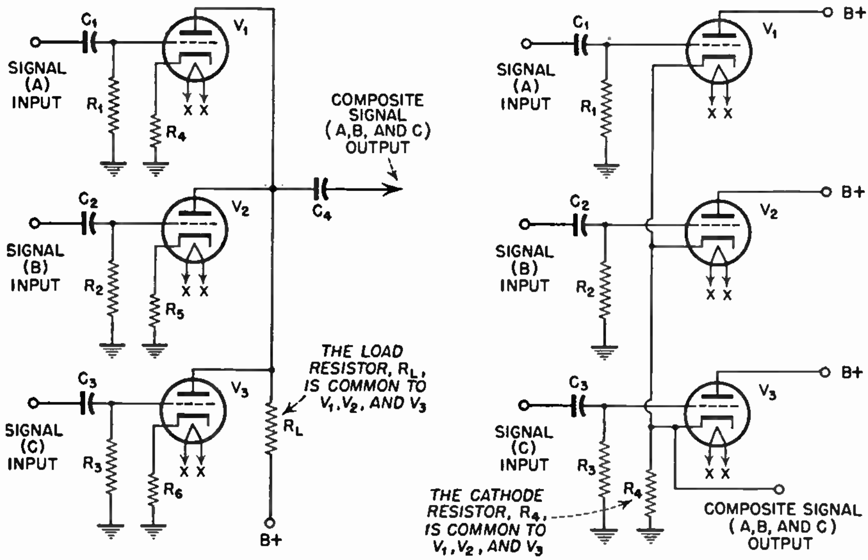


FIG. 5.45 Two methods for combining several signals into a composite signal, either a commonplate-load resistor or a common cathode resistor being employed.

It is good practice in synchronizing-generator design to use the leading edge of one reference signal to establish the timing for all the required signal components before synthesis of these signals to form the composite television signal. Accurate and coordinated timing is thus ensured.

To combine all the accurately timed and required signal components into the complete composite signal requires the use of mixers, modulators, and clippers. One method of signal mixing has already been described. Another method consists in the application of one signal to the grid of a vacuum tube and another to the cathode. The two signals are therefore effectively in series, and the requisite mixing is accomplished.

It is seen that signal mixing may be accomplished in either of two ways: *by introducing two component signals* into the control grids of two vacuum tubes, the signals being combined through use of a load resistor common to both tubes; *by exciting the grids of two vacuum tubes*, the cathodes of which are parallel-connected, the signals being mixed in the common cathode resistor. A third method involves a combination of the two systems just described. Of course, any number of signals may be combined so long as the required number of tubes are employed in effecting the signal mixing. The method to be used will be a function of the waveforms of the various signals to be combined and of the required clipping that must be accomplished simultaneously.

It must be remembered that a signal introduced at the control grid of a vacuum tube will result in a signal of reverse polarity obtaining at the plate of the tube; whereas a signal introduced at the control grid will result in an in-phase signal at the cathode of the tube. Therefore, when cathodes are parallel-connected, the synthesized signal being taken from the cathodes, no polarity reversal results.

Since so many individual signals are mixed throughout the camera chain to attain the complete composite television signal described as the standard television signal, it is important to discuss completely all mixing systems. This discussion will be attempted in the next section so that the reader will understand how so many signals developed by the synchronizing generator and its timing and shaping circuits combine with others to result in this standard waveform, i.e., the standard television signal. It is difficult to separate these mixing circuits into groups that apply solely to the video signal system or into the synchronizing waveform and blanking circuits, because they are fundamentally interrelated and integrated, each depending upon the other in the synthesis of the complete signal desired for transmission.

5.23 Additional Signal-Mixing Circuits. A composite video signal is present at the output of the camera-chain line amplifier; i.e., it is made up of several individual signal voltages that have previously been mixed at a lower level in the television system. The composite signal includes the following voltages:

The video voltage, which originated at the Iconoscope in the studio camera, was subsequently amplified in passing through the video preamplifier and intermediate video amplifier, and was finally introduced into the line-amplifier input.

The shading-correction voltage, which, depending upon the system employed, was introduced either at the input of the video preamplifier or at the intermediate-amplifier input.

The horizontal and vertical pedestal voltages, which are introduced in one typical system at the intermediate video amplifier.

The synchronizing voltages, which are ordinarily injected at the input stage of the video line amplifier.

The block schematic in Fig. 5.46 indicates the relative points in the complete video camera chain at which the various voltages are either mixed or injected to result in the composite video signal that is present at the line-amplifier output. The methods of mixing and injection are not the same for all television systems thus far developed, nor are the signals injected or mixed at the same points in the camera chain. However, the block schematic is typical of one Du Mont television system, which is employed at a number of television stations now in regular commercial operation.

The several components of shading voltage are mixed in proper relation at the shading generator, amplified, and subsequently introduced into the input circuit of the video preamplifier at the studio camera. This procedure is followed when the shading voltages are introduced at low level, as is shown in the block diagram. The shading voltages may also be introduced at a higher level in the system, in which case it is common

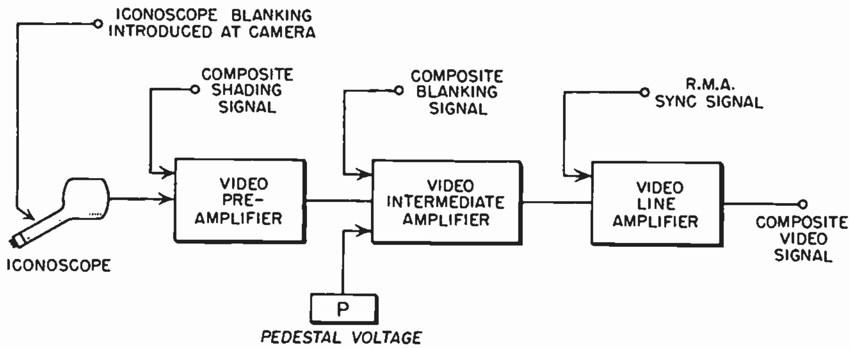


FIG. 5.46 Block schematic indicating where various signal voltages are injected in a typical Du Mont Iconoscope camera chain to result in the composite television signal.

practice to mix or inject these potentials at the first stage of the intermediate video amplifier.

In addition to the shading voltages, the vertical and horizontal pedestal voltages must be injected together in the intermediate video amplifier. The two pedestal voltages are mixed and clipped in the shaping unit, after which they are injected at one point in the intermediate video amplifier. The vertical and horizontal synchronizing voltages, or signals, are also mixed and clipped in the shaping unit. They are then suitably injected into the video line amplifier, usually at the first or second video stage. Suitable coaxial cables bring these various signals from the shaping unit to the video amplifiers where they are introduced and the amplitudes of blanking, pedestal, and synchronizing voltages are each under suitable control at the shaping unit. Then, with the coaxial lines properly terminated at their far ends, the precise voltage amplitude is present at the point of injection. If the coaxial lines are of great length, it may prove necessary to provide amplification before mixing or injection so as to obtain proper amplitude.

The amplitude of the shading voltage, after the various shading-voltage components are mixed, is under control at the shading generator and amplifier. When properly terminated, the coaxial cable that transmits this voltage of the point in the system when mixing, or injection, takes place introduces the optimum value of shading voltage necessary to compensate for the effects of secondary emission at the Iconoscope mosaic.

There are a number of methods of signal mixing and injection in common use in the various television systems that have been developed. These circuits have all seen practical service under routine conditions of operation and have proved satisfactory for the purposes intended. Those circuits and systems in principal use will be discussed, but there are many more.

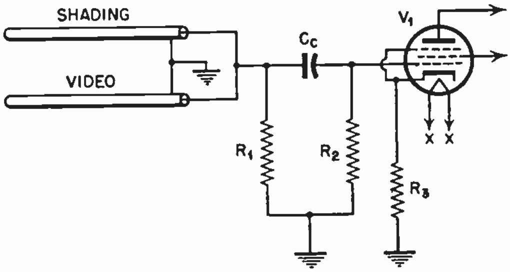


FIG. 5.47 Circuit employed in combining the outputs of the shading amplifier and video preamplifier when mixing is accomplished at high level.

A very simple and at the same time satisfactory means of mixing the composite shading voltage with the video voltage at relatively high level in the camera chain is shown in Fig. 5.47. In this arrangement the video voltage and shading voltages are mixed at the video intermediate-amplifier input, both signals being brought to the amplifier input by coaxial cable. The video signal arrives from the camera preamplifier output at a level, in one case, of approximately 0.1 v., peak to peak, and the shading voltage is transmitted from the shading generator and amplifier at the identical level. The inner conductors of both coaxial lines are parallel-connected at the intermediate amplifier input and are terminated by a common terminating resistor R_1. Therefore, the two signals are mixed in the terminating resistor, and the developed video voltage in corrected form is applied to the control grid of V_1 through the coupling capacitor C_c. Since the two incoming coaxial lines are parallel-connected, the value of R_1 is made one half that necessary to terminate properly one line of the same impedance. The result is that R_1 is small in electrical value, and there is no deleterious effect on the video signal, since the capacitances of the two incoming lines are effectively in shunt. The shading and video voltages originate at cathode-follower stages which do not employ isolating capacitors in series with the inner conductors of the coaxial cables. Identical tubes must therefore be employed in the two cathode followers—one at the video preamplifier output and one at the shading generator or amplifier output, or the cathode resistors at the followers, across which the voltages are developed to feed the lines, must be such that the voltage across one is made equivalent to the voltage across the other. If neither procedure is followed, the biasing of the two followers will be disturbed, since R_1 is common to both because the two lines are parallel-connected at the video intermediate-amplifier input.

A second method of mixing the video and shading voltages in the television system is described in Fig. 5.48. This circuit is employed when

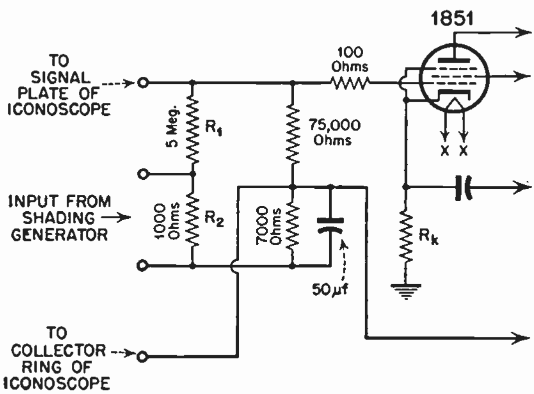


FIG. 5.48 Diagram of the method of introducing shading voltages at low level in the video system.

mixing is accomplished at relatively low level in the system. In this case the mixing occurs at the input to the first stage of the video preamplifier. The video level at this point in the system is approximately 0.01 v. at normal light levels in the studio. Hence, very low level shading voltages are required, effecting economies in shading generator and amplifier construction.

As will be noted, the shading and video voltages are effectively introduced in series at the input of V_1. The signal plate of the Iconoscope or pickup tube is then terminated at high impedance by virtue of R_1, and the coaxial line from the shading generator and amplifier is terminated with 1,000 ohms at R_2. The two voltages are mixed in R_1 and R_2 and directly connected to the control grid of V_1. Because of the low signal level at which mixing occurs, the circuit must be carefully shielded from extraneous noise fields. The interconnecting leads in the mixing circuits must be made short and direct, and components are mounted as close as possible to the control-grid terminal of V_1 to reduce shunt and stray capacitance in the circuit; otherwise, the higher video frequencies may be sharply attenuated. Too, the mixing is accomplished at high impedance where the effects of stray and shunt capacitance are more pronounced.

A method of mixing the synchronizing signal with the video voltage at the line amplifier is shown in Fig. 5.49. The vacuum tube V_2 amplifies the video-signal voltage arriving from the video intermediate amplifier, while V_1 amplifies the synchronizing signal. The plates of the two tubes V_1 and V_2 have a common load resistance R_7, and the two signals are therefore mixed in this common plate-load resistance. Since V_1 and V_2 are parallel-operated, the value of R_7 is made one half the value that would normally be used for one tube. Since additional shunt and stray

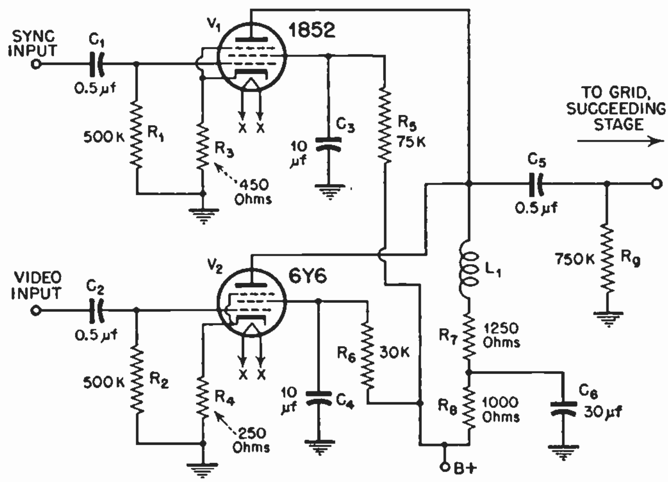


FIG. 5.49 Circuit employed in mixing video and synchronizing voltages.

capacitances are introduced, they must be considered when calculating the values of L and R_L if high-frequency compensation is attempted.

Another mixing circuit, attributed to Madison Cawein of Farnsworth Television and Radio Corporation, is illustrated in Fig. 5.50. It is intended to minimize the effect of tube capacitances across the load resistor R_4 of V_2. Only two tubes are employed in the circuit to combine video, synchronizing, and blanking voltages. The operation of the circuit is very straightforward. If the minimum positive voltage developed in resistor R_9 by the video-signal source represents black, the conduction of space current in V_2 will be at a minimum value. As the voltage across resistor R_9 increases to represent whiter portions, the space current through V_2 increases to proportional value.

During a scanning period the voltages across resistors R_1 and R_2, across which the blanking and synchronizing voltages are developed, are at their minimum negative values, and V_1 conducts maximum current. This reduces the positive potential of the cathode of V_2, thereby increasing the space current through this tube. The blanking signal increases the positive potential of the cathode of V_2, so that this tube now operates in the remote region of plate-current cutoff, where the space current is virtually independent of grid-voltage variations. The current through V_2 is further reduced by the synchronizing signal.

Limiting action for the blanking and synchronizing signals can be obtained by so adjusting the plate voltage of V_1 that the tube is driven into space-current saturation if these signals exceed the required level. It is possible to apply one of the signals to the suppressor grid of V_2. The horizontal synchronizing signal may be applied in this manner.

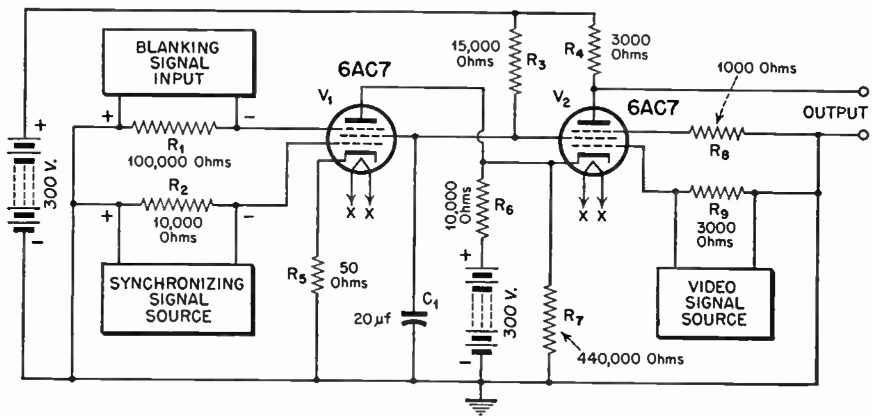


FIG 5.50 Diagram of signal-mixing system. (After Madison Cawein.)

All the voltages are present in the output of V_2 and may be applied to succeeding stages of video amplification to obtain the desired composite signal level or amplitude.

A method for injecting the pedestal voltage into the video signal at the video intermediate amplifier is shown in Fig. 5.51. The operation is similar to that of a pentagrid mixer in that the electron stream within the tube, cathode to plate, is twice modulated by the signal voltage applied to two grid elements. The suppressor grid of V_1 is operated at about 10 v. positive with respect to ground instead of at cathode potential, which is accomplished by means of a voltage divider across +B and ground (R_5 and R_6). The suppressor grid is connected to the voltage divider through a 100,000-ohm resistor R_3, the pedestal voltage at negative polarity being injected by means of the suppressor grid.

A distinct advantage is obtained in employing the circuit shown in Fig. 5.51 for pedestal injection. Clipping can be accomplished in the same vacuum tube in which the pedestal is introduced. It will be noted that a type 1649 tube is used. The operating characteristics of this tube are identical with those of the type 1852, except that the 1649 is a selected low microphonic type. If 50 to 60 v. negative are applied to the suppressor grid, plate-current cutoff will be blocked, that is, the tube will be driven to plate-current cutoff. Thus, with the pedestal voltage in negative polarity applied to the suppressor grid, mixing and clipping will be accomplished within the same vacuum tube. Once the pedestal signal is injected at the suppressor grid (as a negative voltage), it appears in the plate circuit as a positive voltage pulse and is subsequently applied to the grid of the succeeding tube through the coupling capacitor C_4.

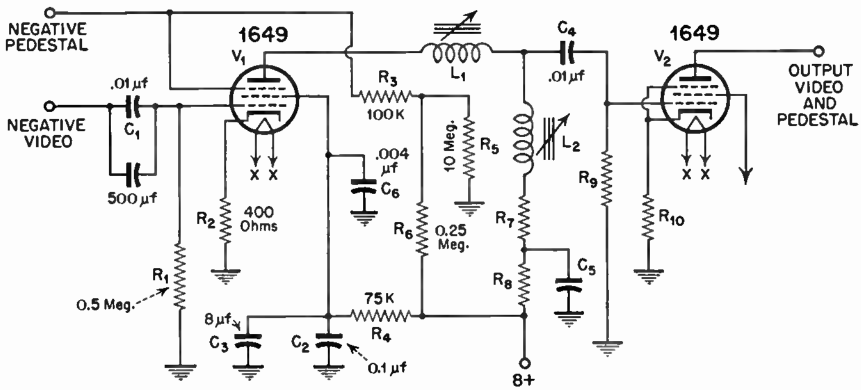


FIG. 5.51 Diagram of method of using suppressor injection to combine video and pedestal voltages.

The pedestal signal is almost always introduced before the synchronizing signal is injected, or mixed, and there should be at least one stage of video amplification between the point in the circuit where pedestal is introduced and the point in the system where the sync signal is introduced. The reason for this is obvious. Sync should be injected where the pedestal is of positive polarity. Otherwise, it is likely that the sync signal will be clipped at the grid of the following tube. As would be the case if the sync were immediately introduced after pedestal is injected, an excess of pedestal voltage could only drive the sync voltage into the positive grid region. With negative polarity, an increase in pedestal could drive the sync signal into the region of plate-current cutoff, clipping the sync signal and thereby causing rolling of the image at the receiver cathode-ray tube in the field, which would be due to loss of synchronism.

5.24 Combining the Equalizing Impulses with the Horizontal Synchronizing Signal. In the previous discussion, many methods of signal mixing in the television system have been described. Some of these methods are applied outside the synchronizing generator proper to combine signals of one kind or another into some desired composite signal.

The techniques are all important toward a complete understanding of the system as a whole. There remains a very important example of signal mixing within the synchronizing generator itself. This is the combining of the equalizing impulses with the horizontal synchronizing signal.

Once the horizontal synchronizing signal has been generated, it is introduced into a modulator. Nine horizontal synchronizing impulses (each

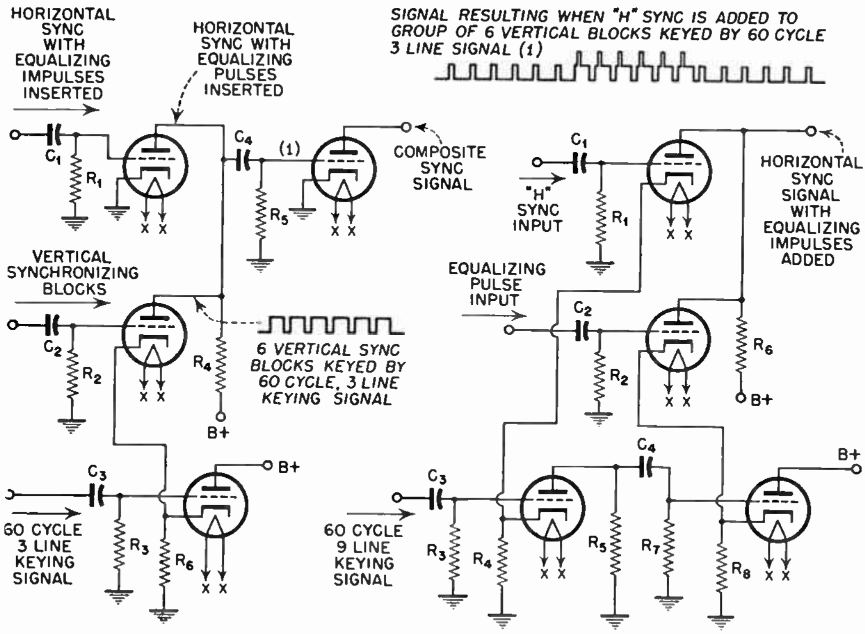


FIG. 5.52

occurring 1.3 μsec. after the start of the horizontal blanking signal, and each having a time duration of 5 μsec.) are keyed out by the nine-line keying signal.

The equalizing impulses, each having a line duration of 0.04 or 4 per cent and a time constant of 2.5 μsec., are introduced into another modulator of the mixing system, i.e., to the control grid of another vacuum tube operating into a load resistor that is common to the modulator or tube into which the horizontal synchronizing impulses are introduced. The two modulators operating into a common load resistor are effectively mixed in this common resistor, thus forming a composite horizontal synchronizing signal, and the horizontal synchronizing impulses are interrupted at 60-c.p.s. intervals by a group of 18 equalizing impulses. Figure 5.52 describes the manner in which this is accomplished in one system.

In studying the foregoing description of the combination of the equalizing impulses with the horizontal synchronizing signal, it is well to examine carefully the circuit diagram shown in the right-hand portion of Fig. 5.52, at the same time considering the information given in Fig. 5.53. The latter indicates the relative sequence of the combined pulses, as well as the manner in which they are individually added.

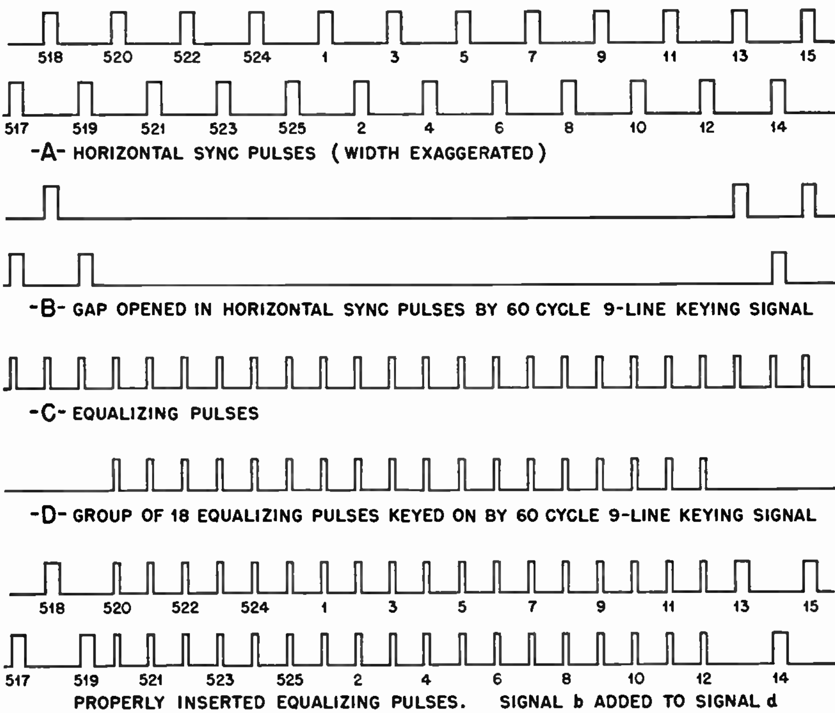


FIG. 5.53 Insertion of the equalizing signal into the horizontal synchronizing signal. (After A. R. Applegarth.)

5.25 Introduction of the Vertical Synchronizing Impulses. A further signal-mixing process employed in the synchronizing generator is of interest, namely, the introduction of the vertical synchronizing impulses. The circuit involved is shown in the left-hand portion of Fig. 5.52. It may be seen that the identical modulation or signal-mixing process previously described is employed. The horizontal sync signal with equalizing impulses inserted, which has already been discussed, is combined with the vertical synchronizing blocks.

The 60-c.p.s. three-line keying signal shown as being introduced to the grid of one tube in the mixing system comprises the modulating signal. The 18 equalizing impulses sustain no interruption, and the vertical synchronizing blocks are added to the center six equalizing impulses. A composite synchronizing signal is the result. It is clipped to dispose of the overlap that occurs between the six center equalizing impulses and the vertical synchronizing blocks. It may be seen that the leading edges of the equalizing impulses have been used to time the leading edges of the vertical sync blocks. The sequence in which the vertical sync blocks are inserted into the composite sync signal, the synthesis of which was discussed in Sec. 5.24, is shown in Fig. 5.54.

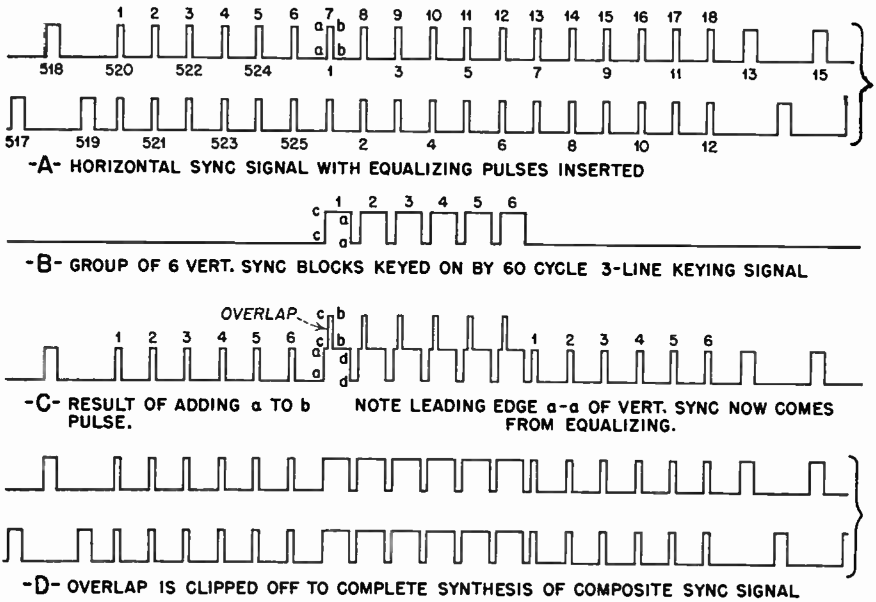


FIG. 5.54 Insertion of the vertical synchronizing blocks into the composite synchronizing signal. (After A. R. Applegarth.)

5.26 Mixing the Picture and Pedestal Signals. The picture signal is added to the horizontal pedestal or blanking signal after the horizontal pedestal signal is modulated by the vertical blanking signal to black it out during the vertical retrace-time interval. To effect this, it is common practice to cut off the picture modulator, or mixer, tube for the time interval during which horizontal and vertical blanking are occurring. Thus the possibility of spurious components of the picture signal, which take place during the blanking intervals and provide interference with the vertical and horizontal synchronizing signals, is prevented.

In the final mixing process, the picture and pedestal signals are mixed with the composite synchronizing signal to form the complete composite TV signal, one suitable for effectively modulating a radio-frequency carrier at the transmitter. One method of mixing these various signal components to obtain the composite video signal is shown in Fig. 5.55.

It may be seen that the three cathodes are parallel-connected, the horizontal pedestal, the vertical pedestal, and the picture signals being fed to separate grids of three vacuum tubes. Thus, the signals mix in the common cathode resistor R_4. There is no polarity reversal, since the composite signal is taken from the parallel-connected cathode circuit. This provides a simple and straightforward method for obtaining the required composite signal.

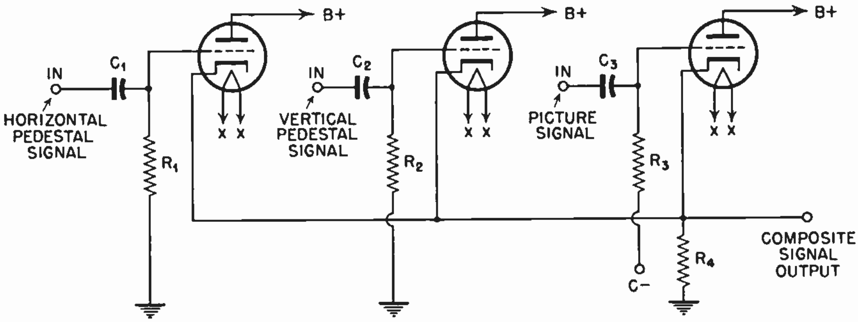


FIG. 5.55 Diagram of one method by which the horizontal pedestal signal may be modulated by the vertical blanking signal and mixed with the picture signal.

5.27 The Standard Television Signal. A knowledge of the standard television signal and of the time duration of the various component impulses and signals that are combined to make up this standard signal is important. In the upper center section of Fig. 5.2 it may be seen that the elapsed time between the transmission of the leading edge of one horizontal synchronizing impulse and the transmission of the leading edge of a succeeding horizontal synchronizing impulse is shown to be equivalent to *H*. The letter *H* refers to one horizontal scan, i.e., the horizontal scanning of one line of picture information plus retrace. (*H* time = 63.5 μsec.) The time duration of the various impulses and signals that go to make up the complete standard television signal are always described in terms of a percentage of one horizontal scan (plus retrace) *H*, or of one vertical scan (plus retrace) *V*.

In the upper left portion of Fig. 5.2 it may be seen that the elapsed time between the transmission of the leading edge of one horizontal synchronizing impulse and the transmission of the leading edge of the succeeding leading edge of the first equalizing impulse is designated as equivalent to *H*. Thus, this time interval is equal to the time from the start of one line to the start of the next. The time duration between the transmission of the leading edge of an equalizing impulse (the last of the first train of six equalizing impulses) and the transmission of the succeeding leading edge of the second vertical synchronizing impulse is also shown as equivalent to *H* time. This occurs in 63.5 μsec. The conclusion is drawn from the fact that 15,750 horizontal lines of picture information are scanned each second, 30 frames of 525 lines each occurring each second of transmission. The product of 30 and 525 is 15,750. Thus, $H = 1/15{,}750 = 63.5$ μsec. The elapsed time required to scan one horizontal line of picture information plus blanking or retrace time = 63.5×10^{-6} sec.

In Fig. 5.2 again, it will be seen that 63.5 μsec. is the time interval existing between the leading edge of one horizontal synchronizing impulse and the leading edge of the first of the series of six equalizing impulses that precede the transmission of the long serrated vertical synchronizing interval. It follows that 63.5 μsec. is also the time interval occurring between the leading edge of one horizontal synchronizing impulse and the leading edge of a succeeding horizontal synchronizing impulse. In either case the time interval is the same. Other time intervals throughout the standard television signal, as illustrated, are compared with the time required to accomplish one horizontal scan and retrace and in terms of per cent (H).

It is indicated that the equalizing impulses preceding the transmission of the long serrated vertical impulse interval take place in the time $3.02H$. These six impulses are therefore transmitted in 191.8 μsec. These six equalizing impulses, which make up the first equalizing impulse interval, are followed by the long serrated vertical impulse interval. The serrated vertical pulse interval occurs in the time $3H$, or in 190.5 μsec. The H interval occurs in 63.5 μsec., and the product of 3 and 63.5 equals 190.5. This vertical synchronizing-impulse interval occurs between the leading edge of the first vertical impulse and the leading edge of the first equalizing impulse of a group of six such pulses which follow the transmission of the serrated vertical impulse interval.

The second equalizing pulse interval, which succeeds the transmission of the long serrated vertical pulse interval, occurs in the time $3H$, or in 190.5 μsec., this time interval being equivalent to that required in transmitting the long vertical pulse interval. The vertical field interval = V = $262.5H$, and is equivalent to a total time duration of 16,667 μsec.

The complete vertical blanking interval, which occurs between the bottom of one picture and the top of another, is shown as taking place in the time $0.075V \pm 0.005V$. The time duration of one vertical field is equivalent to $\frac{1}{60}$ sec., since 60 fields interlaced are transmitted each second. Thus, $V = \frac{1}{60} = 16{,}667 \times 10^{-6}$ sec. Therefore, since the vertical blanking time occurs in approximately $0.075V \pm 0.005$, the time duration is 1250 μsec. According to the standards, $0.08V/H = 21.9$ lines, the maximum vertical blanking time, and $0.07V/H =$ about 18 lines, the minimum vertical blanking time.

In the center right-hand portion of the illustration describing the standard television signal, a detail drawing of the horizontal blanking impulse with the horizontal synchronizing impulse superimposed is shown in the detail of section E. It is seen that the minimum horizontal blanking time is equal to $0.16H$. Thus, the minimum horizontal blanking front-porch minimum time interval is given as $0.02H$. The minimum horizontal front-porch time is 1.27 μsec. The maximum horizontal back-porch interval occurs in $0.06H$, or in 3.8 μsec. The horizontal supersynchronizing impulse base width occurs in $0.08H$, or in 5.08 μsec., which is the time interval occurring between the leading edge and the trailing edge of one horizontal synchronizing impulse taken at the base. The slope of the leading or the trailing edge of the H supersynchronizing impulse must not depart from the vertical by more than $0.004H$ or by more than 0.25 μsec., which is shown in the detail drawing of the section E–E (center right portion of Fig. 5.2). The time interval between the leading edges of successive horizontal impulses shall vary less than ½ of 1 per cent of the average interval.

It may be seen that one equalizing impulse occurs in the maximum interval $0.04H$, shown in the detail drawing D–D (lower left portion of Fig. 5.2). The maximum time interval of one equalizing impulse (leading to trailing edge) is 2.54 μsec. ($0.04H$). Here again the slope of the leading or trailing edge must be held to $0.004H$, or to a tolerance of better than ¼ μsec.

The time interval occurring between the leading edge of one vertical impulse and the trailing edge of the same impulse at the base—in other words, the time duration of one impulse—is given as $0.43H$. The time duration of this impulse is therefore 27.3 μsec. The time interval occurring between the leading edge of the last equalizing impulse preceding the long serrated vertical pulse interval and the leading edge of the first vertical impulse (taken at the base), is defined as $0.5H$. The time interval is therefore 31.75 μsec. The time interval existing between the trailing edge of one vertical pulse and the leading edge of the next vertical impulse to follow is $0.07H \pm 0.01H$. The approximate time duration is 4.445 μsec.

If Fig. 5.2 is examined once more, it will be evident that the duration of one frame can be calculated to occur in 33,333 μsec., and that the vertical field interval is equivalent to 16,667 μsec., i.e., $V = 262.5H = 16{,}667$ μsec. The vertical sync pulse interval occurs in $3H$, or in 190.5 μsec. The equalizing pulse interval succeeding the vertical sync pulse interval also occurs in the time $3H$, or in 190.5 μsec. The leading and trailing edges of each of the equalizing edges must occur in a maximum time of $0.004H$, or in 2.54 μsec. The leading and trailing edges of the vertical sync pulse must also occur in a maximum time of $0.004H$, or in 2.54 μsec. The horizontal line interval H equals 63.5 μsec., and the horizontal blanking interval, including both the front and back porches, equals $0.16H$, or 10.16 μsec.

The front slope (maximum) of the horizontal super sync pulse is given as $0.004H$, or 0.25 μsec. The back slope of this same pulse is identical as to time duration (0.25 μsec., maximum). The leading and trailing edges of vertical blanking should be complete in less than $0.1H$, or in 6.35 μsec. For receiver design, the vertical retrace must be complete in $0.07V$. The equalizing pulse area must lie between 0.45 and 0.5 of the area of a horizontal synchronizing impulse.

Other time constants can be obtained through calculation from the values shown here. Exact measurement of these time constants can be made through use of several special types of oscillograph which have been especially designed for the purpose. An instrument of this type is the Du Mont Type 280 Oscillograph, which has seen widespread use throughout the television broadcasting field in making precise measurements with regard to portions of the standard television signal.

It is readily apparent that in the limiting, integrating (delaying), and differentiating (narrowing) circuits succeeding the timing unit of the synchronizing generator, the component pulses at the requisite frequencies are altered as to shape and time duration to produce the standard television signal. It is seen that the duration of these pulses is measured as a percentage of horizontal or vertical sweep frequency, and that five separate and distinct impulses are combined to form the complete signal. These are:

The vertical blanking signal
The horizontal blanking or pedestal signal
The vertical synchronizing impulse
The horizontal synchronizing impulse
The equalizing impulse

The complete standard television signal, as illustrated, disregards the slight slopes of the leading and trailing edges of the component signals and impulses, and the wave shapes are not drawn to exact scale. All the impulses shown are taken either from the 31,500-c.p.s. sine-wave output of the master oscillator or from the 60-c.p.s. signal derived from the output of the timer—the various signals being timed with respect to the leading edge of the equalizing impulse in one practical television system. In any case, there must be some point selected for use as a reference in timing the various component impulses accurately and precisely.

Inspecting the standard television signal from the standpoint of time duration, it will be seen that the vertical blanking signal occupies the major portion of the complete signal as illustrated. It occupies $0.075V \pm 0.005V$. This component signal has an amplitude that reaches up to and beyond the black level. Its purpose is to bias the grid of the receiver cathode-ray tube to cutoff during the retrace time. Consequently, the retrace time *in the receiver* must be completed at the end of $0.07H$. The horizontal blanking signal extends in amplitude to the identical black level, but lasts only 18 per cent of 1/15,750 sec. The maximum horizontal blanking time is indicated in the detail of section C–C and is given as $0.18H$, or 11.43 μsec. The vertical synchronizing signal may be seen rising above the blanking signal in amplitude and comprising a train of six impulses. The time duration of any one of these pulses is equal to more than 5 + times the duration of one of the horizontal synchronizing impulses.

The amplitude of the horizontal synchronizing impulse may be seen to rise above the blanking signal. The duration of this impulse is slightly greater than half that required of the blanking impulse. The fifth impulse employed in generating the standard signal, namely, the equalizing impulse, is shown in detail D–D (Fig. 5.2). A series of six of these impulses replaces the horizontal synchronizing impulses for a time interval which begins before the start of the vertical synchronizing impulse interval and does not conclude until after this interval is concluded. The actual substitution of a pulse for one of another type is brought about by the keying circuits already discussed. The screen voltage is applied or removed from keying tubes, and the pulses involved are continuously injected into the control grids of these tubes.

In Fig. 5.2 the picture signal is observed to lie between the horizontal blanking impulses, one line of picture information being indicated between each of these impulses. Bright portions of the picture are indicated by zero modulation amplitude, which refers to the maximum white in the picture. Black parts of the picture may reach, according to standards, 75 per cent plus or minus 2.5 per cent of the maximum peak-to-peak amplitude of the complete standard television signal. It follows that the blacker-than-black region occupies approximately 25 per cent of the maximum peak-to-peak amplitude. The various components of the composite TV signal are adjusted with respect to amplitude in various parts of the television system, where the amplitude of the pedestals, the synchronizing impulses, and the picture signal may be independently but precisely controlled within the tolerances prescribed by the licensing authority.

The actual video signal—the product of the light and shade in the scene being televised, the values of which have been converted into electrical signals—will vary rapidly in amplitude. This variation being represented by a frequency change which would be required to reproduce a complex picture structure. It has been shown that the most difficult picture to be reproduced would be a checkerboard pattern of white and black squares, each square representing one picture element. Vertical detail is a function of the number of lines in the picture. To ensure good horizontal detail—as fine as the vertical detail—it must be possible to handle picture elements along lines that are as closely spaced horizontally as the lines are spaced vertically. Considering theoretically that the picture transmitted has an aspect ratio of 1 : 1, the number of elements would be 525 less the blanked lines. However, it is known that the elements are rectangular in shape, since an aspect ratio of 4 : 3 (or 1.33) is employed. Multiplying 525 by 4 and dividing by 3 yields 700. Since the picture is longer in the ratio 4 : 3, it follows that there are 700 elements in each line.

A pair of adjacent elements would be required to represent one voltage cycle. Consequently, while a single line is being scanned, such as is shown in the standard television signal as occurring between two horizontal blanking impulses, it must be possible to transmit 700/2 or 350 c.p.s. In view of the fact that 525 lines are scanned each $\frac{1}{30}$ sec., it may be assumed that the output of the electron tube for image pickup contains a tremendous range of frequencies. But this is practically incorrect, since the blanked-out lines of the picture have not been considered.

To determine the bandwidth required for transmitting the information in the picture, the following equation is used (to an approximation):

$$\text{Bandwidth} = \frac{\text{horizontal picture elements}}{2} \times \text{number of lines per frame} \times \text{number of pictures per second}$$

Thus

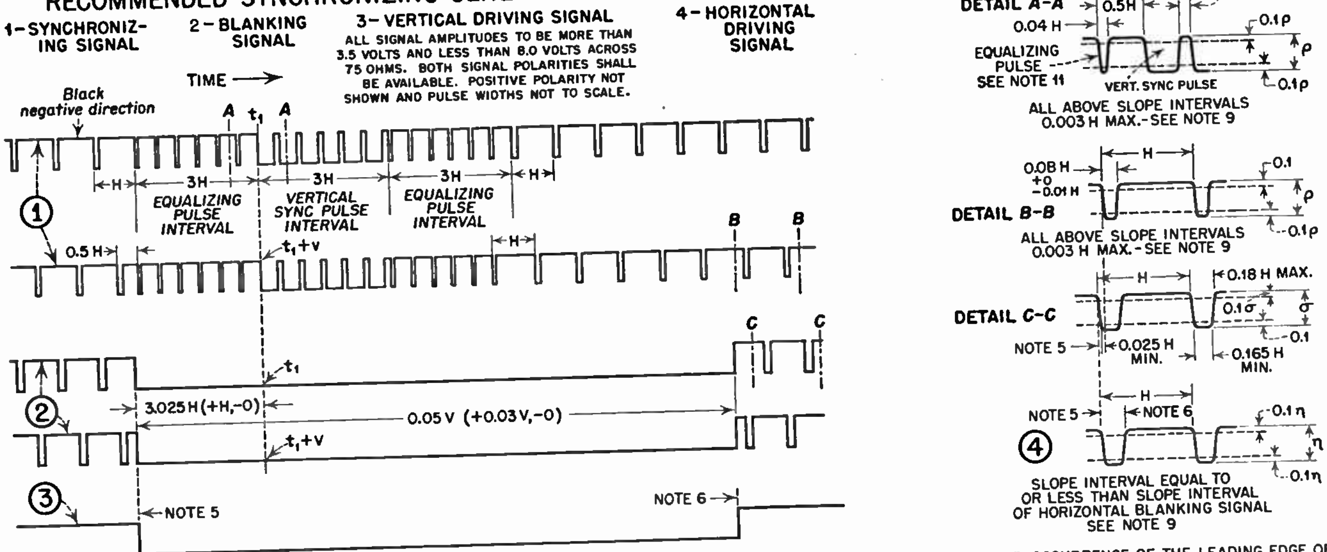
$$350 \times 525 \times 30 = 5{,}512{,}500 \text{ c.p.s. or } 5.5 \text{ mc. per sec.}$$

(The blanked lines are not considered in this equation.)

In following the interpretation given, it should be remembered that one cycle equals two picture elements, since interlaced scanning is employed, and only alternate lines are scanned each field. The picture signal that occupies the interval between adjacent horizontal blanking impulses (for line-by-line scanning in a horizontal manner) is a very high frequency signal. The F.C.C. allows a bandwidth of 4.25 mc. per sec. The slight loss in horizontal resolution and fine detail is not apparent at the screen of the receiver cathode-ray tube, and the permitted band proves satisfactory for all practical purposes.

The recommended synchronizing-generator waveforms are shown in Fig. 5.56. Here are indicated the four waveforms that must be delivered to the television system from the output of the synchronizing generator and have been named by R.M.A.:

RECOMMENDED SYNCHRONIZING GENERATOR WAVE-FORMS



NOTES—

1-H = TIME FROM START OF ONE LINE TO START OF NEXT LINE.

2-V = TIME FROM START OF ONE FIELD TO START OF NEXT FIELD.

3-LEADING AND TRAILING EDGES OF VERTICAL DRIVING AND VERTICAL BLANKING SIGNALS SHOULD BE COMPLETE IN LESS THAN 0.1 H.

4-ALL TOLERANCES AND LIMITS SHOWN IN THIS DRAWING APPLY FOR LONG TIME VARIATIONS ONLY, AND NOT FOR SUCCESSIVE CYCLES.

5-TIMING ADJUSTMENT, IF ANY, MUST INCLUDE THIS CONDITION.

6-HORIZONTAL AND VERTICAL DRIVING PULSE WIDTHS ARE ADJUSTABLE FROM ONE HALF TO ONE TIMES THEIR RESPECTIVE BLANKING PULSE WIDTHS.

7-THE TIME RELATIONSHIP AND WAVE-FORM OF THE BLANKING AND SYNCHRONIZING SIGNALS SHALL BE SUCH THAT THEIR ADDITION WILL RESULT IN A STANDARD RMA SIGNAL. THE TIME RELATIONSHIP MAY BE ADJUSTABLE, BUT MUST INCLUDE THIS CONDITION.

8-THE STANDARD RMA VALUES OF FREQUENCY AND RATE OF CHANGE OF FREQUENCY FOR THE HORIZONTAL COMPONENTS OF THE SYNCHRONIZING SIGNAL AT THE OUTPUT OF THE PICTURE LINE AMPLIFIER SHALL ALSO APPLY TO THE HORIZONTAL COMPONENTS OF THE OUTPUT SIGNALS FROM THE RECOMMENDED SYNCHRONIZING GENERATOR.

9-ALL SLOPE INTERVALS TO BE MEASURED BETWEEN 0.1 AND 0.9 AMPLITUDE REFERENCE LINES.

10-TIME OF OCCURRENCE OF THE LEADING EDGE OF ANY HORIZONTAL PULSE "N" OF ANY GROUP OF TWENTY HORIZONTAL PULSES APPEARING ON ANY OF THE OUTPUT SIGNALS FROM A RECOMMENDED SYNCHRONIZING GENERATOR SHALL NOT DIFFER FROM "NH" BY MORE THAN 0.0008 H WHERE H IS THE AVERAGE INTERVAL BETWEEN THE LEADING EDGES OF THE PULSES AS DETERMINED BY AN AVERAGING PROCESS CARRIED OUT OVER A PERIOD OF NOT LESS THAN 20 NOR MORE THAN 100 LINES.

11-EQUALIZING PULSE AREA SHALL BE BETWEEN 0.45 AND 0.5 OF THE AREA OF A HORIZ. SYNC PULSE.

12-THE OVERSHOOT ON ANY OF THE PULSES MUST NOT EXCEED 2%.

RMA SUBCOMMITTEE ON STUDIO FACILITIES
APPROVED JAN. 22, 1946
REVISED OCT. 9, 1946

FIG. 5.56

The synchronizing signal
The blanking signal
The vertical driving signal
The horizontal driving signal

Very precise standards for these signals have been set by the R.M.A. Subcommittee on Studio Facilities. The *synchronizing-signal waveform* indicated is that which must be present at the output of the picture line amplifier. It is in this amplifier that the composite synchronizing signal, containing both horizontal and vertical components, is mixed with the picture and blanking signal to produce the composite television signal. The composite television signal is that signal, obtained at the output of the line amplifier, which is necessary for modulation of the video transmitter.

The minimum standard set for synchronizing-signal tolerance is such that the time of recurrence of the leading edge of any horizontal impulse N of any group of 20 horizontal impulses shall not differ from NH by more than $0.001H$. H is defined as the average interval between the leading edges of the horizontal impulses as determined by an averaging process carried out over a period of not less than 20 or more than 100 lines.

The leading edges of the horizontal synchronizing impulses must recur with precise regularity. The rate of change of the frequency of recurrence of the leading edges of these impulses is not to be greater than 0.15 per cent per second as they appear at the line-amplifier output. The frequency of recurrence of the leading edges of the horizontal synchronizing impulses is determined by an averaging process. This process is also carried out over a period of not less than 20 or more than 100 lines, these lines not including any portion of the vertical blanking signal.

A precise standard has been set with reference to the frequency of the horizontal and vertical scanning impulses. They must not vary from the values established by the standards of frame frequency and number of scanning lines by more than plus or minus 1 per cent, irrespective of power-line frequency variations.

In network operations and in normal switching at the line amplifier, the synchronizing signal amplitude must be maintained with little variation before and after switching. The maximum variation in synchronizing-signal amplitude should not be greater than ± 4 per cent, even though the synchronizing signals may be shifted during the switching operation. It is important that the synchronizing signals be uninterrupted for periods of time longer than 0.01 sec. at the line-amplifier output during such switching operations.

It is necessary at times to switch from one synchronizing source to another within the same local or metropolitan area. Such a situation arises, for example, when the program originating point is shifted from a field pickup location to a local studio. In this case, a portable synchronizing generator supplies the synchronizing signals for the field camera chain, while the master control room synchronizing generator supplies signals to the local studio camera chain. When generators are switched, the phase of the succeeding vertical blanking signal, as viewed at the main-line amplifier output, must not lead by more than 5 per cent, nor lag by more than 1 per cent of one vertical field. Ordinarily, a sync phasing unit is included in the array of equipment at the master control room, and the two signals, one from the remote point and one from the local studio, are properly phased before the switch is actually made. Another recent development in master control room equipment is a sync stretching unit, a piece of equipment so designed that the sync signal may be removed from the composite TV signal at blanking level, after which it is possible to stretch the amplitude of the synchronizing impulses, compensating for any compression that might have taken place in the system. When the sync amplitude is increased to the proper level, this signal is again combined with the other impulses to provide the composite television signal. However, in passing through the sync stretching unit, the synchronizing signal amplitude has been restored to what it was before compression reduced the signal amplitude. Such a device is particularly useful in network operations, since some sync compression inevitably takes place in the transmission of the synchronizing impulses through coaxial-cable facilities. As much as 20 per cent compression has been noted at times in the line connecting New York and Washington.

In order to standardize synchronizing-generator design, R.M.A. has recommended that the standard synchronizing generator be capable of delivering four signals into 75-ohm loads. These are, specifically, the *horizontal driving signal*, the *vertical driving signal*, the *blanking signal* (made up of horizontal and vertical components), the *synchronizing signals* (comprising horizontal and vertical components).

To standardize the performance of the synchronizing generator further, the industry has set the minimum amplitude of each of the four signals as 3.5 v., peak to peak, the generator being so designed that either positive or negative polarities are available at the generator output. The d-c voltage across any output of the generator should not exceed 15 v. The maximum signal-voltage output should not exceed 8 v., peak to peak. In order to provide adequate control of horizontal and vertical driving impulses, suitable adjustments should be provided at the generator, so that these impulses may be varied between ½ and 1 times their respective blanking pulse widths.

In the standard synchronizing generator, the time relationship and waveform of the blanking and synchronizing signals should be such that their addition will result in a standard R.M.A. signal. The time relationship of the two signals may be adjustable, but this condition must be met.

The variation in the time interval between the leading edges of successive vertical driving impulses must not exceed 5 per cent of one horizontal period, and the variation in width between successive vertical driving impulses should not exceed 5 per cent of one horizontal period. It is important that the regularity with which the impulses are generated be held within precise limits, and is particularly important in network operations where programs originate from a great many points, since it is likely that each pickup point will have in operation a synchronizing generator to initiate the driving pulses for the camera chain in use at that program pickup point.

The time of recurrence of the leading edge of any horizontal pulse N of any group of 20 horizontal impulses appearing on any of the output signals from a recommended synchronizing generator should not vary or differ from NH by more than $0.0008H$, where H is the average interval between the leading edges of the pulses as determined by an averaging process carried out over a period of not less than 20 or more than 100 lines. The time interval required for the leading and trailing edges of the horizontal and vertical driving signals should not exceed the tolerances given by the corresponding blanking signals. The time interval for the leading and trailing edges of the horizontal and vertical synchronizing and equalizing impulses should not exceed $0.003H$ (0.19 μsec.).

The voltage level during the substantially flat portion of any single impulse and the voltage level during the substantially flat portion of the signal in the interval between impulses appearing on any of the output connections from the recommended synchronizing generator should not vary by more than ± 2 per cent of the average peak-to-peak signal amplitude. Hum and other interference voltages should be less than 2 per cent and amplitude modulation of the output signals should also be less than 2 per cent of the peak-to-peak signal amplitude.

5.28 Approximate Check of Sync to Blanking. A rather simple means of obtaining an approximate check of sync to blanking is to observe the raster of a line monitor or any monitoring cathode-ray tube upon which the composite signal may be seen. The raster on the screen of the tube is observed while the sweeps are operated at half speed. In this manner both vertical and horizontal blanking may be viewed at the center of the screen. The normal pedestal and sync levels are fed to the monitor. The video gain at the camera control unit, or in the part of the television system where this level is controlled, is set at minimum. The brilliance and contrast of the monitor is adjusted so that the raster appears white, the blanking gray, and the sync black. In *inspecting the vertical blanking* from top to bottom, the following characteristics should be observed:

1. The blanking should start just ahead of the first equalizing impulse. This impulse is the narrow pulse that occurs near the center of the horizontal scan (see Fig. 5.3).

2. Three of the equalizing pulses should precede the long serrated pulse, because the sweeps are being applied at one half speed. There are actually six such impulses being transmitted. The three equalizing impulses can be seen in the upper portion of the rectangular gray window observed near the center of the screen.

3. Three serrated impulses should appear beneath these three equalizing impulses and should reach almost into the horizontal blanking. These three pulses appear to be quite long as compared with the apparent horizontal dimension of the observed equalizing impulses and pass through the center of the small gray rectangular window. The distance from the horizontal blanking to the end of this pulse should be the width of an equalizing impulse.

4. Three more equalizing impulses should follow the vertical serrated impulses.

5. The vertical blanking time should be adjustable from 18 to 21 horizontal lines. Since the last equalization impulse is 9 lines away from the start of the blanking, it becomes a simple matter to count off the additional 9 to 12 lines from this point.

In making a rough check of the *horizontal*, the following procedure is recommended:

1. If the width of the sync pulse is known, it may be used as a standard to which the horizontal blanking width can be checked. This pulse width should be approximately $0.075H$.

2. The front porch of the blanking should measure slightly more than one third of the pulse width.

3. The total blanking width should be twice the width of the pulse.

It is, of course, more accurate to employ an oscillograph that permits introduction of marker pulses, accurately timed in microseconds, across the observed waveforms, impulses, or signals, the impulses being adjusted with respect to duration and the marker pulses used as a reference with respect to time.

5.29 Vertical and Horizontal Saw-Toothed Deflection Generator. Figure 5.57 describes a saw-toothed deflection generator which may be used to produce the saw-toothed waveform required for scanning at the Iconoscope.

A 60-c.p.s. negative pulse is applied to the control grid of the first section of the 6N7. It appears at the plate of this first section in reversed polarity, i.e., as a positive impulse. It is coupled through a

0.25-μf. capacitor to the control grid of the second-triode section of the 6N7. This second section is biased beyond cutoff by application of about −16 v. of negative bias through the 0.5-megohm grid resistor. While the second section of the 6N7 is blocked, the 0.1-μf. capacitor in series with a 0.1-megohm resistor R_6, in the plate section of this triode section, is charged through R_4 and R_5. The positive 60-c.p.s. pulse applied to the control grid of the second section of the 6N7 is large, and this second grid is driven positive, resulting in the 0.1-μf. capacitor

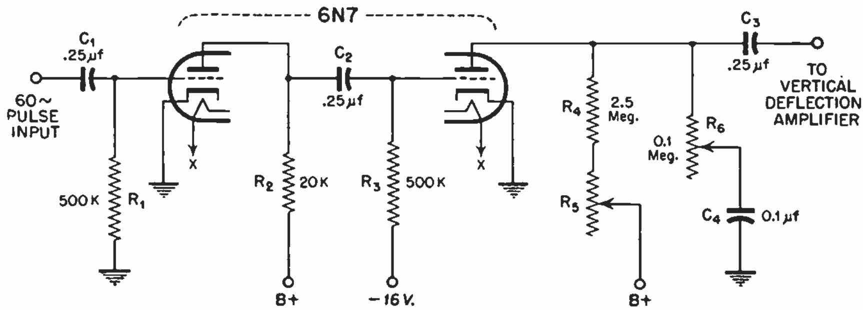


FIG. 5.57 Vertical saw-toothed deflection generator.

being discharged through the tube. At the conclusion of each 60-c.p.s. driving impulse, the grid is once again blocked, with the result that the capacitor assumes a further charge. Thus, the capacitor is charged and discharged 60 times each second; or, it passes through one cycle of charge and discharge as each 60-c.p.s. impulse is introduced through the circuit.

The amplitude of the saw-toothed voltage is a function of the adjustment of R_5, since the value of inserted R controls the amount of charge on the capacitor across which the saw-toothed waveform is constructed. The resistor R_6 is employed in peaking the saw-toothed wave. It serves to predistort the saw-toothed wave to compensate for distortion introduced by the inductive load on the saw-toothed wave amplifier when the 60-c.p.s. saw-toothed wave is admitted to the vertical coils of the electromagnetic deflecting yoke. The value of R_6 is adjusted until linear vertical scanning is obtained. The adjustment is accomplished with vertical test bars, which are discussed elsewhere in the text (pages 145–146). These test bars are superimposed upon the raster of a cathode-ray tube monitor (see Fig. 5.58).

The same circuit may be adapted to horizontal scanning at the line frequency of 15,750 c.p.s. If the circuit is modified for generating the horizontal saw-toothed waveform, R_6 is entirely eliminated. The coupling capacitors are made 0.05 μf., R_4 and R_5 are each made 0.04 μf., and C_1 and C_2, are made about 0.0001 μf. The circuit will function then as described above: a 15,750-c.p.s. pulse is introduced at the grid of the first triode section of the 6N7 and results in the required horizontal waveform at the output.

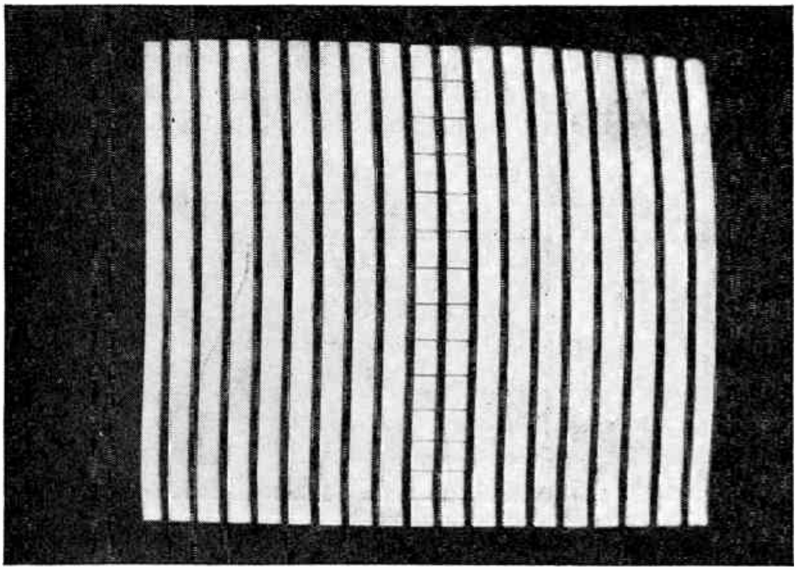


FIG. 5.58 Vertical and horizontal test bars superimposed.

5.30 Vertical Deflection Amplifier. The vertical saw-toothed voltage just described may be amplified and applied to the vertical deflection coils of a magnetic cathode-ray tube or to the vertical deflection coils

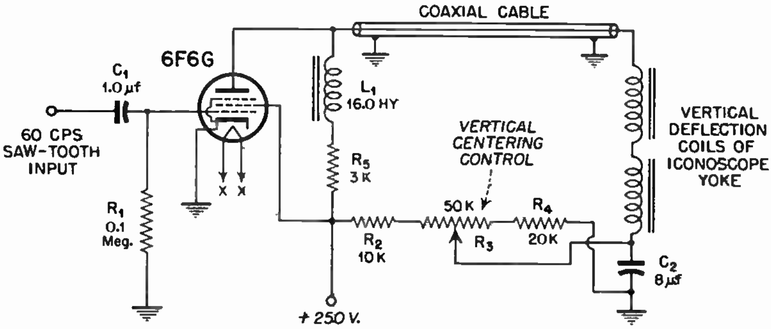


FIG. 5.59 Vertical deflection amplifier.

of an Iconoscope. For Iconoscope vertical deflection, an amplifier such as that shown in Fig. 5.59 may be required.

It is seen that the plate voltage is shunt-fed through a 16-h. choke, the output deflection current passing through the two vertical Iconoscope deflection coils and an 8-μf. electrolytic capacitor to ground. The 50,000-ohm potentiometer controls a small d-c component of current, which is permitted to flow through the deflection coils. By controlling the amount of d-c potential permitted to flow through the vertical deflection-coil windings, vertical centering of the mosaic of the pickup tube is achieved. As this control is operated, the image will be seen to move vertically across the mosaic of the Iconoscope.

In the application of such an amplifier for vertical deflection at the Iconoscope, it is common practice to locate this amplifier in the control room along with other camera-control equipment, the vertical saw-toothed output being transmitted to the studio camera over a suitable length of coaxial cable. It is also possible to locate the vertical Iconoscope deflection amplifier at the camera, the centering control being associated with other supervisory controls in the video control room, and the 50,000-ohm potentiometer being connected to the deflection amplifier at the camera by means of a suitable cable.

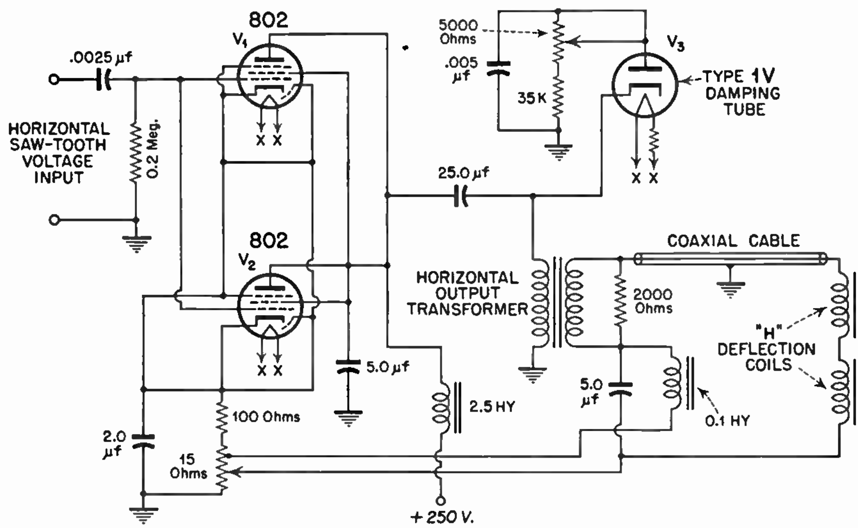


FIG. 5.60 Horizontal deflection amplifier.

5.31 Horizontal Deflection Amplifier. The deflection coils of an Iconoscope deflection yoke do not have the same number of turns for both the horizontal and vertical sets of coils. Fewer turns are provided in the vertical coils. Thus, large current is required for this low-impedance winding to provide the necessary deflection. Tubes such as types 807, 802, 6L6, and so on, are ordinarily employed in the final horizontal deflection-amplifier design. A circuit employing two type 802 vacuum tubes parallel-connected is shown in Fig. 5.60.

The output of the parallel-connected amplifiers is fed through a horizontal output transformer of special design and has a step-down ratio of 15 : 1. A coaxial cable connects the secondary with the horizontal deflection coils of the Iconoscope yoke. Additional information concerning the yoke construction has been given in the chapter describing electron tubes for image pickup.

Horizontal centering of the image is obtained through the introduction of a d-c component of current in the *H* deflection coils of the Iconoscope yoke. The d-c component of current is the result of a voltage drop across a part of the 15.0-ohm potentiometer, which in part provides cathode bias for the parallel-connected type 802 vacuum tubes.

One difficulty in horizontal amplifier design and operation is that due to oscillation and is the result of shock excitation. The frequency of 15,750 c.p.s. for 525-line definition at 30 frames per second is required for the horizontal deflection system. However, the return trace of the saw-toothed wave occurs at an extremely rapid rate, although at the same frequency. Therefore, the rate of change of the primary current in the output transformer is greater than would normally obtain at the scanning frequency. The voltage drop across the transformer windings can be very high because of the reactive voltage drop at the horizontal frequency. High-voltage insulation is essential. Ceramic insulation must be used in the tube sockets, and all plate circuit wiring must be kept well dressed away from the amplifier chassis, so that it will not arc to ground.

When the saw-toothed generator directly provides excitation for the deflection amplifier, the polarity is such that a decrease in effective plate current obtains on the fly-back portion of the wave, i.e., on the return trace. A type 1V diode rectifier is so connected in the circuit that the tube is placed between the plates of the deflection amplifiers and ground, and the cathode of the diode rectifier is connected to the plates.

Since the amplifier plate current decreases on the fly-back time, the deflection amplifier plates and the cathode of the 1V diode become highly positive with respect to ground. The 1V is not conducting on this portion of the cycle. When oscillations due to shock excitation begin, the second alternation forces the plates of the 802 tubes and the cathode of the diode negative with reference to its plate; current passes; and a low-resistance shunt develops across the primary of the deflection transformer. The result is effective damping of the oscillation.

It has been mentioned that the peak positive voltage during the vertical sweep retrace may increase to 3,000 v. or more. The type 802 and 1V tubes will not provide long life under such high potentials. Therefore, it is necessary to insert a 5-ohm resistor in series with the heater winding of the 1V tube. The resistor effectively reduces the insulation temperature within the tube and thus permits it to withstand the high inverse peak voltage that obtains.

5.32 Keystone Correction. In the design of the Iconoscope, it was found impossible to make the mosaic perpendicular to the direction of the electron beam that was being emitted by the electron gun. Actually, the beam strikes the mosaic at an angle of 30 deg. from the perpendicular. This arrangement is necessary, since the reflected light, passing through the optical lens system of the camera, must reach the mosaic, and had the gun been placed perpendicular to the mosaic, it would have interfered with the transmission of light.

The result of placing the gun at a 30-deg. angle with reference to the normal is a keystone-shaped image at the Iconoscope output. The explanation is that the effective path that the electrons must take in reaching the mosaic is shorter in arriving at the lower edge of the target than at the top, the deflection of the beam being a function of the length of the beam. Without keystone correction the image will appear narrow at the lower edge of the picture and wider at the upper edge. It must be remembered that the image is inverted at the mosaic, since the light forming the image passes through the optical lens system before reaching the target of the tube. In other words, when the scanned line is narrower at the Iconoscope, it will appear broader at the receiver viewing tube.

A simple circuit intended to accomplish keystone correction is described in Fig. 5.61. A 6J7 tube is employed as the horizontal waveform generator. It is usually incorporated in the camera-control unit and is located in the video control room so that the engineer may effect instant correction. The tube is biased to cutoff. The capacitor C_2 charges through R_4 and R_5. A 15,750-c.p.s. saw-toothed wave from the synchronizing generator is introduced to the control grid, which causes the grid to go positive, with the result that the tube resistance is decreased, discharging C_2. The capacitor then charges again on the next 15,750-c.p.s. wave arriving from the synchronizing generator. This action takes place 15,750 times per second. The saw-toothed wave produced is used to drive the type 802 tubes parallel-connected, comprising the horizontal amplifier, the output of which is connected to the H deflection coils at the Iconoscope.

Keystone correction is obtained by introducing the 60-c.p.s. vertical saw-toothed waveform as indicated. It is seen that the plate and screen grid voltages are modulated with this voltage. The balanced modulation that results is obtained because the saw-toothed voltage developed across C_2 is made to vary without the average value across the capacitor changing. A decrease in potential across C_2 through R_4 obtains when the modulating voltage is in the negative direction. A reduction in screen voltage takes place at the same time and results in a reduction in plate-current discharge during the sync impulse and an increase in the minimum voltage at which C_2 discharges. The maximum and minimum voltages across C_2 can be made to vary at an identical rate providing the modulation components on the plate and screen grid are properly proportioned, the average voltage across C_2 remaining constant.

Keystone balance is brought about through adjustment of R_7 and provides the proper ratio between screen and plate-modulating potentials. The potentiometer R_6 is the keystone-amplitude control and regulates the amount of modulating potential applied to both plate and screen. If too small a modulating potential is applied, keystone correction will

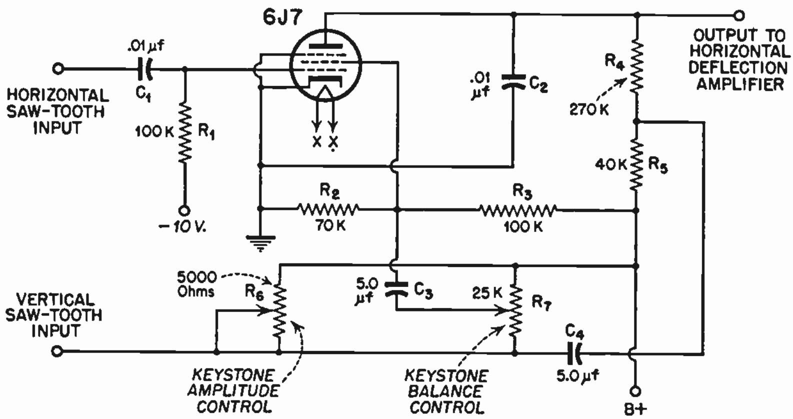


FIG. 5.61 Keystone-correction circuit.

not, of course, prove adequate. Overmodulation results in an inverted keystone pattern.

5.33 Line-to-Line Clamping Circuits. A clamping circuit has been defined as an arrangement whereby either amplitude extreme of a waveform is maintained at a certain level of potential. In modern television systems, line-to-line clamping techniques have come into widespread use. These circuits are found in practically all commercially produced equipment, particularly in camera chains and associated apparatus. Such circuits are employed to improve the effective low-frequency response of video amplifiers and to eliminate extraneous low-frequency pickup, such as 60-c.p.s. a-c which may be superimposed on the video signal. They are very satisfactory for the purpose.

To illustrate the operation of line-to-line clamping circuits, the simple diagram in Fig. 5.62 is shown. Let us assume that a sinusoidal waveform, such as that shown at (*b*), is impressed on the simple circuit illustrated through the small internal resistance r_0. If the switch *SW* is open, the applied waveform will appear unattenuated at the output.

If the switch is repeatedly closed at intervals of time Δt, as illustrated at (c), the output waveform will appear as shown at (d). It is obvious, therefore, that should the switch be opened and closed at a rate that is more rapid than the frequency represented by E, the result will be practically to remove E at the output. Such operation will also be true if the switch SW is made to function, or operate, at the horizontal frequency of 15,750 c.p.s., and the waveform E occurs at a rate of 60 c.p.s. This description of the simple circuit shown illustrates how a low-

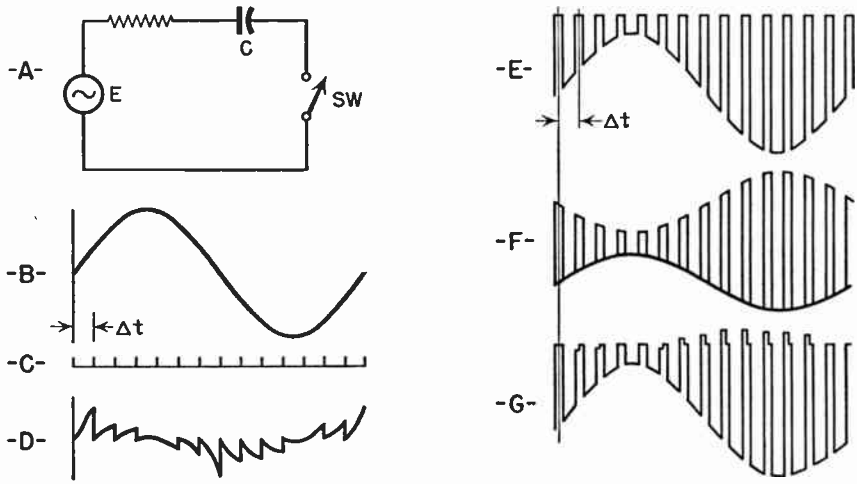


FIG. 5.62 An idealized clamping circuit and pertinent waveforms.

frequency source of interference may be eliminated from the principal waveform.

If the input waveform is made E instead of B (see Fig. 5.62) i.e., interrupted by pedestals which rise to a fixed and predetermined level, the same waveform will appear at the output. But if some circuit element is inserted ahead of C to result in the circuit having poor low-frequency response, then the waveform obtaining at the output will be as shown in f, if the switch SW remains in the open position. The low-frequency component is attenuated, but the pedestals will remain at identical amplitudes. Now, if the switch SW is closed at intervals of time Δt, this waveform will be converted to the waveform shown at g. If the switch is operated at a rate that is more rapid than the frequency of the wave represented by E, the effect will be to reproduce E at the circuit output without attenuation.

This explanation shows in simple terms how an improvement may be made of the effective low-frequency response of a video amplifier, such as is used in television. Of course, the actual line-to-line clamping circuits are much more involved although the principle of operation remains fundamentally the same. It is to be emphasized that the utility of a clamp in restoring the apparent low-frequency response depends upon the provision of a fixed pedestal at the instant the switch is closed. A typical clamping circuit is illustrated in Fig. 5.63.

The diodes in this clamping circuit function exactly as the switch *SW* of the simple circuit. It closes at the instant that the pulses are applied. Therefore, there is a replacement of any charge that was lost by *C* after the time of application of the last pulse of a train.

At the time the pulses are applied, points *A* and *B* shown in the dia-

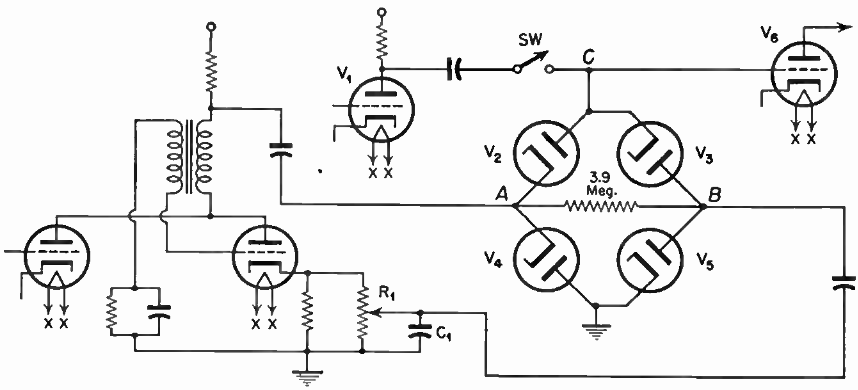


FIG. 5.63 Line-to-line clamping circuit.

gram are effectively short-circuited to ground through the diode resistance of tubes V_4 and V_5. The diodes are not a perfect short, however, so *A* and *B* will be essentially equal if the diode resistances are equivalent.

If we consider the two upper diodes (V_2 and V_3) and the clamped point *C*, all four diodes are nonconducting between pulses. When pulses are applied, V_2 and V_3 will conduct. The current will then flow from point *B* to point *A* through V_3 and V_2. If *SW* is opened, point *C* will assume ground potential, provided that $R_3/R_2 = R_5/R_4$. If the switch is closed, any positive potential applied at point *C* between pulses will result in current flowing from *C* to *A*, and this current flow will result in the potential at *A* changing. This effect depends upon the fact that a low impedance to ground is present at the instant of application and that the clamping pulse did not come from a source having low impedance. Should a negative potential be developed at *C* between pulses, current flow would pass through V_3, but the action would be similar.

The 3.9-megohm resistor connected between points *A* and *B* is employed to prevent point *A* from drifting in a negative direction, thereby rendering the clamp inoperative. Since point *C* is at high impedance, a portion of the pulse at A will appear at C as a result of the cathode-plate capacity of V_2. By the same token, a pulse will appear at C from point B. When the signals at A and B are completely balanced in phase and amplitude, nothing will appear at C. There will, however, develop a slight unbalance, since the cathode clamping pulse will tend to increase more rapidly than the plate clamping pulse. Balancing of the pulses may be accomplished through use of R_1 and C_1. R_1 is employed to balance the amplitude of pulses, and C_1 is used to delay slightly the cathode pulses.

BIBLIOGRAPHY

1. Cocking, W. T., "Synchronizing in Television," *Wireless World*, January 22, 1937, p. 74.
2. Tyers, P. D., "Television Scanning and Synchronizing," *Wireless World*, August 6, 1937, p. 115.
3. Wheeler, H. A., and A. V. Loughren, "The Line Structure of Television Images," *Proc. I.R.E.*, Vol. 26 (May, 1938), p. 540.
4. Engstrom, E. W., and R. S. Holmes, "Television Deflection Circuits," *Electronics*, January, 1939, p. 19.
5. A Television Bibliography, *Electronics*, March, 1939, p. 47.
6. Ridgeway, D. V., "Line Deflectors," *Wireless World*, June 15, 1939.
7. Tyres, P. D., "Scanning Coil Construction," *Wireless World*, Sept. 14, 1939, p. 248; Sept. 21, 1939, p. 279.
8. Fink, D. G., *Principles of Television Engineering*, McGraw-Hill Book Company, Inc., New York, 1940.
9. Zworykin, V. K., and A. H. Morton, *Television*, John Wiley & Sons, Inc., New York, 1940.
10. "Standards of Good Engineering Practice Concerning TV Broadcast Stations," Released by F.C.C., Dec. 20, 1945.
11. Applegarth, A. R., "Synchronizing Generators for Electronic Television," *Proc. I.R.E.*, March, 1946.
12. Townsend, C. L., "The Clamp Circuit," *Broad. Engrs. J.*, Part I, January, 1947; Part II, April, 1947.
13. *Television*, Vol. III (1938–1941), RCA Victor Division, Radio Corporation of America, Educ. Division, Camden, N.J., 1947.
14. *Television*, Vol. IV (1942–1946), RCA Victor Division, Radio Corporation of America, Educ. Division, Camden, N.J., 1947.
15. Friend, A. W., "Television Deflection Circuits," *R.C.A. Review*, March, 1947.
16. Morrison, H. L., "A Precision Device for Television Pulse Width and Slope Measurement," *R.C.A. License Bulletin* LB-717, June, 1947.
17. Schoenfield, E., W. Brown, and W. Milwitt, "New Techniques in Television Synchronizing Signal Generators," *R.C.A. Review*, June, 1947.
18. Poch, W. J., "Sync Generator Frequency Stability and Remote Pick-ups," *Communications*, July, 1947.

19. BLEWITT, J. P., and J. H. RUBEL, "Video Delay Lines," *Proc. I.R.E.*, December, 1947.
20. Bulletins of the Radio Manufacturers Association that are related to standards in the television industry.

REVIEW QUESTIONS

5–1. Explain the function of the synchronizing generator in the modern television system.

5–2. What is meant by (a) "line frequency"? (b) "field frequency"? (c) "equalizing impulse frequency"?

5–3. How are the vertical synchronizing blocks formed?

5–4. Discuss (a) the horizontal synchronizing signal; (b) the vertical synchronizing signal.

5–5. (a) What are the equalizing impulses, and how may they be formed? (b) Describe the frequency-divider system of a modern synchronizing generator.

5–6. Define the following terms: (a) saw-toothed waveform; (b) square wave; (c) integrating network; (d) differentiating network.

5–7. Explain how the signal at field frequency may be synchronized with the utility power-line frequency.

5–8. (a) What is meant by the horizontal blanking signal? (b) Define (1) front porch; (2) back porch.

5–9. (a) What is the time duration of one active horizontal line of the picture? (b) What is the time duration of the horizontal blanking signal?

5–10. (a) What are the serrated vertical pulses? (b) How are they formed?

5–11. Discuss the operation of (a) the multivibrator; (b) the blocking-tube oscillator; (c) the counter-circuit timer.

5–12. Describe the operation of an equalizing impulse multivibrator.

CHAPTER 6

THE VIDEO AMPLIFIER AND CATHODE FOLLOWER

6.1 Introduction. In the typical television system there exist a number of video amplifiers between the output of the pickup tube in the camera and the viewing tube at the receiver output. These amplifiers are all similar with respect to over-all frequency-response and phase-shift requirements. However, they are dissimilar in certain operating requirements, voltage and power capabilities, and the services they are

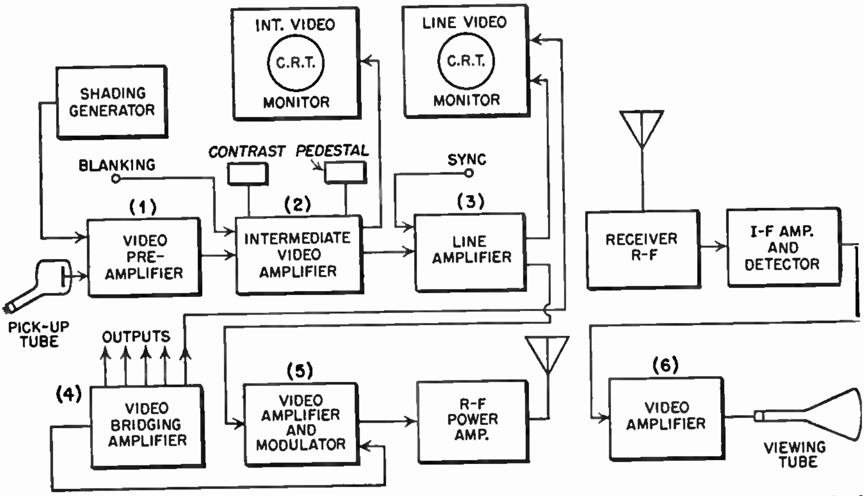


FIG. 6.1 Block diagram showing relative positions of video amplifiers in a typical high-definition television system.

called upon to perform. Their design and construction determine to a greater extent than any other part of the system the faithfulness with which the television picture is finally reproduced at the receiver viewing tube. For this reason they are of paramount importance to the television engineer.

Figure 6.1 illustrates the positions that these video amplifiers occupy in a modern high-definition television system. It will be seen that the arrangement includes six amplifiers, each specifically designed to satisfy a special operating requirement. They may be described as the *video preamplifier* (located in the television camera); the *intermediate video* *amplifier;* the *video line amplifier;* and the *video bridging* or *distribution amplifier* (the latter three being situated in the control room); the *video modulator* (a part of the video transmitter); and the *video amplifier* of the television receiver. All are important in a completely modern system designed for the transmission and reception of a high-definition television picture.

The first amplifier in the chain of equipment is the *preamplifier,* located in the television camera housing. Its purpose is to increase the voltage at the output of the pickup tube to a level suitable for transmission over a coaxial cable to the input of the video intermediate amplifier situated in the control room. With normal light level in the studio, the voltage at the output of the pickup tube is at very low level, approximating 0.01 v., peak to peak. The exact amplitude of the voltage at this point in the system is a function of the incident light at the mosaic of the pickup tube, the beam current employed in this device, and other considerations of lesser importance. The magnitude of this voltage must be increased to a minimum of about 0.1 v. before transmission over the interconnecting coaxial cable. The increase is made so that the signal voltage will be of such amplitude as to overcome the effect of extraneous noise fields which might otherwise result in appreciable induced noise voltages in the cable, thereby limiting picture quality. To satisfy this requirement, the preamplifier usually incorporates three or five stages of video amplification.

If shading-correction voltages are injected at low level, as indicated in the typical system described, they are introduced at the signal input of the preamplifier. In some systems, other than that shown, shading voltages are introduced at high level. The shading potentials are injected either at the intermediate amplifier or at some other convenient point where the signal level is high. The preamplifier must be very carefully designed because of the low signal level at the system input.

The *intermediate video amplifier* is in reality a signal-mixing and control amplifier. It is an important part of the control-room equipment and is connected electrically between the output of the camera preamplifier and the video line-amplifier input. The coaxial cable connecting the preamplifier at the camera terminates at its input. It therefore receives the video output of the preamplifier. Into this voltage amplifier are usually injected the pedestal and blanking voltages. The magnitude of the pedestal voltage (the base upon which the horizontal sync signal is constructed) determines the relative or over-all brightness of the reproduced picture. The blanking voltage eliminates the return trace of the scanning beam. Picture contrast is also under control in the video intermediate amplifier. The gain of an early stage in this amplifier (usually the first stage) is adjusted manually through means of a voltage-dividing input potentiometer to accomplish the purpose. In some instances the synchronizing voltage is injected in the intermediate amplifier, but always after the blanking and pedestal voltages have been applied. In the conventional video intermediate amplifier five or six stages are employed, the number of stages and the circuit design varying among the several equipment manufacturers.

In one type of video intermediate amplifier, two outputs are provided. One output, through coaxial cable, drives the line amplifier. The second output transmits video, pedestal, and blanking to a cathode-ray tube picture monitor. The monitor is provided with separate sync. Thus, it is possible for the operator to monitor continuously the output of the camera chain, of which the intermediate amplifier is a part, and at a point in the system at which the signal is transmitted to the line amplifier and video mixing system.

The *video line amplifier* accepts the output of the intermediate amplifier. Its several stages of amplification increase the signal voltage to sufficient amplitude for transmission over a suitable coaxial cable to the video master control room or transmitter. Whatever the case, the peak signal-output voltage is in the order of 1.5 to 2 v. In one typical line amplifier four stages are employed, one of which is a cathode-follower stage. If the synchronizing voltage, adding receiver sync to the video wave, is injected at the line amplifier, a sync amplifier is provided to increase the amplitude of this voltage to that proper for injection. The output of the line amplifier, therefore, usually introduces a composite signal into the coaxial cable that it feeds. This composite signal is comprised of video, shading, pedestal, and synchronizing voltages. In some installations, where one master control room receives the outputs of several studio control rooms, it is preferred to insert sync at the master control room at a common point in the system, after all switching, and it is fed to each of the viewing monitors. A composite signal is fed to each control room for injection at viewing monitors. The horizontal and vertical saw-toothed voltages and the blanking voltage are likewise fed to the individual control rooms from a common synchronizing generator. However, the synchronizing voltage for synchronizing receivers in the field is injected at an amplifier in the master control room.

If several viewing monitors are utilized in the studio control room, one connected at the output of each intermediate video amplifier so that the output of each chain may be viewed before mixing is accomplished, then these monitors must be fed separate sync. A dual triode (such as a 6SN7) can be employed in the line amplifier as a sync signal amplifier and phase inverter. The sync signal reaching the line amplifier from the synchronizing generator is amplified and the phase inverted before it is fed to each of the viewing monitors. A composite signal is fed to the line-amplifier viewing monitor, i.e., the cathode-ray tube viewing monitor employed for monitoring the output of the line amplifier.

Ordinarily, several cathode-follower stages are electrically connected to the line-amplifier output. These are in addition to the normal output. One stage provides composite signal to an oscillograph so that the information contained in the composite signal may be examined, analyzed, and continuously monitored during normal operation. Another cathode follower supplies composite signal to the cathode-ray tube line-viewing monitor, so that the picture itself may be continuously viewed by the video engineer, or operator, as well as other interested members of the control-room staff.

If several camera chains are employed, mixing and switching of several video intermediate amplifier outputs usually take place at the line-amplifier input. This is the most convenient point in the system for effecting the necessary switching of camera chains. At relatively high level, a minimum of noise is introduced into the system when switching and mixing is so accomplished. A convenient arrangement of push buttons, relays, and mixing potentiometers, all arranged in a suitable circuit, permits the development of fades, lap dissolves, superimpositions, and other scene transitions required by the program staff. In one system an all-electronic signal mixing system is made use of.

The *video bridging or distribution amplifier* is employed to amplify the composite video signal and distribute it by means of coaxial cable to a number of locations where viewing monitors are operated. At least one such unit is almost always installed at each video control room. In large installations several are rack-mounted, the inputs and outputs of each being terminated at a convenient video patch panel. Thus, the composite signal "on the air" may be fed back to the remote studio by master control, or from the transmitter location by means of coaxial cable, and patched into the input of the bridging amplifier. Its several cathode followers in turn can then supply composite signal to viewing monitors in offices, teletheaters, clients' rooms, or other desired locations. It is customary for at least one output to be patched to the video control console, where the video engineer may, by means of a suitable switching arrangement, instantaneously connect the input of the line-amplifier viewing monitor to either the output of the line amplifier or the bridging-amplifier output. The engineer is thus able to compare the quality of the picture being transmitted with that of the output of the control-room line amplifier. The arrangement is also useful in facilitating program cueing, especially where several individual control rooms feed programs to a common transmitter or master control room.

Once the composite video signal reaches the transmitter, it enters the *modulator*. The signal voltage and power at the modulator's output must be of such magnitude as to modulate completely the radio-frequency carrier available at the radio-frequency power amplifier. The complete modulation system will be later discussed in the section devoted to video transmission (pages 555–558). It suffices to say here that the level required at the modulator output and the total installed tube capacity required are, in turn, a function of the design incorporated in the radio-frequency power amplifier. Since the d-c component of picture brightness must be transmitted, it follows that direct coupling is necessary between the video modulator and the radio-frequency modulated amplifier. However, the modulator must possess identical characteristics as to frequency response and phase shift, as do the preceding video amplifiers operating at lower signal level in the system.

The remaining *video amplifier* shown in the typical layout is connected between the second detector of the television receiver and the grid of the receiver-viewing tube. It, too, must possess excellent frequency response and must be corrected for phase shift throughout the required pass band if satisfactory pictures are to result. The number of video stages employed between the second detector and the viewing tube is a function of the polarity of the signal at the output of the detector and the required gain. If the picture phase is negative at this point in the system, its current or voltage increases in magnitude as the picture elements become darker. An odd number of video stages must then be employed, since each amplifier reverses the phase by 180 deg. It is assumed that the output of the final receiver video amplifier is connected to the modulating grid of the picture tube. The number of stages that are employed may be any odd number of stages necessary to obtain sufficient signal amplitude to modulate the grid of the cathode-ray viewing tube. If positive picture polarity obtains at the output of the second detector of the video receiver, then an even number of stages is necessary. Although the picture phase is changed 180 deg. each time it passes through a video-amplifier stage, this has nothing to do with phase distortion. Only the polarity of the picture undergoes a change. No time delay is introduced by the vacuum tube through which the picture signal passes.

6.2 Frequency and Phase Distortion in Video Amplifiers. The video amplifier, whatever its purpose in the television system, will fail to reproduce faithfully the original scene before the studio cameras if it does not fulfill certain very definite requirements as to minimum frequency and phase distortion. Actually, the video amplifier must demonstrate negligible attenuation at any pass frequency throughout a very broad band. This band extends from 60 c.p.s. for television systems employing 30-frame interlaced scanning to well above 4 mc. per sec., or higher. The frequency response must not deviate more than 2 per cent at the minimum and maximum pass frequencies, as compared with response at the mid-frequency called for in the amplifier design. At first sight this over-all response requirement will appear difficult of achievement to those engineers more concerned in the past with audio-amplifier construction. However, with reasonable care in design and construction, the standard is fully met.

Phase shift must be linear with respect to frequency throughout the pass band. This means there must be constant time delay over the entire useful frequency range. Since the video amplifier is similar in

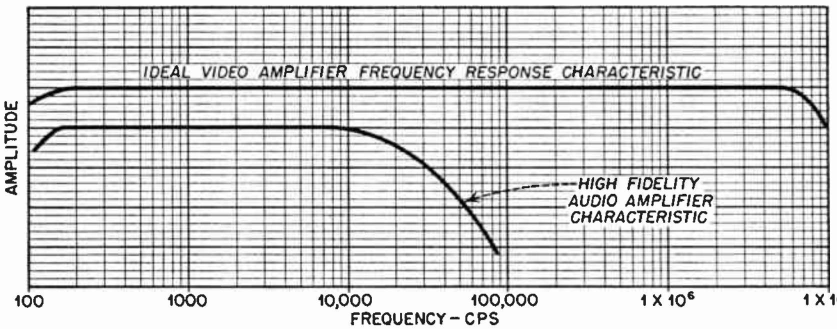


FIG. 6.2 Comparative gain-frequency characteristics of a high-fidelity audio amplifier and an ideal video amplifier employed in television systems.

many respects to the conventional *RC*- (resistance-capacity) coupled audio amplifier, it is well to discuss first the factors limiting the frequency response and phase shift in such an amplifier. This discussion will afford the engineer or student a better insight into the development of the video amplifier. Actually, there are only two respects in which the video amplifier differs from the *RC*-coupled audio amplifier. The video amplifier must be designed to pass a band of frequencies several megacycles wide without discrimination and must present constant time delay over this frequency range. Plots of two frequency-response curves are shown in Fig. 6.2. One curve illustrates the bandwidth requirement in a high-fidelity audio-frequency amplifier, and the other indicates the wide-band response of a typical video amplifier. Considering the upper-frequency limit of the high-fidelity audio amplifier to be 15,000 c.p.s., the video amplifier must pass a band of frequencies 300 times wider.

A conventional *RC*-coupled stage of audio-frequency amplification is shown in Fig. 6.3. Both pentodes and triodes are employed in video amplifiers, as in audio amplifiers. However, the pentode is the preferred type, owing to its higher trans-conductance. It is difficult to design wide-band video amplifiers with sufficient voltage gain when triodes are used exclusively. For this reason, the discussion of the *RC*-coupled amplifier stage will concern one in which a pentode is specified. Since the plate-load impedance Z_p is always of less value than the grid resistor R_g in the typical video voltage amplifier, this factor will be assumed throughout the treatment.

To perceive fully the limitations as to frequency response in the conventional *RC*-coupled amplifier, it is well to consider the plot of output

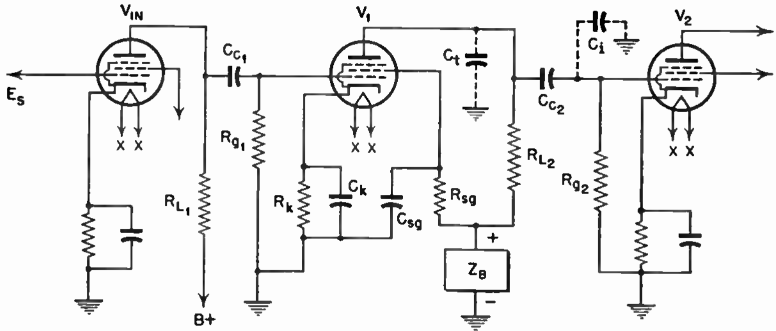


FIG. 6.3 Conventional *RC*-coupled amplifier stage.

voltage versus frequency shown in Fig. 6.4. At f_o the output voltage is zero. With an increase in pass frequency, the output voltage of the amplifier rises to 70.7 per cent of the maximum at f_1, increases to a maximum at some frequency above f_o, and then remains constant over a broad band

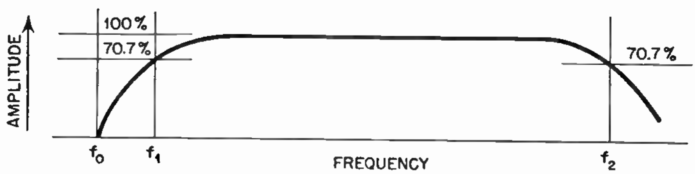


FIG. 6.4 Gain versus frequency characteristic of a typical *RC*-coupled amplifier.

until a frequency is reached at which the output voltage begins once more to decline. At f_2 the output voltage is again 70.7 per cent of that reached at maximum throughout the mid-frequency range. The reason for the reduction in output voltage at pass frequencies below f_1 is the capacitors employed in the amplifier circuit. The capacitive reactance of these components is inversely proportional to both frequency and capacitance. Attenuation at the higher or lower pass frequencies will also be a result of the location of the various circuit capacitances, including shunt capacitance. The reactance developed at the coupling capacitances C_{c1} and C_{c2} (see Fig. 6.3) serves to retard the flow of current in parts of the circuit where they may be located. Excellent low-frequency response is obtained by making C_{c1} and C_{c2} sufficiently large, so that at the lowest frequency for which the amplifier is designed X_C is small compared with the value of $R_{g1 \text{ and } 2}$. At high frequencies, the reactances of distributed and tube capacitances decrease and effectively by-pass $R_{L1 \text{ and } 2}$ reducing Z_L, the load impedance, and stage gain.

A limitation on the high-frequency response is imposed by the output capacitance of the tube C_t, the distributed capacitance C_d, and the input capacitance of the succeeding stage C_i. These reactances act in parallel effectively to shunt the load resistance R_L. The most serious limitation, insofar as low-frequency response is concerned, is imposed by the time constant R_gC_c. This constant must be long as compared with the period of the lowest pass frequency suggested in the design.

If the gain of the amplifier is not essentially linear throughout the pass band, frequency distortion will result; in other words, the shape of the complex wave introduced into the amplifier input will be altered at the output if all the harmonics or harmonic components of the wave fail to be equally amplified. It is well known that the reduction in gain at the higher pass frequencies, in which region the harmonics lie, is due to a finite reduction of the plate-load impedance due to the shunting effect of the distributed and interelectrode capacitances.

Linear phase shift is the same thing as constant time delay. If the phase delay is not the same at all pass frequencies, the introduced wave will evidence distortion when viewed at the amplifier's output. Phase distortion is usually not of consequence in conventional audio amplifiers, since the ear cannot detect the average phase shift encountered in such amplifiers. However, if the time delay is not equivalent at all pass frequencies in the case of the video amplifier, portions of the reproduced image will be displaced as compared with other portions of the identical scene. The result, of course, is disagreeable distortion which promotes eyestrain. The time delay over the frequency band passed by the amplifier must be zero or constant. Thus, if the time delay at each frequency throughout the desired band is equal, there will be a displacement of the picture as a whole. The time delay at any frequency within the pass band is related to the phase angle as follows:

$$\Delta t = \frac{\phi}{2\pi F}$$

where ϕ = phase angle.

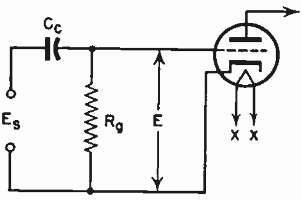
Thus, the phase angle is a direct function of Δt, and constant time delay demands that the phase angle increase or decrease linearly. Therefore, it can be seen that the phase angle must be linear with frequency throughout a band extending from about 60 c.p.s. to well over 4 mc. per sec.

The amount of detail seen in a television image is almost entirely a function of the high-frequency response of the video amplifiers in the system. The lower pass frequencies have little to do with fine-detail fidelity. This is true for frequencies as great as the line frequency of 15,750 c.p.s. The higher the amplifier frequency response can be made, the sharper the picture detail will become, because extremely fine picture detail, such as fine lines and small areas of different shades, produces high frequencies in the pickup tube. If the amplifiers that follow this tube are not able to pass these high-order frequencies with negligible discrimination, then much of the fine picture detail is lost, and the resulting image lacks "snap." The rectangular wave resulting from the Iconoscope beam passing sharply from dark to light or from light to dark over horizontal picture detail not only is constructed of the fundamental, or base, frequency, but includes a number of harmonic components as well. If the rectangular wave thus generated is transmitted without its harmonics, "rounding" occurs and results in the rectangular wave assuming a quasi sine-wave shape. Fine, sharp detail is then lost. It must be emphasized that the extended bandwidth requirement of the video amplifier is necessitated by the scanning frequency employed and the necessity for the undistorted reproduction of rectangular rather than sine-wave impulses. During the process of scanning an image reflected upon the mosaic of the pickup tube, the greater the detail, the more extended the frequency response required; and the more instantaneous the transition from black to white or from white to black, the more extended the bandwidth requirement. It must be remembered that in order to reproduce faithfully a rectangular wave possessing infinitely steep leading and trailing edges and a perfectly flat top, an infinite number of odd-order harmonics must be transmitted in addition to the fundamental frequency of the square wave. It has been shown that a rectangular impulse of repetition frequency of 15,750 c.p.s. (the horizontal frequency employed in the modern television system) and a time duration of 20 per cent of one cycle will require 200 harmonics. In other words about 3.15 mc. per sec. must be transmitted by the video amplifier in order to reproduce the impulse faithfully without distortion. A square wave of symmetrical shape would require the transmission of only 20 harmonics to be faithfully reproduced. Therefore, a television image containing a vertical line with width about 20 per cent of the width of the picture would require an upper frequency limit of 3.15 mc. per sec.

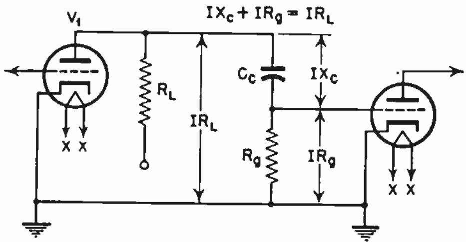
It should be observed that the higher the amplifier response can be made, the sharper the picture detail will become, and that as the high-frequency transmission capability of the video amplifier is improved, general picture quality improves in proportion.

6.3 Low-Frequency Distortion in Video Amplifiers. Low-frequency response in the video amplifier is of no less importance. It determines the faithfulness with which the vertical background shading of the picture is transmitted. In high-definition electronic television systems operating at 30 frames per second with 60 fields interlaced, the vertical dimension of the picture is scanned 60 times each second. Therefore, if the variation of illumination from upper to lower edge of the scanned area is to be faithfully reproduced, the video amplifier must be capable of transmitting a 60-c.p.s. component of the signal as brought about by the change in background illumination.

Again, in Fig. 6.3, it will be noted that the signal voltage E_s applied to the control grid of V_{in} is amplified and applied across R_{L1}, after which it must meet negligible capacitive reactance with respect to R_{g1} at the coupling capacity C_{c1}, if it is to be passed along to the control grid of V_1. Below 200 c.p.s., the effect of the coupling reactance is of great importance. And, as has been said, if the video amplifier must pass all frequencies in the low-pass region without discrimination (as low as 60 c.p.s.), then low-frequency compensation must be carried even lower, so that the gain at 60 c.p.s. will not be attenuated. It has been shown (Fig. 6.4) that there is no abrupt change from the mid-frequency response to zero-frequency response, the



SIMPLE ELECTRICAL EQUIVALENT OF THE GRID RESISTOR-COUPLING CAPACITOR NETWORK



THE R-C COUPLING CIRCUIT ACTS AS A VOLTAGE DIVIDER AT LOW-PASS FREQUENCIES

FIG. 6.5

response gradually declining as the pass frequency is reduced. Therefore, in judicious video-amplifier design, low-frequency compensation is introduced down to about 30 c.p.s. This compensation absolutely ensures that there will be no serious frequency discrimination at the desired lower limit of 60 c.p.s.

There are four points in the circuit where low-frequency attenuation may occur. Of first importance as a possible source is the grid resistor–coupling capacitor network shown in Fig. 6.5. With the signal voltage E_s constant, the impressed voltage E obtaining across the circuit grid to cathode is a function of the grid resistance R_g over the impedance of R_g and C_c

$$\left(\frac{R_g}{\sqrt{R_g^2 + X_{Cc}^2}}\right).$$

The ratio of impressed voltage (grid to cathode) to input signal voltage may be expressed as E/E_s. Thus, it is seen that

$$\frac{E}{E_s} = \frac{R_g}{\sqrt{R_g^2 + X_{Cc}^2}}$$

The reactance X_C of the coupling capacitance C_c is inversely proportional to frequency. Thus, the ratio of resistance to impedance, as well as the ratio of impressed voltage E to input signal voltage E_s, is reduced as the frequency is lowered. Although the tube gain is the same for all pass frequencies, less grid voltage will therefore be available to drive the next stage at the lower frequencies.

In determining the effectiveness of the grid resistor–coupling capacitor network at the lower frequencies, it is the usual practice in amplifier design to calculate the coupling efficiency of the R_gC_c combination at 1,000 c.p.s. and then to compare this value with the percentage of coupling efficiency at 30 c.p.s. They should approach an equality if no low-frequency discrimination is to occur. Therefore, correction must be attempted at this point in the circuit.

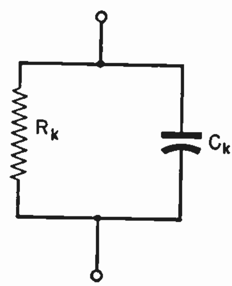


FIG. 6.6 Theoretical electrical equivalent of the cathode RC network.

Low-frequency distortion may be introduced by the cathode resistor–capacitor network (Fig. 6.6). It is the result of degeneration. It may be that the required grid bias for the amplifier is obtained by making use of the voltage drop across a resistor series connected with the cathode. The total electron current flowing through the tube must pass through this resistor, and in the case of the pentode it is the sum of the screen and plate currents. Because the total electron current flowing through the cathode resistor is subject to variation, since the applied signal voltage E_s varies, a varying voltage develops across the cathode resistor R_K. In order to provide a steady value of grid bias for the tube, the signal voltage is by-passed around the cathode resistor by means of a cathode by-pass capacitor. To ensure a low-impedance path around the cathode resistor for the alternating components of the signal voltage, the impedance of the by-pass capacitor must be made very low. The time constant of R_KC_K must be made very long as compared with the period of the lowest pass frequency. The determined value of C_K is usually in the order of 100 μf., or more.

The reason for degeneration at this network is because its impedance varies with pass frequency. If cathode degeneration is allowed to occur, the gain of the stage is decreased by the factor $\frac{1}{1 + G_m Z_K}$.

The gain of the stage is expressed as

$$A = (A_1)\left(\frac{1}{1 + G_m Z_K}\right) = \frac{A_1}{1 + G_m Z_K}$$

where A = actual gain of the stage
A_1 = stage gain without degeneration
Z_K = cathode-circuit impedance (parallel combination of the cathode resistor and by-pass capacitor) expressed in ohms

In design work, it is usually the practice to calculate the actual stage gain as expressed by the above equation at both 1,000 and 30 c.p.s. The output of the stage, insofar as the network impedance Z_K is concerned, should approach an equality at both frequencies after correction.

The screen-grid resistor–by-pass capacitor combination, $R_{sg}C_{sg}$ (Fig. 6.3) may also result in low-frequency degeneration. The screen current is normally about 10 per cent of the plate current, the screen-plate transconductance approximating 12 per cent of the control-grid or cathode-plate transconductance. Degeneration can be avoided in the screen-grid circuit by selecting the values of the screen-grid by-pass capacitor so that the time constant resulting will be at least three times as long as the period of the lowest pass frequency chosen in design specifications. Thus

$$T_C = RC > \frac{3}{f}$$

where C is in farads, R is in ohms, and f is a constant equal to 30 c.p.s., approximately.

It has been shown that the total impedance of the screen grid circuit Z_s is, for all practical purposes, equal to the reactance of the screen-grid by-pass capacitor. In cathode-circuit degeneration, if the product $G_m Z_K$ is made equal to 1, the gain will be reduced 50 per cent. The effect of the screen grid is much less, a reduction in gain at an equivalent low frequency being only 2 per cent if $G_m Z_s$ is made equal to 2.

In selecting the proper value of screen-grid by-pass capacitor the following method is recommended. Since the screen-grid circuit impedance is equal to the reactance of the screen-grid by-pass capacitor and 2 per cent reduction in low-frequency response is all we may tolerate, then it is well to determine first the capacity reactance required.

$$X_C = \frac{2}{G_m}$$

where G_m = control grid-plate transconductance

After solving for X_C above, which is taken at 30 c.p.s., we next obtain the value of the required capacitance.

$$C = \frac{X_C}{2\pi F}$$

The value of the screen-grid resistor is determined as follows:

$$TC = RC > \frac{3}{f}$$

Thus,

$$RC = \frac{3}{f} \qquad \text{and} \qquad R = \frac{\frac{3}{f}}{C_{sg}}$$

where f = lowest frequency to be passed
R = value of the screen resistor in ohms
3 is from the equation for RC, since the time constant of the network must be three times as long as the lowest pass frequency

The screen current should approximate 10 per cent of the plate current for judicious design. If, after the value for R is determined, it is found that the screen current is improper, then R must be set for the screen-grid requirement and C calculated.

Video-amplifier low-frequency compensation by the introduction of a discrete impedance in the screen-grid circuit has been discussed in the literature and design formulas derived. Comparisons of this type of compensation with compensation effected exclusively in the plate circuit have been made. The results indicate that although combined screen and plate compensation offer appreciable gains in performance, its application is somewhat limited by practical considerations, such as variations in dynamic screen resistance, increased susceptibility to over-all amplifier regeneration, and the possibility of amplitude distortion where large screen and plate swings are encountered at the same instant. A wide variation in screen resistance among different samples of tubes of a given type has been found, and tube replacements in an amplifier employing screen-grid compensation result in a tilt of the previously balanced wave.

The use of large values of screen-grid by-pass capacitance, as shown, is preferred to any attempted compensation in the screen-grid circuit. If the methods shown in the text are followed, degeneration can be avoided in this circuit. Frequency compensation can be more expeditiously accomplished in the plate circuit by methods to be shown.

The fourth point in the circuit at which low-frequency distortion may occur is in the internal impedance Z_B of the power supply. The use of a well-regulated power supply is essential in the operation of high-fidelity video amplifiers. Otherwise, Z_B will be, for all practical purposes, equal to the reactance of the output filter capacitor of the power supply. This component would have to be very large in value in order to ensure regulation and proper harmonic attenuation. The reactance of the large capacitor would vary inversely with frequency. This impedance can be made to have little effect on the low-frequency response through the use of *RC* filters. The design of such filters will be treated later (pages 323 to 326).

Low-frequency distortion may also be a function of phase shift. The low-frequency characteristic of the amplifier determines the faithfulness with which the vertical background shading of the image is reproduced. A phase shift of only several degrees, due to the values chosen for the grid-leak–coupling-capacitor network, can result in rather serious time delay. At this point serious time delay in the circuit results in a change in intensity between the lower and upper portions of the reproduced image, assuming that a solid background color is being transmitted. If the background is not of solid color, the effect is even more pronounced. If several video-amplifier stages are operated in tandem, each stage possessing a similar time constant and phase shift of several degrees in each such network, the total effect can create quite serious distortion.

A square wave is ideal for investigating the low-frequency response of a video amplifier under development. This is because a background that is half solid black and half solid white along the vertical axis will result in a square wave at the amplifier output. The departure of the voltage shape from that of a true square wave is inversely proportional to the time constant of the R_gC_c network. The greater the product of R_gC_c, the more the output wave approaches that of a true square wave. Should the time constant of this network prove too low, the top of the square wave will be sloped instead of flat and the lower the product R_gC_c is made, the more pronounced is the slope.

The transmission characteristics of the R_gC_c network are such that

$$\frac{E_c}{E_s} = \frac{t}{CR}$$

where E_s = original voltage amplitude
E_c = voltage drop during a pulse
t = time of one pulse in seconds
CR = time constant of R_gC_c

In video-amplifier design, the grid-leak resistance must not be made too large, or instability will result. This is the effect of secondary grid emission in the tube. And C cannot be made too large, since the shunting effect on the higher pass frequencies will be too pronounced. Ordinarily, values for C_c extend from 0.04 to 0.25 μf., and R_g extends from 0.2 to 0.5 megohm. Exact determination of these values will be shown later (pages 323–326).

It should be pointed out that excellent low-frequency response in video amplifiers allows transients to be reproduced without the objectionable bounce experienced at times. This bounce takes the form of an instantaneous movement of the television picture in a vertical direction across the screen of the cathode-ray picture tube. The picture may be said to jerk up and down in the vertical plane, although the raster or time surface remains stationary. Amplifiers that fail to reproduce faithfully the lower frequencies in the pass band are most susceptible to bounce. The use of well-regulated power sources to supply the necessary d-c potentials to the amplifier will also minimize bounce, which usually results from sudden incremental changes in line voltage. There are, however, many other possible sources of this effect throughout the television system. The use

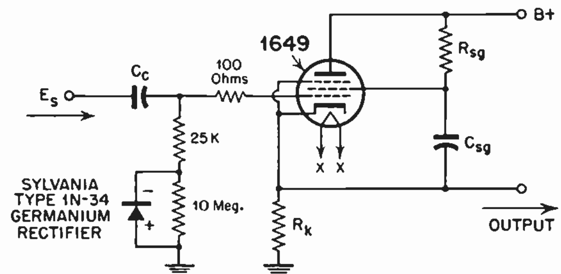


FIG. 6.7 Anti-"bounce" circuit employed at cathode-follower output stage of video preamplifier.

of a high-capacity capacitor in series with the coaxial line input at the line-amplifier output will remove direct current from this line, thereby eliminating, or minimizing, bounces that interfere with transmission when camera chains are switched at the mixing system. The use of a circuit device, such as a type 1N34 germanium crystal diode, in shunt with a fairly high resistance, the parallel combination connected from signal path to ground at suitable points throughout the video-amplifier system, will do much to reduce the bounce effect to the minimum (see Fig. 6.7). Any clamping device that is employed must be adjusted for instantaneous control, since bounces occur with great rapidity, and the surge must be instantly clamped.

6.4 High-Frequency Distortion in Video Amplifiers. High-frequency attenuation in video amplifiers is brought about almost exclusively by the reduction in plate-load impedance. This attenuation is a result of the shunting effect of the interelectrode and distributed capacitances encountered in a typical stage of amplification. With proper amplifier design and construction, the effects of the shunt capacitances are of no consequence below 100,000 c.p.s. The network responsible for high-frequency attenuation may be considered as comprising R_L, the load resistance, in shunt with three elements of capacitance, namely the tube output capacitance C_o, distributed capacitance C_d, and the input capacitance of the following stage C_i. The effective impedance of this network is

$$Z = \frac{R_L X_C}{\sqrt{R_L^2 + X_C^2}}$$

where X_C = capacitive reactance of the combined shunt capacitances, C_o, C_d, and C_i

The gain of a typical video amplifier is a direct function of the plate load impedance (see Fig. 6.8). Within the range of load resistances commonly encountered in amplifiers employing pentodes, the total gain is equal to the product $G_m Z_L$. At the lower frequencies, where the com-

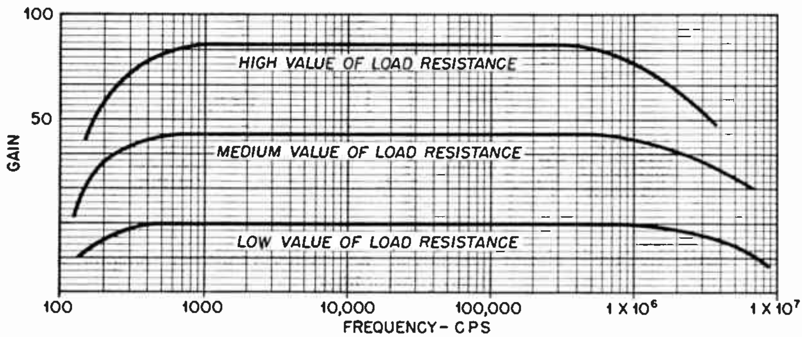


FIG. 6.8 Variation of voltage amplification with frequency in a typical video amplifier stage as the value of plate-load resistance (R_L) is changed.

bined effects of stray and shunt capacitances are of no concern, $Z_L = R_L$ and the total gain is equal to the product $G_m R_L$. Thus, the combined shunt reactances of C_o, C_d, and C_i impose a limitation on the high-frequency response of the amplifier. There must be a definite knowledge or a fair approximation, therefore, of the values of the combined capacitances before high-frequency compensation can be attempted. To some extent the combined effects of the shunting reactances can be minimized by reducing the value of R_L, but this cannot be carried too far since stage gain suffers as R_L is reduced. As the total reactance of the combined shunt and stray reactances approaches R_L, the load impedance Z_L decreases rapidly, with an accompanying reduction in stage gain.

The input capacitance of a vacuum tube is that interelectrode capacitance existing between the control grid and all other elements. The output capacitance of the vacuum tube is the interelectrode capacitance existing between the plate and all other elements of the tube. To determine the total output capacitance of a triode, the grid-plate capacitance

C_{gp} must be added to the plate-cathode capacitance C_{pK}. The reason is that the static interelectrode capacitances for triodes are usually listed in tube manuals, whereas the dynamic interelectrode capacitances (C_{in} and C_{out}) are shown only for tubes employing more than one grid element.

It has been pointed out by E. A. Henry of R.C.A. and many others that the *Miller effect* must be taken into consideration when the effective or dynamic input capacitance of a triode is determined. The grid and plate voltages of a triode amplifier are not in phase. So, if the grid voltage is increased 2 v. positive, the gain being 10, then the plate voltage will suffer a reduction of 20 v. The net change between grid and plate will be 22 v. and will result in a capacity current in the grid circuit much greater than that which would otherwise obtain. Therefore, the effective input capacitance of a triode is a function of the stage gain. The dynamic input capacitance of a triode is expressed as

$$C_{\text{in}} = C_{gK} + [C_{gp}(1 + A)]$$

where C_{in} = effective input capacity
C_{gK} = grid-to-cathode interelectrode capacitance
C_{gp} = grid-to-plate interelectrode capacitance
A = stage gain

The dynamic input capacity cannot be determined, therefore, without definite knowledge of the stage gain. Triode gain is expressed by the equation

$$A = \frac{\mu Z_L}{Z_L + R_p}$$

where A = stage gain
μ = amplification factor of the tube
Z_L = plate-load impedance of the tube
R_p = plate resistance of the tube $(\Delta E_p/\Delta I_p)$

The stray capacitances are difficult to determine. In judicious design it is advisable to measure the capacitance of each component to the nearest ground or the metal chassis, whichever is closer. The measurement should be made after the components are mounted on the amplifier chassis in what appears to be the most desirable locations. A dependable capacitance bridge is employed in making the measurements. The components may then be rearranged slightly, if necessary, to ensure the lowest possible stray capacitance for the particular layout. The sum of the distributed capacitances of all the components measured are then added numerically, and the final value is taken as the minimum distributed capacitance to be encountered. Since the stray capacitance of the leads cannot be determined before the amplifier is completely wired, an estimate should be made based on previous experience. In a well-designed amplifier the total distributed capacitance will usually lie between 10 and 25 $\mu\mu$f.

A shunt-peaking coil in the plate circuit of the video amplifier provides inductive reactance which may be used to compensate for the capacity reactance due to the strays. The upper or plate end of this inductance should always be kept well away from ground. This coil, of the high-permeability iron-core type, is adjustable as to total inserted inductance. Thus, the amount of inductance employed may be varied as the amplifier is aligned for flat frequency response. Since this coil can, of itself, present some distributed capacitance to ground, it should be mounted on a high-grade dielectric material. The principal axis of the coil should be kept at right angles with respect to the chassis.

To prevent high-frequency instability, shield cans may be employed over all peaking coils. Such shields should be of sufficient size to provide the desired shielding without being too close to the winding. To avoid coupling voltages circulating in the metal chassis, all ground connections for each stage must be made at a common point. The metal chassis should almost never be employed as a ground terminal point. Nor should machine screws that protrude through the chassis be so employed, since they only provide friction contact with the chassis. All ground leads should be as short and as direct as it is possible to make them. Coupling between adjacent stages can be minimized by orientation of the coils for the least evidence of instability or by the individual shielding of each amplifier stage. Proper shielding of one coil from another is very important. All interconnecting wiring in portions of the circuit where stray capacitance may produce a shunting effect at the higher frequencies must be kept well away from the chassis and at a reasonable distance from components over and about which they must pass. The physical lengths of such leads, particularly those in the grid or input circuits, must be kept to the absolute minimum. Otherwise, the finite capacitance of the leads themselves will prove too great.

Some time spent in experimentally laying out the placement of components before any circuit wiring is attempted, as well as in a study of the routing of interconnecting wiring, will prove very worth while. Because of the importance of keeping wiring in a position that affords the minimum shunting effect, some design engineers prefer to employ a rigid bus bar wherever possible.

6.5 Low-Frequency Compensation. In the discussion of low-frequency attenuation, it was shown that distortion could be introduced in any of four networks to be found in a typical stage of video amplification. Of these four networks, two can be eliminated as possible sources of low-frequency attenuation, provided that judicious and careful design and layout are employed. Of great importance is the use of a well-regulated power supply of low internal impedance. A discussion of the development of such supplies will be undertaken later. With the use of such a supply, the plate impedance Z_B is made independent of amplifier-current demand insofar as possible. The distortion at low frequencies, introduced by the network comprising the screen-grid resistor and by-pass capacitor, can be made entirely negligible through the selection of a suitably large value of by-pass capacitance, as has been previously shown.

Correction for low-frequency distortion introduced by the networks comprising the coupling-capacitance and grid-resistor combinations, respectively, can be obtained through the use of a suitably designed RC filter (see Fig. 6.9).

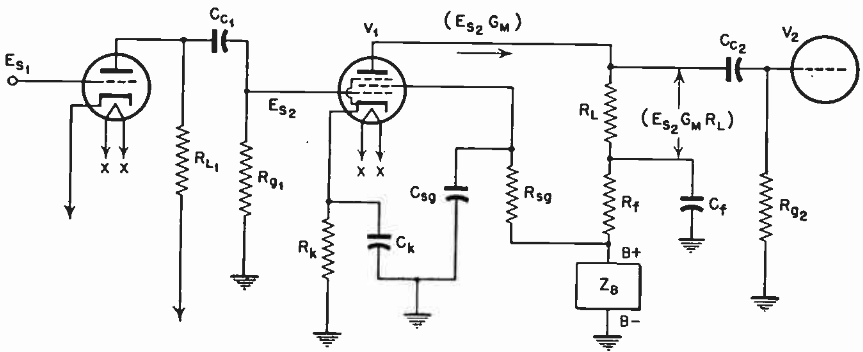


FIG. 6.9 Video-amplifier stage with low-frequency correction.

First, the grid resistor is chosen as a very large value, usually in the order of 0.5 megohm. A value of about 0.01 μf. is chosen for the coupling capacitor at the input to the first stage of amplification, as well as for the input to the second stage. This value is made large in order to have negligible reactance at the lower pass frequencies. At the same time, it should not be made so large that leakage might develop. It may be observed that by keeping the value of either C_{c1} or C_{c2} small, C_f also may be made smaller. Reducing the physical size of either C_{c1} or C_{c2} serves to reduce the shunt-circuit capacitance, thereby improving the high-frequency response by allowing a greater value of R_L to be employed, which also provides more gain.

The time constant of R_LC_f is made equal to the time constant of the network $C_{c2}R_{g2}$ at the input of the succeeding stage, R_f being made about twenty times the reactance of C_f at the lowest frequency to be passed by the amplifier. In other words, the product R_LC_f must approximately equal the product $C_{c2}R_{g2}$. This product is correct for all frequencies within the pass band of the amplifier at which R_f is ten (or more) times greater than the capacity reactance of C_f.

The result of this method of correction is that as the voltage across the grid resistor R_{g2} decreases because of an increase of reactance at the second coupling capacitance C_{c2} (as the frequency decreases), the capacity reactance of C_f also becomes greater. Thus, the shunt impedance of C_fR_f is added to R_L as a part of Z_L. In obtaining a proper understanding of what actually occurs in low-frequency compensation, the engineer must remember that a low-frequency square or rectangular wave is being passed by the video amplifier.

The wave being passed by the video amplifier consists of a low-frequency component, represented by its flat top, plus a number of high-frequency components, which are represented by the leading and trailing vertical edges or sides of the wave. Since the capacitance of C_{c1} or C_{c2} is fairly large, the reactance is such that the higher pass frequencies are transmitted without discrimination, the reactance of either coupling capacitor being inversely proportional to the frequency. Therefore, the networks $C_{c1}R_{g1}$ or $C_{c2}R_{g2}$ result in no appreciable attenuation. But the low-frequency component of the square or rectangular wave meets finite impedance in passing through either coupling capacitance, and the attenuation as well as the phase shift results in a sloping top. The amount by which the top of the wave slopes is inversely proportional to the time constants of $C_{c1}R_{g1}$ or $C_{c2}R_{g2}$. Therefore, rather large time constants are employed in these networks in video amplifiers.

In either case the transmission characteristic of the network to the square or rectangular wave is

$$\frac{E_c}{E} = \frac{t}{CR}$$

where E = original voltage amplitude
E_c = drop in voltage during the pulse
t = time of one pulse in seconds
CR = time constants of the networks $C_{c1}R_{g1}$ or $C_{c2}R_{g2}$

Thus, with the addition of the network R_fC_f below R_L, the high-frequency components of the square or rectangular wave are effectively by-passed around R_f to ground, the load resistance being equal to R_L. The top of the wave or low-frequency component, however, is not appreciably affected by the reactance of C_f. Thus, the Z_L is increased by the parallel impedance of R_fC_f in series with R_L. The final result is that the gain of the pentode is made greater by the amount of added impedance, and the discrimination at low pass frequencies due to $C_{c2}R_{g2}$ is counteracted effectively for all practical purposes.

In a video amplifier where R_L is small in comparsion with R_p, the gain from grid to plate is expressed by the equation

$$A = G_mZ_L$$

Through correction, the time constants of $C_{c2}R_{g2}$ and R_fC_f have been made equal, so that the voltage increases across Z_L in proportion to the reduction in voltage across R_{g2} will, for all practical purposes, remain fixed or a constant.

It has been shown that the network comprising R_KC_K can introduce low-frequency distortion in the video amplifier. Either optimum adjustment of C_fR_f or $C_{c1}R_{g1}$ may be used to afford correction, though correction through adjustment of C_fR_f is the preferred method. The a-c voltage developed across the cathode-circuit impedance is a function of the product of IK, the impedance varying with signal frequency. The voltage developed across the impedance will appear across R_L as amplified by the gain of the video stage. The plate current passes through both R_KC_K and R_fC_f, so like distortion will occur in either network if the time constants approach equality. However, the plate current does not flow in the same direction in the two networks, so the distortion across R_L that results from improper adjustment of R_KC_K will be canceled by the distortion occurring in the network C_fR_f, provided that the amount of distortion developing in either network is the same. Such an equality obtains when $R_KC_K = R_fC_f$ and

$$\frac{C_K}{C_f} = \frac{R_f}{R_K} = A$$

where A is the stage gain for pentodes, or where

$$A = \frac{\mu Z_L}{Z_L + R_p}$$

for the case of a triode stage.

If reasonable fixed values, depending upon the required bias, are established for R_KC_K, and the stage gain is known, then the finite values for C_f and R_f can be calculated.

$$C_f = \frac{C_K}{A}$$

$$R_f = A \cdot R_K$$

Thus,

$$R_K \cdot C_K = R_f \cdot C_f$$

$$1 = 1$$

The result of such correction is the absence of frequency distortion in the path plate to ground due to the presence of the network R_KC_K. Phase delay is proportional to frequency.

The interstage coupling capacitor may be allowed to project half way into each compartment by means of a hole of suitable diameter drilled through the wall of a shield separating the stages. The input and output circuits of each shielded stage can be separated insofar as practicable, and stray and circuit capacitance can be minimized by so arranging the components that the plate lead, the plate resistor, and the upper end of the peaking coils are as far removed as possible from the chassis and grounded components such as by-pass capacitors.

6.6 Obtaining Bias Voltage for the Video Amplifier. There are several methods by which grid bias may be obtained in the video amplifier. These are shown in Fig. 6.10. A bias battery may be used; a voltage divider in the negative end of the plate-voltage power supply; a cathode resistor and by-pass capacitor network, such as that just described; or a combination of several methods. Use of a bias battery is discouraged

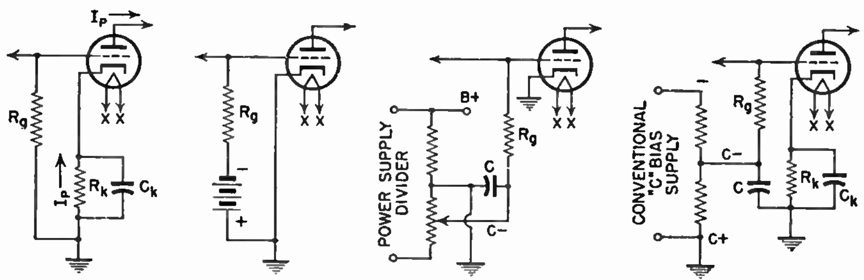


FIG. 6.10 Diagrams of four methods of obtaining bias for the video amplifier.

in commercial design, since the battery must be checked periodically to determine whether the terminal voltage has been reduced and this consumes time. Moreover, a battery is bulky and occupies too much space on the chassis. It will be found that a battery will introduce noise into the amplifier when its life is almost depleted, and sometimes the source of this noise is most difficult to locate.

The use of miniature bias cells, such as those used in radio receivers, should be avoided in video amplifiers. The mountings for these small cells are so constructed that a friction contact provides the necessary electrical connection in the circuit. High resistance often develops at the points of contact, or vibration causes the cells to become loose in their mounts, so that contact with the circuit is intermittent. As a result, "bounces" occur in the signal which are difficult to localize. "Bounces" from this cause may be eliminated by securing the bias cell in its holder with a ½-in. live-rubber grommet. The grommet is drawn tightly over and about the entire cell and holder. These small bias cells should never be used in camera preamplifiers, since the movement of the camera on its dolly transmits vibration to the cell in its mount and is certain to result in disagreeable "bounce" in the video signal.

The voltage divider in the negative end of the power supply is not recommended, since bias voltage is then dependent upon the total load current passing through the divider to supply the required potential. This current, in turn, is subject to change as the current demand fluctuates.

By using a cathode resistor and by-pass capacitor, space is conserved on the chassis and a constant network is then responsible for the required bias. The total plate and screen current of only one tube determines the bias, which means that there is less possibility of the bias voltage changing during operation. Also, a larger value of R_g is permitted. With the values of commercial low-voltage electrolytic capacitors readily available, it is quite easy to compensate down to a very low pass frequency in the network $R_K C_K$.

It is possible to employ inverse feedback in the video amplifier to improve low-frequency stability. This is accomplished by entirely eliminating the by-pass capacitor C_K. The gain of the stage is reduced when feedback is employed, and the susceptibility to instability is reduced. This condition is highly desirable if additional stages can be employed in a particular design to obtain the required gain, input to output.

With the resistor R_K by-passed by C_K and no feedback employed,

$$A = G_m R_L$$

where A is theoretical gain.

With the capacitor C_K removed from the network, the feedback factor K is determined by the following equation:

$$K = \frac{R_K}{R_K + R_L}$$

If E_{s_1} represents the admitted signal voltage with feedback and E_{s_2} represents the necessary input voltage without feedback to obtain the same stage output, then,

$$\frac{E_{s_1}}{E_{s_2}} = 1 + K(A)$$

The above equation expresses the value by which the input voltage E_{s_1} without feedback must be multiplied to obtain the same voltage gain with feedback; or,

$$\text{Gain} = AK = KG_m R_L$$

When employing feedback, R_K must be kept to as small a value as will allow sufficient bias and circuit stability, so that the sacrifice of gain will not be too serious. This same condition also dictates the use of a tube possessing relatively high transconductance.

6.7 High-Frequency Compensation. In the discussion of low-frequency compensation of video amplifiers, it was found that the change in series reactance of the *RC* coupling circuit necessitated the correction so that the plate-load impedance and the voltage gain increased in proportion to the decrease in voltage across the coupling capacitor with a change in frequency.

At the higher pass frequencies, those above approximately 100,000 c.p.s., compensation is necessary in order to maintain the plate load impedance Z_L and, consequently, the stage gain A uniform over the frequency range that the amplifier is designed to transmit. Compensation becomes necessary at these higher frequencies because of the shunting effect of tube interelectrode capacitances, socket wiring, and circuit capacitances, all of which reduce the gain at the higher pass frequencies.

It must be remembered that the gain and phase characteristics of the video amplifier at low frequencies determine the faithfulness with which the general background shading is transmitted, since the amplifier, of necessity, must pass at least a 60-c.p.s. component of the signal produced by that change in background illumination.

It has also been stressed that the ability of the amplifier to transmit the higher pass frequencies, those above approximately 100,000 c.p.s., without discrimination determines the ability of the amplifier to transmit the fine detail found in the average television image. This condition is due to the fact that the harmonic content of the signal is directly responsible for detail fidelity and, as the upper frequency limit is extended, the sharpness and "snap" in the picture increases proportionately. When the harmonic frequencies are present, the image becomes very brilliant and has all the appearance of a fine-grain photograph. The picture becomes "crisp" and "sharp" as the upper pass band is extended, just as sound becomes more brilliant and colorful as the higher audio frequencies are passed by the high-fidelity audio amplifier.

6.8 Shunt Peaking. In view of the facts stressed above, the importance of employing special types of vacuum tubes having low interelectrode capacitance and of exercising infinite care in circuit wiring and equipment layout to keep the length of leads to the minimum and well above ground becomes immediately evident.

In the diagram in Fig. 6.13, the high pass frequencies are attenuated in transmission through the amplifier by the output capacitance C_o, the distributed capacitance C_d, and the input capacitance of the succeeding stage C_i, all acting effectively to shunt the load resistance R_L. This attenuation serves to reduce the over-all voltage gain at the higher frequencies by reducing the load impedance Z_L. It is possible to compensate for the effect by any one of at least three methods, which are shown in Fig. 6.11. The effects of high-frequency compensation are shown in Fig. 6.12.

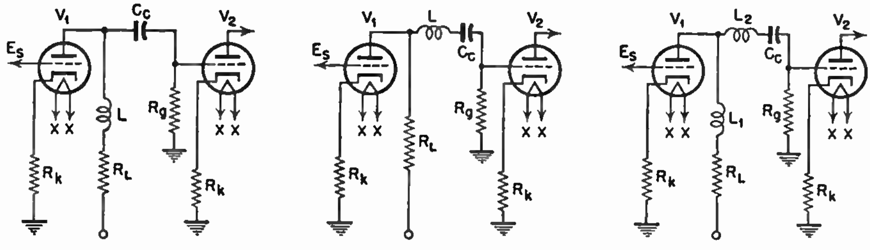


FIG. 6.11 Diagrams of three methods of high-frequency compensation.

The high-frequency range may be extended by adding a small value of variable inductance as shown in (*A*) in Fig. 6.11, which serves to boost the high frequencies while exercising negligible effect upon the lower pass frequencies. Such correction is known as "shunt compensation."

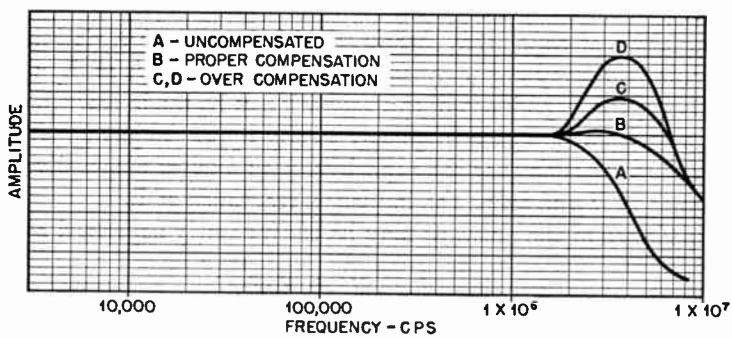


FIG. 6.12 Curves illustrating the effects of high-frequency compensation upon the band-pass characteristic of a video amplifier.

A second method of high-frequency compensation is shown at (*B*) in Fig. 6.11 and is termed "series compensation," a small value of variable inductance being series-connected with the coupling capacitor C_c, so that it resonates at the higher pass frequencies with the input capacitance C_i of the following stage. The result is an increase in the magnitude of current through C_c, bringing about greater voltage gain in the amplifier. The two methods described above are combined in the circuit shown at (*C*) in Fig. 6.11, thereby adding to the high-frequency peaking effect of shunt compensation the resonant effect of series compensation. Both result in greatly improved high-frequency response. This last method of compensation is termed "combination" or "series-shunt compensation." All methods at present in use will be discussed in detail. Series peaking will yield about 50 per cent more gain than shunt peaking, and combination peaking will yield about 80 per cent more gain than shunt peaking for the same response.

R_L = LOAD RESISTANCE
C_O = TUBE OUTPUT CAPACITANCE (V_1)
C_d = CIRCUIT AND STRAY CAPACITANCE
C_i = TUBE INPUT CAPACITANCE (V_2)

$$Z = \sqrt{R_L^2 + (X_{C_O} + X_{C_d} + X_{C_i})^2}$$

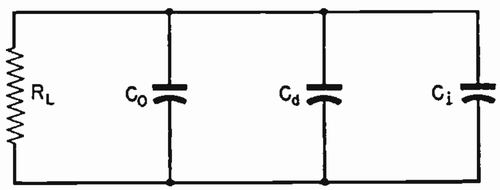


FIG. 6.13 Diagram of an equivalent network, combining R_1, C_o, C_d, and C_i into a common impedance, which effects high-frequency response.

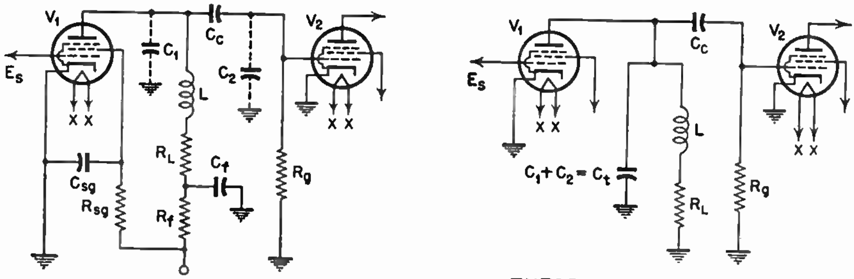
In (*A*) in Fig. 6.11 the addition of the peaking coil in series with R_L introduces a finite amount of inductive reactance to the plate-load network and serves to counteract the effect upon the impedance Z_L brought about by the variation of capacitive reactance with frequency variation of the shunt circuit and stray capacitances. With the addition of L, which is made variable, the impedance of the network can be made essentially constant in value from zero pass frequency to any upper frequency where the network values are such that the capacitive reactance of C is equivalent to the resistance of R and twice the inductive reactance of L.

The impedance of the network may be conveniently expressed as

$$Z = X_C \sqrt{\frac{R^2 + X_L^2}{R^2 + (X_C - X_L)^2}}$$

As has been shown, if the impedance is plotted against frequency, it may be observed that the impedance increases at a frequency of $0.2f$, where f is the upper correction frequency chosen in the amplifier design, and indicates a smooth rise to about $0.6f$, after which the impedance indicates a slow decrease, finally becoming equal to the low-frequency impedance at f. The amount of increase is approximately 0.5 per cent at $0.2f$ and 3 per cent at $0.6f$. The theoretical electrical equivalent of the shunt peaked circuit is shown in Fig. 6.14 ($C_o = C_1$ and $C_i = C_2$).

For practical values of R_L, which are ordinarily very low in video amplifier design, the inductance L has a value of about 10 to 50 μh. Consequently, it evidences negligible effect upon either the impedance or phase angle at frequencies below about 100,000 c.p.s. At higher pass frequencies, where the shunt susceptance of C_o and C_i becomes appreciable, the inductive reactance of the added inductance is of great importance. Attenuation of the signal and time delay due to phase shift are brought about by the reduced total reactance of the output and distributed capacitances as the frequency is increased beyond that point. Simultaneously, the rise in frequency results in increased inductive reactance at L, which, added to the load resistance R_L, causes the load impedance to increase. Thus, increased gain is obtained to compensate for the deleterious shunting effects of C_o and C_i. Since the phase shift at the added inductance is



FUNDAMENTAL CIRCUIT OF SHUNT PEAKED STAGE

THEORETICAL ELECTRICAL EQUIVALENT OF THE SHUNT PEAKED VIDEO STAGE

FIG. 6.14

opposite in sign to that caused by C_o and C_i, linear phase shift as well as constant time delay is obtained.

In designing an amplifier to include shunt peaking, three circuit elements must be taken into consideration. These are C_o and C_i, which are added to represent one value, the determination of which has already been discussed. It is customary to make R_L equivalent to the reactance of the combined capacitances C_o and C_i at the upper pass frequency (f_c) for which correction is desired. Then,

$$R_L = X_{C_o} + X_{C_i} \text{ at } f_c$$

The inductance of L is made such that its reactance at f_c is 0.5 that of $X_{C_o} + X_{C_i}$ at f_c; thus, $0.5(X_{C_o} + X_{C_i})$ at f_c.

And

$$L = \frac{R_L}{4\pi f_c}$$

The stage gain becomes

$$A = G_m Z_L$$

where A = stage gain

G_m = transconductance of the tube in mhos

Z_L = plate load impedance $(\sqrt{R^2 + (X_L - X_C)^2})$

It must be noted that although the result of high-frequency compensation is to make more uniform the gain at the top desired video frequency, the magnitude of R_L that can be allowed, and thus the voltage gain achieved, is an inverse function of $C_o + C_i$. As the value of f_c is extended, R_L must be reduced. Likewise, the over-all gain suffers a reduction. Therefore, it is of extreme importance to select tubes of high transconductance and low interelectrode capacitance. Great care must also be exercised in reducing stray and shunt capacitance in the circuit.

The phase shift, as well as the time delay, for a single stage of amplification employing shunt compensation may be expressed as

$$\phi = \tan^{-1} \frac{1}{4}\left[\left(\frac{f}{f_o}\right)^3 + 2\left(\frac{f}{f_o}\right)\right]$$

where f = frequency of the signal for which the phase shift is being calculated

f_o = upper frequency to be passed by the amplifier

f and f_o are in megacycles per second, and

ϕ is in radians

$$T = \frac{\phi}{2\pi F}$$

where F is in cycles per second, and T is the time delay in seconds.

It is necessary to overcompensate and undercompensate in some stages in a multistage video amplifier in order to obtain a composite, or over-all, response, which is essentially flat. The reason for the compensation is that each stage in tandem may evidence the same discrimination at some portion of the pass band. The effect is additive where a number of stages are involved. Thus, although the deficiency of one stage may not prove appreciable, by the time the signal is transmitted or passed through a number of stages in tandem, each contributing like discrimination, the effect can prove serious. This condition applies also to phase distortion, since the time delays at any single frequency for a number of stages are additive and result in quite serious phase shift.

It has been pointed out that shunt peaking, as described, will become perfect if f_o is selected such that it is approximately 40 per cent higher than the maximum correction frequency desired. At the same time, however, a reduction in gain of about 30 per cent occurs. Therefore, in judicious commercial design, a reduction in gain of approximately 15 per cent is tolerated. Thus, the value of load resistance is taken as

$$R_L = 0.85(X_{C_o} + X_{C_i}) \text{ at } f_c$$

and

$$L = \frac{0.3}{(2\pi f_o)^2 C_o + C_i}$$

With proper design the video amplifier may be made to demonstrate frequency and phase characteristics that are little short of amazing to the engineer who was previously concerned only with audio amplifiers.

The value of peaking-coil inductance for the shunt-compensated amplifier may also be determined by another method, taking into consideration R_LC_t, and the upper frequency to be passed by the amplifier f_o. It is to be remembered that C_t represents the total capacitance shunting the circuit and includes both tube and wiring capacitances.

The value of R_L is selected to equal the reactance of C_t at the upper frequency to be passed by the amplifier. The value of C_t is measured with L removed from the amplifier circuit. Therefore,

$$R_L = \frac{1}{2\pi f_o C_t}$$

The value for L is determined from $2\pi f_o L = R_L/2$ at the upper video frequency to be passed f_o. Therefore,

$$L = \frac{R_L}{4\pi f_o}$$

It is seen that the resonant frequency of L and C_t is $\sqrt{2}$ times the upper pass video frequency f_o. The gain is essentially constant up to the frequency f_o and is equivalent to $G_m R_L$.

The time delay in terms of f and f_o can be expressed as

$$T = \frac{1}{2\pi f} \tan^{-1} \left[\frac{1}{4} \left(\frac{f^3}{f_o^3} + 2\frac{f}{f_o} \right) \right]$$

It has been shown by Seeley and Kimball* that the difference in time delay over the video band (from 1,000 c.p.c. to f_o) is $0.0231/f_o$ sec. If f_o is 3 mc. per sec., this time-delay departure corresponds to 0.0077 μsec. The values selected for compensating the circuit can be

$$R_L = \frac{1}{2\pi f_o C_t} \qquad \text{and} \qquad L = \frac{R_L}{4\pi f_o}$$

Seeley and Kimball observed that the values so determined do not necessarily result in the optimum phase and amplitude response. A more constant time delay and amplitude response can be achieved by choosing a slightly different value of R_L and L.

If the ratio of the load resistance R_L to capacitive reactance X_C at the upper pass frequency is designated by p, and the ratio of inductive to capacitive reactance at f_o is designated by s, we can set up the following

* See Bibliography, p. 354.

equations:

$$p = \frac{R}{X_C} = 2\pi f_o C_t R_L$$

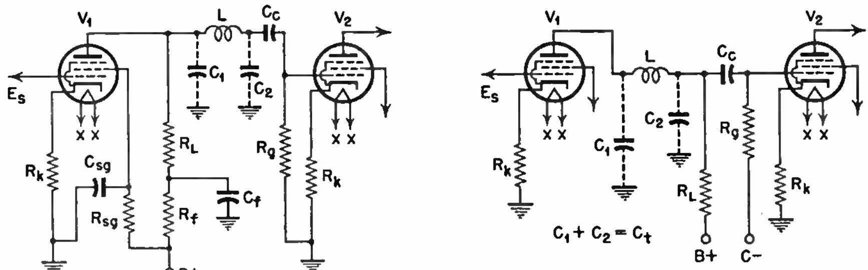
$$s = \frac{X_L}{X_C} = (2\pi f_o)^2 L C_t$$

The values chosen in the previous case are $p = 1$ and $s = 0.5$. However, if we use $p = 0.85$ and $s = 0.3$, the time-delay curve will be almost precisely flat, and the gain will be only slightly less than that for the higher values of s and p over the entire pass band. The use of lower values of s and p results in lower gain, it being decreased by approximately 15 per cent at all frequencies.

In an actual case, we may consider a video amplifier stage that employs a type 1851 tube. The total load-circuit capacitance ($C_{in} + C_{out}$ plus wiring and stray capacitance) is approximately 25 $\mu\mu f$. If the top frequency f_o is chosen as 3 mc. per sec., X_C will be 2,120 ohms. If p equals 1, the load resistor will also be 2,120 ohms, and the inductance of the shunt-peaking coil (for s with a value of 0.5) will be

$$\frac{2{,}120}{2 \times 2\pi f} = 56 \ \mu\text{h}.$$

The actual gain will equal 19 per stage for a tube with mutual conductance of 9,000 μmho.



SERIES PEAKED VIDEO AMPLIFIER STAGE

SERIES PEAKED STAGE WITH R_L CONNECTED AT THE LOW CAPACITY SIDE OF THE FILTER

FIG. 6.15

6.9 Series Peaking. A video-amplifier circuit in which series peaking is employed is illustrated in Fig. 6.15. It is evident that the variable peaking coil L is series-connected between the plate of V_1 and the control grid of V_2; hence the term "series peaking." As stated before, the use of series peaking affords about 50 per cent more gain than shunt peaking, though a combination of both, as we shall see later, yields the most completely satisfactory circuit.

Three components in the circuit are important from the point of view of amplifier design. These are L, the added series inductance; R_L, the plate-load resistance; and C_1 and C_2, the output capacitance of V_1 and the input capacitance of V_2. It may be seen that L, C_1, and C_2 form a typical low-pass filter network common in many circuit applications. The theoretical electrical equivalent is shown in Fig. 6.16. Thus, the output voltage developed across the load resistance R_L is finally applied through this low-pass filter to the control grid of V_2. In determining the value of combined total capacitance of C_1C_2 by the means previously discussed, a 2 : 1 ratio between C_1 and C_2 is required, although the ratio may be transposed through moving R_L to the other terminal of L, as shown in

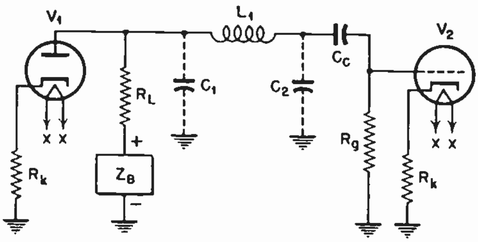


FIG. 6.16 Electrical equivalent of series-peaked video stage.

Fig. 6.15. A ratio of 2 : 1 is entirely practical insofar as the available tubes for video-amplifier design are concerned. If C_1 is less than C_2, a small value of capacitance may be added in shunt with C_1. First an attempt should be made to reduce the value of C_2 by good mechanical layout of the circuit, selection of tubes, and so on. It is axiomatic in video-amplifier design to connect R_L at the low-capacitance side of the low-pass filter as shown in the schematic diagram.

The desired ratio of 2 : 1 may be quite easily maintained. The coupling capacitance C_c may be transposed to the input side of the inductance L, thereby shifting the capacitance of C_c to ground from C_1 to C_2. Thus,

$$C_t = C_1 + (C_2 + C_{\text{stray}})$$

$$= C_1 + C_2 = \text{total capacitance}$$

$$C_2 = 2C_1$$

$$R_L = (1.5)(X_{C_t} \text{ at } f_c)$$

$$L = \frac{1}{2(2\pi f_c)^2 C_1} = 0.67 C_t R_L^2$$

The latter expression is more universally used in determining the finite value of L where C_t is utilized in solving for L, C_t being more important than the separation of C_1 and C_2 in the filter network.

The arrangement of C_1, L, and C_2 is seen to be such that R_L is now shunted by C_1 and also by the series-connected components L and C_2. At the higher pass frequencies in the video amplifier, however, C_2 is effectively separated from C_1 by the inductance L, and there is an appreciable reduction in the shunting effect of the capacity across L at any high frequency within the pass band. Therefore, the value of R_L may be proportionately increased with improved voltage-gain characteristics at all pass frequencies. At the lower pass frequencies Z_L is equal to R_L, while at the frequencies above about 100,000 c.p.s., Z_L is equal to R_L and X_{C_0} parallel-connected. Therefore, the video voltage developed across R_L is applied across L and C_2 series-connected, the excitation voltage E_{s2} for V_2 being the drop across C_2. Uniform input E to V_2 throughout the upper range of frequencies to be passed, referred to as the high-frequency pass band, is effectively maintained, since the resonant increase in current in LC_2 as the frequency increases is of sufficient magnitude to nullify the effects of X_{C_2} decreasing with increased frequency and the output voltage of V_1, reducing due to the shunting effect of C_1, which is effectively in parallel.

Series peaking provides a sharper high-frequency cutoff than does shunt compensation and a much more uniform phase characteristic.

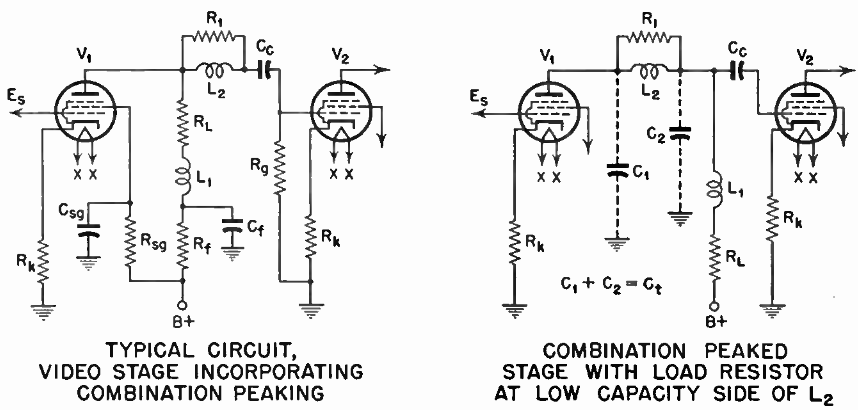


Fig. 6.17

6.10 Series-Shunt, or Combination, Peaking. Actually, in commercial video-amplifier design combination peaking will, for obvious reasons, be found to be the preferred method of high-frequency compensation. The fact that at least 80 per cent more gain per stage may be obtained, as compared with the gain through the use of simple shunt peaking, makes it the desirable method to employ. The preference is due to the fact that for a given set of circuit conditions, a load resistor having 80 per cent more resistance may be employed, the stage gain being equivalent to G_mR_L with the amplifier stage properly compensated.

If shunt or series peaking alone is employed, it is often necessary to reduce greatly the value of the plate-load resistance in order to obtain the desired uniform frequency response. In such cases, the gain suffers accordingly. With a reduction in gain per stage, more stages must be used in tandem to develop the required output. This does not result in economical design and reduces band pass. It is more desirable, therefore, to employ a circuit that permits the maximum gain per stage, together with the desired frequency-response characteristic. The series-shunt peaking circuit is shown in Fig. 6.17.

The proper values for the components used in this method of peaking are determined through solution of the following equations:

$$C_t = C_1 + C_2$$

$$C_2 = 2C_1$$

$$L_1 = 0.12C_tR_L^2$$

$$L_2 = 0.52C_tR_L^2$$

$$R_L = 1.8X_{C_t} \text{ at } f_c$$

A 2-to-1 division of capacitance in C_t is required for optimum performance; i.e., the ratio of C_2/C_1 is adjusted to equal 2. The adjustment is accomplished by experimentally trying various mechanical positionings of components, wiring, and so on, while measuring the two capacitances by means of a reliable capacitance bridge or Q meter.

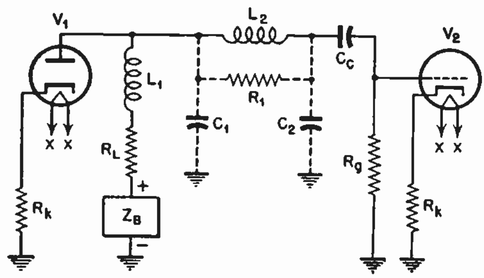


FIG. 6.18 Simple electrical equivalent of combination peaked video stage.

The load resistor R_L is again placed at the low-capacity side of the inductance L_2, and R_L and L_1 may be transposed in the circuit, since stray capacitance will be minimized to a greater extent if a resistance is placed on either side of L_2 than if L_1 were so connected in the circuit. The simple electrical equivalent of the combination peaked video stage is shown in Fig. 6.18.

Sometimes a resonant rise of voltage or frequency response is found at some part of the high pass band, particularly if the distributed capacitance of L_2 is quite high or if the ratio of the two capacitances making up C_t

are not in proper proportion. This can be nullified by the insertion of a "swamping" resistor R_1 across L_2 as shown in Fig. 6.18. The effect is to lower the Q ($Q = X_L/R$) of the series inductance L_2. The value of the required resistor is determined empirically, although it will result in a value being chosen that is at least four to six times the value of R_L in most cases.

The stage gain will become

$$A = G_m Z_L$$

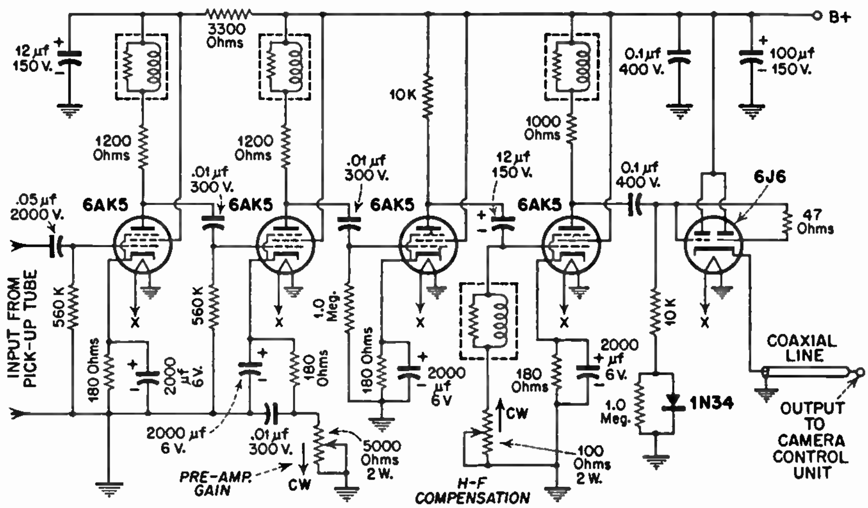


FIG. 6.19 Typical video preamplifier associated with a television camera employing an Image Orthicon pickup tube. Shunt high-frequency compensation is made use of in this amplifier.

6.11 Shunt *M*-Derived Type of Video Amplifier. A shunt *M*-derived type of video amplifier has been described by A. B. Bereskin* and by A. Preisman.† It is seen to be quite similar to that employed in conventional shunt peaking, a small trimmer capacitor being added to shunt the series plate inductance. In some versions of the circuit that have been shown in literature, the peaking coil is wound in several layers, the distributed capacitance of the coil providing the necessary shunt capacitance. However, it has been shown that control of peaking is greatly facilitated by employing a simple single-layer solenoid, maintaining the

* A. B. Bereskin, "Improved High Frequency Compensation in Video Amplifiers," *Proc. I.R.E.*, October, 1944.

† A. Preisman, "High Frequency Response of Video Amplifiers," *Communications*, December, 1942; January, 1943.

A. Preisman, "Television Studio Installation Designed for Research and Instruction," *Communications*, March, 1945.

distributed capacitance at approximately 1 $\mu\mu$f. through careful design, and with a small trimmer capacitor applied in shunt with the solenoid for precise peaking (see Fig. 6.20).

The values of L, C, and R in terms of total capacitance C_t are derived through use of the following equations:

$$L = \frac{0.49}{\omega_h{}^2 C_t}$$

$$C = 0.354C_t$$

$$R = \frac{1.085}{\omega_h C_t}$$

where $\omega_h/2\pi$ is the upper frequency to which uniform response within 2 per cent of the selected low-frequency value is desired.

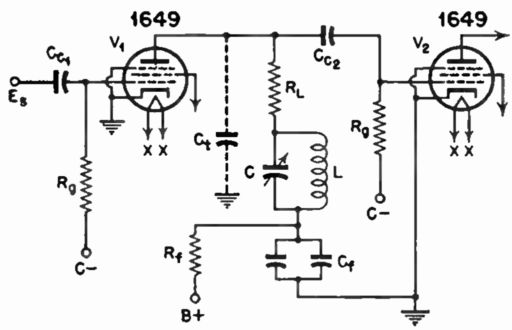


FIG. 6.20

The resonant frequency F_r of the tuned circuit LC_t is $\omega_r/2\pi$, and ω_h equals $0.7\omega_r$.

A Q meter may be employed to adjust the M-derived video stage, and L may be adjusted within the stage itself. In the absence of a Q meter, the resistor in series with L is short-circuited. With the resistor removed from the circuit, L and C_t provide a simple parallel resonant circuit. The peaking coil in the succeeding video stage is also short-circuited, the plate-load resistor being shunted with a 200-ohm resistor. This stage is then flat to an upper frequency limit of 8 mc. per sec. or greater. Its impedance is at a low value. Therefore, its frequency response is not disturbed when a vacuum-tube voltmeter is shunted across the circuit for measuring purposes.

The reason for so modifying the succeeding stage is to convert it into a buffer stage, across which measurements may be conveniently made. Were the vacuum-tube voltmeter placed in shunt with the M-derived amplifier under adjustment, the circuit would be disturbed. This precaution is unnecessary if the succeeding stage is a cathode-follower stage, since it will normally operate as a buffer stage.

To provide a source of signal for the circuit under adjustment, a suitable signal generator is connected to the control grid of the stage. The vacuum-tube voltmeter in shunt with the output of the succeeding buffer stage will indicate a maximum deflection when L and C_t are resonant. A greater number of turns are used at L than are required, so that it resonates with C_t below the desired frequency $\omega_r/2\pi$. Turns on the solenoid L are then removed, one by one, until it resonates at $\omega_r/2\pi$.

The proper value for the shunt capacitance C is determined through resonating L on the Q meter with the instrument's variable capacity adjusted to any convenient value and at a suitable frequency. The variable capacitance of the meter is then reduced by the value of C, and the trimmer is added and adjusted until resonance is again obtained.

It has been shown that when the M-derived stages are adjusted in accordance with the above equations the response will indicate a gradual and smooth decrease from the upper frequency limit chosen. This eliminates sharp resonant peaks in over-all response when several video stages are employed in tandem, and undesirable echoes are eliminated. The upper frequency limit may be about 6 mc. per sec. or higher, providing excellent frequency response.

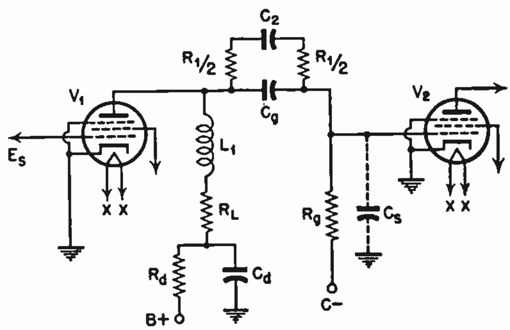


FIG. 6.21

6.12 The Balanced Interstage-Coupling Network. A balanced interstage-coupling network for video amplifiers, based on an original circuit developed by A. Preisman and later described in literature in modified form by D. E. Norgaard and J. L. Jones of General Electric, offers a unique method whereby both low- and high-frequency compensation may be obtained with negligible phase shift.

The circuit is shown in Fig. 6.21. The network R_dC_d operates both as a decoupling circuit and as part of the low-frequency compensation circuit. The phase shift and amplitude characteristic brought about by this network is compensated for by the proper proportions of R_1, R_g and C_g, as well as R_L, which form the balance of the network when considered at low frequencies. The circuit will uniformly pass all frequencies from a very low frequency to an upper limit of about 5 mc. when C_2 is short-circuited and proper bias is applied to the lower end of R_g to result in the required bias at the grid of V_2. Proper high-frequency compensation by means of L_1, which takes account of C_s, is carried out in the conventional manner. The use of a physically small coupling capacitance C_g in this circuit results in C_s being smaller than in conventional circuits, yet the low-frequency response is improved through use of R_1. Choice of C_2 allows the low-frequency cutoff to be adjusted without affecting the high-frequency characteristics of the coupling network. Phase shift at the lower pass frequencies is small when the reactance of C_2 is small compared with R_1.

Considered at the low pass frequencies, the plate current I_p of V_1 will divide between the two branches of the network in a constant ratio independent of frequency when the impedances of the two branches are proportional. Therefore, if

$$\frac{R_g}{R_L} = K$$

$$\frac{R_1}{R_d} = K$$

$$\frac{C_d}{C_g} = K$$

where K is a real number, the impedance of the right-hand branch is K times that of the left-hand branch, and

$$E_{g2} = I_{p1}R_g\left(\frac{1}{1 + K}\right)$$

The latter equation includes the case where C_2 is short-circuited. Under this condition the network exhibits no low-frequency amplitude discrimination or phase shift. When it is desired to eliminate d-c coupling, C_2 can be chosen to afford the desired low-frequency performance. Typical values for the circuit components are given as

$$\begin{aligned}
R_L &= 1{,}000 \text{ ohms} \\
R_g &= 250{,}000 \text{ ohms } (K = 250) \\
R_d &= 10{,}000 \text{ ohms} \\
R_1 &= 2{,}500{,}000 \text{ ohms} \\
C_d &= 1\ \mu\text{f.} \\
C_g &= 0.004\ \mu\text{f.} \\
C_2 &= 1\ \mu\text{f.}
\end{aligned}$$

When C_2 is made 1 μf. in value, the phase shift at 10 c.p.s. is less than 0.37 deg. Capacitance between C_2 and ground will have only negligible effect on the high pass band because of the high-frequency isolation provided by the two halves of R_1. It will be noted that the determined value of R_1 is divided in half, the two resulting resistors being placed on either side of C_2. Thus, C_2 is not critical as to physical location in the amplifier chassis, but may be placed where convenient.

6.13 The High-Peaked Stage. The quality of the video image is to a great extent a function of the signal-to-noise ratio encountered in the system. The higher this ratio can be made, the more generally satisfactory will be the resulting pictures. Most of the noise developed in any

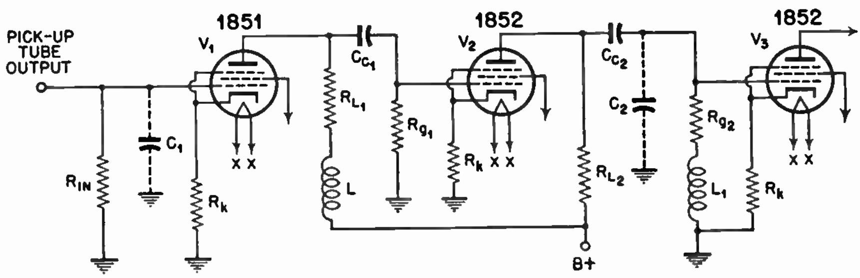


Fig. 6.22

television system occurs at the point where the low-level output of the pickup tube is electrically connected to the input or signal grid of the first video stage.

A typical input network is shown in Fig. 6.22. All the components employed in this network are usually mounted on a small sheet of material having excellent insulating qualities. The components are mounted as close to the signal contact of the pickup tube as practicable. The components are so arranged that interconnecting leads are as short and as direct as it is possible to make them. The pigtails and short leads on such components themselves are utilized for interconnecting leads in the network. It is very important that the lead connecting the signal-plate contact, or cap, on the Iconoscope bulb to the load resistor be made extremely short and direct. This type of connection reduces the noise pickup at this point, since electrostatic coupling between this lead and extraneous noise fields is thereby minimized. The procedure also offers some decrease in the loss at high pass frequencies owing to the lead's stray capacitance to ground.

No shielded wire is used in making up the interconnections in the input network, since the reactance of such cable at the higher pass frequencies is so low that the signal voltage at harmonic frequencies—resulting in detail fidelity—might be effectively shunted to earth before reaching the control grid of the first video stage of the preamplifier.

The signal voltage at this point is very low, approximating 0.01 v. at normal light levels at the mosaic of an Iconoscope. Therefore, components of small physical size may be used in making up the required input-coupling network. It follows that the smaller the physical size of the components can be made, the higher will be the shunt reactance of these parts to earth and the lower the losses at the higher pass frequencies. The more care exercised in the development of this input-coupling network, the greater the possible high-frequency response of the entire video system and the greater the signal-to-noise ratio obtained.

Sometimes, to produce the greatest possible signal-to-noise ratio at this point in the system, frequency distortion is disregarded. The distorted signal is then passed through one or two video stages and amplified; as the next step a complementary network is introduced which affords equal and opposite distortion to that resulting in the input network. This method is a convenient one for obtaining a greater signal-to-noise ratio than would otherwise develop.

The output of the Iconoscope (or other pickup device) is developed across R_{in}. This voltage, in turn, is developed across the input impedance of the first tube V_1. The shunt reactance due to capacitance C_1 will afford a limitation as to the possible high-frequency response available at the control, or signal, grid-C_1 representing the shunt and stray capacitance at the input of the tube.

If series, shunt, or combined peaking is employed between V_1 and V_2, the linearity of frequency response obtaining at the control grid of the first tube can be maintained, even though it be distorted in the high pass region owing to the presence of C_1. The network L_1C_2 is then employed as the load impedance of V_2. This network is complementary to the input network $R_{\text{in}}C_1$, since it has both opposite phase and impedance characteristics and the time constants of both networks are made equal.

It is a relatively simple matter to determine the value of the components necessary for this type of high-peaked video amplifier.

Let C_1 = total circuit and stray capacitance of the input stage
C_2 = total circuit and stray capacitance of the high-peaked stage
f_c = highest frequency for which correction is desired
R_{in} = nominally 100,000 ohms

Then

$$R_{L_2} > 10X_{L_1} \text{ at } f_c$$

$$X_{C_{c2}} < 0.1\, R_{L_2} \text{ at the lowest frequency}$$

$$R_{g2} = \frac{L_1}{R_{\text{in}}C_1}$$

where R is in ohms, L is in microhenrys, and C is in micromicrofarads.

$$L_1 = \frac{(25.33)(10^3)}{(2f_c)^2(C_2)}$$

It is seen that the resonant frequency of the complementary network L_1C_2 is thus made twice f_c.

The high-peaked stage so designed will operate at a loss, although the over-all voltage output throughout the pass band will be higher than if a lower value of load resistor were used in order to ensure that the high-frequency response at the pickup-tube output would be transferred to the signal grid of V_1 and the signal-to-noise ratio will be much improved. As stated, the high-peaked stage is sometimes employed to avoid the laborious detail involved in the design of a preamplifier input network capable of assuring excellent high-frequency response.

6.14 Noise in Video Amplifiers. It was seen in the preceding section that the problem of the preamplifier input network has received considerable attention. The reason for this attention is that the signal-to-noise ratio encountered at this point in the television system usually determines the minimum signal-to-noise ratio possible in the complete chain of equipment. It is here that the signal level is the lowest to be found anywhere in the transmitting system. Consequently, the noise problem is the greatest. It was shown how the noise level at the input to the first stage of the video preamplifier could be kept to the minimum while at the same time maintaining good high-frequency response in spite of the stray shunt and circuit capacitances that are present. However, there are other sources of noise that must receive attention.

It is well-known that the wider the pass band is made in any amplifier, the greater will be the resulting output noise level, because the total noise voltage at the amplifier output represents the algebraic sum of all the noise voltages that obtain at random frequencies throughout the pass band. It follows that the wider the pass band is made, the more important becomes the noise problem. Too, stage gain reduces as amplifier response increases, so that the signal level is reduced, while the noise level increases as the response is made wider. Video amplifiers capable of passing frequencies from 60 c.p.s. to an upper limit of several megacycles per second present a noise problem not found in amplifiers of any other type.

As pointed out, the coupling resistance at the output of the pickup tube is the circuit element across which the video voltage is first developed. There is also developed across this resistor a random, fluctuating voltage that is brought about by the thermal agitation of the electrons in the resistor. The noise voltage thus produced is amplified by the succeeding video amplifier, as is the picture signal. The picture will become unintelligible if the noise voltage is of approximately the same order as that due to the video signal. It has been shown that if the r.m.s. noise voltage is equivalent to 30 per cent of the video peak-to-peak voltage, the picture is intelligible but tiring to watch. A signal-to-noise ratio of 10 : 1 yields a good picture, although the noise is recognized as snow over the entire picture raster. When the signal-to-noise ratio is made such that the noise represents not more than 3 per cent of the video signal, an excellent picture results.

If high-frequency noise predominates, a greater noise level can be tolerated, since low-frequency noise is far more objectionable to the observer. The noise generated at the first tube in the video amplifier can also be objectionable. It is the usual practice to try several tubes of the type called for in the preamplifier design. The tube permitting the least noise, or snow, as observed at the output of the chain, is chosen for permanent installation.

Noise may be introduced by the Iconoscope or other pickup tube. Such noise is a function of the magnitude of the beam voltage employed. Considerable improvement in the picture signal can be obtained by employing a low beam current (hence, low output). If the beam current is kept low, the noise level due to the presence of the camera tube in the system can be kept so low as to prove negligible in comparison with that due to other sources. Pictures also become easier to shade as the beam current is reduced.

It has been shown that the objectionable signal-to-noise ratio in a video signal is dependent upon the type of noise encountered and the conditions under which the picture is viewed. The noise spectrum in the video system can be weighted to account for the subjective effect upon observers, as is done at audio frequencies. The noise spectrum may be divided into four principal ranges.

The *first range of the noise spectrum* is that encompassing the pass band extending from zero to 15 or 20 c.p.s. Noise voltage developing at these frequencies results in considerable eye fatigue, even though only small amounts are present. The *second range of noise frequencies* extends from the picture-repetition rate to the line-repetition rate, i.e., 30 to 15,750 c.p.s. No eye fatigue is caused by noise voltage at these frequencies, although disagreeable interference with the picture results. The *third range* extends from the line-repetition rate to ten or twenty times this rate. The effect of any noise within this band depends upon the frequency of interference; it becomes of greater concern when harmonically related to the line-scanning frequency.

The *fourth range* extends from approximately twenty picture elements to one picture element in pitch. The effect of noise voltages lying within this higher range is similar to that brought about by the medium frequencies lying in the third range, although the higher the frequency of the noise voltage becomes, the less obvious is the general effect upon the picture.

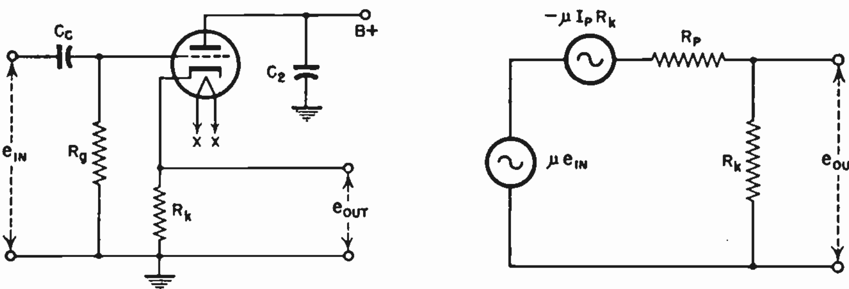
The high-frequency range is wider and, thus, the total noise is greater than in the other regions of the pass band but of less observable effect. The noise voltages in ranges one and two are more objectionable to the viewer and must be minimized.

There are two principal sources of noise in the amplifier, not including expected sources such as rosin joints, cold-solder joints, poor and improper connections, faulty insulation in cables and component supports, noisy batteries (if used), microphonics, and external noise pickup. The two principal sources of noise may be described as thermal agitation in resistors and emission noises in vacuum tubes used in video amplifiers. As pointed out before, tube noise can be kept to the minimum by experimentally trying tubes of a given type in a particular video stage until one is found that yields the minimum amount of noise. So far as the author is aware, there is no method by which thermal agitation in resistors may be avoided. It follows that the signal level must be kept at such amplitude that the noise is not objectionable. In practice, the gain per amplifier stage is kept sufficiently high to maintain the magnitude of the signal voltage always greater than that of the noise voltages due to thermal agitation in resistors and emission noises in tubes, even at minimum video-signal levels.

6.15 The Cathode Follower. With the advent of wide-band amplifiers in television and oscillograph circuits, a great deal of interest has centered around the cathode follower. The cathode follower is actually a degenerative vacuum-tube circuit in which inverse feedback is obtained by means of a cathode resistor that is not by-passed and across which the output voltage is taken. It is characterized by low output impedance, which permits direct output coupling to a low impedance coaxial line. Since the output voltage of the conventional plate-loaded amplifier is at a comparatively high impedance, unless changed by an impedance-transforming device, such as a transformer, the obtaining of a proper impedance match to a coaxial line of nominal impedance presents a problem with no practical solution. To design a transformer to pass without discrimination, a band several megacycles wide is impractical. The cathode follower has high input impedance which permits coupling at high impedance to the output of a preceding voltage amplifier. It also demonstrates wide frequency response and may thus be employed in any conventional television system without the introduction of frequency distortion. Its inherent simplicity of design and low cost have resulted in widespread usage. The voltage gain of the cathode follower is necessarily less than unity, and it is characterized by low d-c output voltage to ground. Therefore, the circuit may be easily applied either as a video power amplifier or as an impedance-transforming device.

The characteristic high input impedance and low output impedance of the device make it particularly applicable to coupling between pulse-generating stages, or pulse amplifiers, and coaxial transmission lines possessing shunt capacitance that might otherwise result in deleterious high-frequency effects. The cathode-follower output "follows" the grid input voltage and is therefore at the same polarity. Its ability to follow is responsible for its being described in literature as a "follower."

The fundamental circuit of a typical cathode follower is shown in Fig. 6.23, together with the theoretical electrical equivalent of the circuit. Essentially a single-stage inverse feedback circuit is shown, the output voltage being taken across the resistor in the cathode circuit. No by-pass



FUNDAMENTAL CIRCUIT OF THE CATHODE FOLLOWER

THEORETICAL ELECTRICAL EQUIVALENT OF THE CATHODE FOLLOWER CIRCUIT

Fig. 6.23

capacitor is employed, and either the plate of the vacuum tube is connected directly to the source of positive plate potential, or to the plate load resistor, if it is included in the circuit. The resistor is suitably by-passed with a low-reactance capacitor at the signal frequencies to be encountered. When a positive signal is applied to the control grid of the tube, the increase in plate current through the cathode resistor R_K produces a greater I_pR_K drop, the cathode becoming more positive by the magnitude of the voltage drop. If a negative signal is applied to the control grid, a reduction in the I_pR_K voltage drop obtains and the cathode becomes less positive. Therefore, the voltage across the cathode resistor R_K is observed to follow the grid, which serves effectively to reduce the difference of potential between the control grid and cathode brought about by the input signal.

When no signal is applied to the control grid, there is a certain magnitude of plate current flowing through the cathode resistor. A voltage drop occurs across R_K, establishing the amount of zero signal bias for the tube. Therefore, any signal variation occurring at the control grid results in plate-current variation through R_K, which reduces the effectiveness of the input signal voltage.

6.16 Voltage Gain of the Cathode-Follower Stage. In the theoretical electrical equivalent of the cathode-follower circuit (see Fig. 6.23), the signal applied between the control grid and ground is represented by a theoretical a-c generator, the output voltage being given as μe_{in}. The degenerative voltage across the cathode resistor R_K is shown as a second theoretical a-c generator represented as $-\mu I_p R_K$. The negative sign indicates that the degeneration occurring brings about a reduction in the voltage that is effective in driving current through the vacuum tube. Thus, the net voltage present in the circuit can be expressed as $\mu e_{\text{in}} - \mu I_p R_K$. The current actually flowing in the tube may be stated as follows:

$$I_p = \frac{\mu e_{\text{in}} - \mu I_p R_K}{R_p + R_K} = \frac{\mu e_{\text{in}}}{R_p + R_K(\mu + 1)}$$

where μ = amplification factor of the tube
R_p = a-c plate resistance of the tube

The output voltage may be expressed as

$$e_{RK} = I_p R_K = \frac{\mu e_{\text{in}} R_K}{R_K + R_p(\mu + 1)}$$

And the voltage gain of the stage becomes

$$A = \frac{e_{RK}}{e_{\text{in}}} = \frac{\mu R_K}{R_p + R_K(\mu + 1)}$$

The above conditions apply only in the case of the cathode follower that employs a triode. When a pentode is made use of, the amplification factor is much higher. Gain is then expressed as

$$A = \frac{R_K}{\dfrac{1}{G_m} + R_K}$$

For the triode cathode-follower stage, the dynamic input capacitance is given as

$$C_{\text{eff.}} = \frac{C_{gK}}{1 + G_m R_K} + C_{gp}$$

For the pentode cathode-follower stage, the dynamic input capacitance may be expressed as

$$C_{\text{eff.}} = \frac{C_{\text{in}}}{1 + G_m R_K}$$

It must be remembered that, unlike the effects in the plate-loaded amplifier, a positive input to the cathode follower results in a positive output and a negative input results in a negative output. There is, therefore, no polarity inversion, such as is experienced with the plate-loaded amplifier, because a change in plate current due to the impressed signal voltage produces a change of potential across R_K in the same direction as that of the applied signal.

Lack of gain is due to the fact that any change in input voltage must appear, in part, as a change in bias voltage in order to bring about a change in plate current. Only the balance of the input voltage appears at the output of the cathode follower. Thus, gain is always less than unity. For this reason, the cathode follower is often employed, not as an amplifier, since it has less than unity gain, but rather as an impedance-transforming device. It is thus regularly encountered as the output coupling stage in video amplifiers in the television system. It is also used within a composite amplifier of several stages as a buffer stage between input and output stages. As such it isolates the input section of an amplifier, operating at low level, from the output section of the same amplifier, operating at high signal level, thereby serving to minimize the possibility of regeneration. Operated in this manner it does not alter the picture polarization, since it does not bring about polarity inversion.

6.17 Input and Output Impedance of the Cathode Follower. As has been stated, the input impedance of the cathode follower is always high and is operated with the grid negative with respect to the cathode. The negative grid makes it possible to apply a positive signal voltage of high amplitude between signal grid and ground and without the possibility of grid current flow. This is the result of the degenerative action of the cathode-circuit resistor, the high impedance being maintained essentially constant during the positive alternation of the input signal voltage. Thus, the device lends itself admirably to applications as a video power amplifier and is quite commonly found as the output stage of composite video amplifiers in the television system.

Owing to the fact that the degenerative action effects a reduction in input voltage below the applied amplitude, less current flows through the interelectrode capacitances of the vacuum tube. The input capacitance is therefore less than that for the same tube when operated as a conventional video amplifier. Because of its high input impedance, the cathode follower demonstrates negligible loading effect upon the circuit driving it.

The output is usually connected to the load through a suitable low-impedance coaxial cable. The theoretical electrical equivalent of the output circuit is shown in Fig. 6.24.

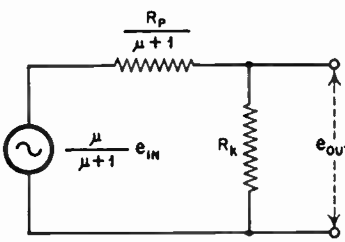
The output impedance is low, and the impedance is usually expressed, in the case of a triode, as

$$Z_o = R_o = \frac{(R_K)\left(\frac{R_p}{\mu + 1}\right)}{R_K + \frac{R_p}{\mu + 1}} = \frac{R_K R_p}{R_p + R_K(\mu + 1)}$$

When a pentode is employed as a cathode follower, the output impedance may be expressed as

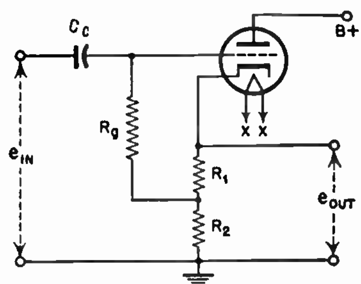
$$Z_o = R_o = \frac{R_K}{1 + R_K G_m}$$

It should be noted that whereas the output of a plate-loaded amplifier is essentially constant, the output impedance of the cathode follower may not necessarily remain constant under all operating conditions. The output impedance of the cathode follower is equal to R_K in shunt with $1/G_m$. Since the transconductance of a vacuum tube is a function of plate



THEORETICAL ELECTRICAL EQUIVALENT OF THE OUTPUT CIRCUIT OF THE CATHODE FOLLOWER

FIG. 6.24



CATHODE FOLLOWER WITH Z_0 MATCHED TO LOAD

FIG. 6.25

current, it is subject to variation with changes in instantaneous input signal voltage amplitude. Since $1/G_m$ is a factor influencing output impedance, the output impedance may vary with signal voltage. If the input signal voltage reaches such a negative value that plate current no longer flows, then G_m becomes zero. As a result the instantaneous output impedance of the follower becomes equal to R_K. And if the signal voltage swings from some positive value, a sudden change in output impedance will result. On the positive alternation of the cycle, the output impedance will be a low value and equivalent to that shown in the above equations. On the negative alternation it will assume a higher value and will be equal to the value of R_K. Such a variation in output impedance can have an effect upon the frequency response of the circuit.

The output voltage of the follower is essentially distortionless when operated within its normal range. If the input voltage is made too high, limiting action occurs and the output voltage is distorted with reference to the input voltage. If the input voltage is a negative voltage of sufficiently great magnitude, limiting action can occur, since plate-current cutoff is eventually reached. Any further change in the negative direction at the control grid does not appear in the output wave form. To make use of negative signals of greater magnitude, the conventional cathode-follower circuit may be modified as shown in Fig. 6.25. Bias is reduced, since the grid resistor is terminated at a more positive point along the cathode resistor R_K. Thus, the input voltage can swing to a larger negative value without resulting in plate-current cutoff.

Stated simply, R_K is divided into two sections, R_1 and R_2. R_1 is selected so that the voltage drop across it will equal the required bias. Since the grid is returned to the junction of R_1 and R_2, the correct bias will be obtained; the G_m will not change, but R_K will be increased and so will the output voltage. Too, Z_o will be changed. A perfect match can be obtained to a coaxial line.

6.18 Output Voltage of the Cathode Follower. If the voltage gain of the cathode follower is the same as that of a conventional plate-loaded amplifier, and if the output impedances of the two circuits are equal, it can be shown theoretically that a greater output voltage can be obtained from the follower. If it is assumed that both circuits are so operated that plate current is not permitted to flow, then, with the output voltage low as compared with plate voltage, it can be assumed that the plate-to-cathode voltage is constant. Therefore, maximum plate current in the comparable circuits will be the same with the grid-to-cathode voltage zero. If this value of current is termed mI_p then for the plate-loaded amplifier it has been shown that

$$\text{Peak } e_o = mI_pR_L$$

and for the cathode follower

$$\text{Peak } e_o = mI_pR_K$$

With the output impedances of the two amplifiers equal, R_K of the follower is greater than the R_p of the plate-loaded amplifier. This shows that the peak output voltage is greater in the case of the cathode-follower circuit. With the gain of the two circuits equal, greater output voltage may be obtained by increasing the input voltage.

It has been shown that maximum current will flow in the plate-loaded amplifier when $e_i - E_c = 0$. In the cathode-follower circuit, the net grid-to-cathode voltage is $e_i - E_c - e_o$. Since $e_o = Ae_i$, the peak input voltage for the cathode follower is expressed as

$$\text{Peak } e_i = \frac{E_c}{1 - A}$$

for maximum plate current.

The equation indicates that extremely high input signal voltage would be necessary to result in the grid-cathode voltage reaching zero when the voltage gain is close to unity. From the practical standpoint, the grid-to-cathode voltage may reach zero because of plate-current saturation before the peak signal input voltage reaches the required value for maximum plate current. If the input voltage is raised above that necessary to cause saturation, grid current will flow.

The ratio of distortion introduced by a cathode follower to that introduced by a conventional plate-loaded amplifier having the same output voltage has been shown to be

$$\text{Distortion ratio} = \frac{1}{1 + A}$$

For practical purposes, the conventional cathode follower introduces no appreciable distortion if the circuit components are selected according to the design equations given and provided that the drive is not made too great. It will deliver the required power into a coaxial line with a perfect impedance match, and this with a transfer of voltage approaching unity. It is simple of design, inexpensive, and requires little or no attention insofar as maintenance is concerned.

6.19 Power Output of the Cathode Follower. The most common application of the cathode follower in television systems is as a power amplifier capable of passing a very wide band of video frequencies. As such it must pass, with negligible attenuation, a range of frequencies some 300 times broader than is required of the best-designed high-fidelity audio-frequency amplifier. Employed as a video power amplifier, the load resistance R_K represents the load itself, and the total output power is dissipated within this load. In many applications in television, the cathode follower is connected to the load by means of a coaxial cable. The cable is terminated at its far end in its characteristic impedance. Figure 6.26 indicates two methods of cathode coupling to such a transmission line. With proper termination of the cable, the terminating impedance is made equal to the output impedance of the cathode follower. The output impedance, in this case, will be equal to $1/G_m$. The output impedance obtainable can be regulated through control of the d-c operating points of the vacuum tube employed, although it is generally obtained through choice of the vacuum tube. Thus, if the desired output impedance is 100 ohms, then a 6AG7 with G_m of 11,000 μmhos might be selected, provided that the available power output proves satisfactory.

The maximum power that may be obtained from the cathode follower is a function of the current capacity of the vacuum tube selected. If no grid current is drawn, then the maximum voltage obtained is equivalent to the product of load impedance and the cathode current that flows when the grid to cathode voltage becomes zero. The peak power output may be expressed as

$$m\,P_o = (m\,I_c)^2 R_K \text{ (for the case of a resistive load)}$$

In Fig. 6.26(A), it may be seen that the inner conductor of the coaxial cable is connected to the cathode or upper end of R_K, the outer conductor being at ground potential. At the far end of the coaxial cable the inner conductor is connected to the termination resistor R_2. The coaxial cable commonly employed in television circuits has a surge impedance of approximately 72 ohms, although the surge impedance of the various types available may vary quite widely from this average value. For a long coaxial line, both the effective value of R_K and the value of the terminating resistance R_2 should match the surge or characteristic impedance of the

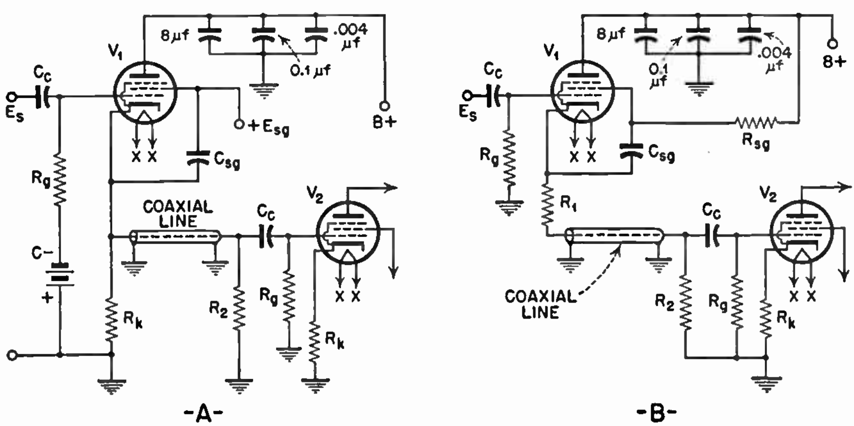


Fig. 6.26

coaxial line to prevent reflections and to maintain essentially uniform transmission characteristics. For short coaxial lines, an exact impedance match is not always required, and R_K may be selected so as to be greater than the impedance matching value and the terminating resistor made about 100 ohms for increased output. Insofar as the bias resistance is concerned, the cathode resistor and the terminating resistor are parallel-connected. Thus, if the coaxial-cable impedance is to be even approached by the terminating resistance, additional bias must be employed to keep the plate current within reasonable limits.

The effective resistance of R_K is not the same as the ohmic resistance of this component. Since the effective dynamic plate resistance of the tube is in parallel with R_K, then this effective dynamic value is very low, owing to the high transconductance of the pentode. Thus, the output impedance looking into the line is equivalent to

$$Z_o = \frac{\left(\frac{R_K R_p}{\mu + 1}\right)}{R_K + \left(\frac{R_p}{\mu + 1}\right)}$$

Therefore, by increasing the ohmic value of R_K, both the gain and output impedance are raised. When operating into a low-impedance line where no frequency attenuation is desired, it is advisable to sacrifice gain in order to match the output impedance to the line.

With the surge impedance of the line known, the value for the cathode resistor must be calculated and this value, with a given type of vacuum tube, will effect the proper impedance match.

The value of R_K is determined through solution of the following equation:

$$R_K = \frac{Z_o R_p}{R_p - Z_o(\mu + 1)}$$

In Fig. 6.26(*B*), the sum of R_1 and the load resistance R_2 is made equal to the desired cathode-bias resistor, the value of R_2 being that required to terminate properly the coaxial transmission line at its far end. When long lines are involved, both ends are terminated, as is shown in Fig. 6.26(*A*).

BIBLIOGRAPHY

1. *Television*, Vol. 1, RCA Victor Division, Radio Corporation of America, Educ. Division, Camden, N.J., 1936.
2. Seeley, S. W., and C. N. Kimball, "Analysis and Design of Video Amplifiers," *Television*, Vol. 2, R.C.A. Institute's Technical Press, New York, 1937, p. 241.
3. Maloff, I. G., and D. W. Epstein, "Television Tubes," *Electronics*, November, 1937.
4. Everest, F. A., "Wide-Band Television Amplifiers," *Electronics*, January, 1938.
5. Preisman, A., "Some Notes on Video Amplifier Design," *R.C.A. Review*, Vol. 2, April, 1938.
6. Engstrom, E. W., and R. S. Holmes, "Television Video Amplifiers," *Electronics*, August, 1938.
7. Herold, E. W., "High Frequency Correction in Resistance Coupled Amplifiers," *Communications*, August, 1938.
8. Fink, D. G., "A Laboratory Television Receiver," *Electronics*, July, August, September, October, November, and December, 1938.
9. Kauzmann, A. P., "New Television Amplifier Receiving Tubes," *R.C.A. Review*, January, 1939.

10. SEELEY, S. W., and C. M. KIMBALL, "Analysis and Design of Video Amplifiers," *R.C.A. Review*, January, 1939.
11. BEDFORD, A. V., and G. L. FREDENDALL, "Transient Response of Multistage Video-Frequency Amplifiers," *Proc. I.R.E.*, April, 1939.
12. WHEELER, H. A., "Wide Band Amplifiers for Television," *Proc. I.R.E.*, July, 1939.
13. ZWORYKIN, V. K., and I. G. MORTON, *Television*, John Wiley & Sons, Inc., New York, 1940.
14. WILDER, M. P., and J. A. BRUSTMAN, "A Video Signal Generator," *Electronics*, April, May, June, July, August, 1940.
15. TRIMMER, J. D., and Y. J. LIU, "Distortion in Compensated Amplifiers," *Electronics*, July, 1940.
16. MUNIZ, R., and A. TAIT, "A Simple Television Pre-Amplifier," *Electronics*, April, 1941.
17. RICHTER, W., "Cathode Follower Circuits," *Electronics*, November, 1943.
18. BERESKIN, A. B., "Improved High Frequency Compensation for Wide Band Amplifiers," *Proc. I.R.E.*, October, 1944.
19. PACINI, H. P., "Cathode Follower Calculations," *Electronics*, October, 1944.
20. HANSEN, W. W., "Transient Response of Wide Band Amplifiers," *Electronic Industries*, November, 1944.
21. PREISMAN, A., "Television Studio Installation," *Communications*, March, 1945.
22. HENRY, E. A., "Practical Design of Video Amplifiers, *QST*, April, 1945; May, 1945.
23. MORITZ, C., "Transient Video Amplifiers," *Electronics*, June, 1945.
24. HAMILTON, G. E., and T. MAIMAN, "Voltage Stabilizers," *Communications*, November, 1945; December, 1945.
25. SMITH, A. D., JR., "Wide Range Electronic Sweeper," *Communications*, January, 1946.
26. KIVER, M. S., *Television Simplified*, D. Van Nostrand Company, New York, 1946.
27. *Engineering Handbook*, National Association of Broadcasters, Washington, D.C., 1946.
28. KRAUSS, H. L., "Graphical Solutions for Cathode Followers," *Electronics*, January, 1947.
29. KURSHAN, J., "Cathode Follower Gate Circuit," *Rev. Sci. Instruments*, September, 1947.

REVIEW QUESTIONS

6–1. (a) In what respect does the video-frequency amplifier differ from a conventional audio-frequency amplifier? (b) What is the desirable frequency range of each?

6–2. Explain (a) "series compensation"; (b) "shunt compensation"; (c) "combination peaking."

6–3. Describe a common means of low-frequency compensation in video-frequency amplifiers.

6–4. How does the plate load of a video amplifier affect the over-all gain of the amplifier?

6–5. What are some of the factors that influence both the bandwidth and gain of a video-frequency amplifier?

6–6. What are the desirable characteristics of a tube for use in video-amplifier design?

6–7. (a) Describe the function of a cathode follower. (b) What are its uses in television?

6–8. How may the cathode-follower output be connected to coaxial transmission lines? Name at least two methods for connection.

6–9. (a) Discuss the power output of the cathode follower. (b) Discuss the voltage output of the follower.

6–10. Describe several specific types of video amplifiers, and discuss (a) their particular features; (b) their advantages and disadvantages; (c) their applications.

CHAPTER 7

THE VOLTAGE-REGULATED POWER SUPPLY

7.1 Introduction. The video amplifier must obtain its d-c operating potential from a well-regulated electronic power supply. The unregulated power supply, if employed, will very likely result in low-frequency distortion, because the internal impedance of such a supply is essentially equal to the capacity reactance of the output filter capacitor of the supply, and this reactance will vary with frequency. In some of the earlier power supplies employed in television, it was found necessary to make the value of the power-supply output capacitor as great as 1,000 μf., or more, to avoid low-frequency relaxation oscillation, or *motor-boating*. Motor-boating will occur at low pass frequencies, if an attempt is made to employ a poorly regulated d-c power supply, and line-voltage surges of a transient nature will result in severe picture bounce. Actually, the output impedance of any well-regulated power supply used to provide d-c operating potentials to a video amplifier should be considerably less than 1 ohm. Development of such a supply is not as difficult as may at first be assumed, since excellent voltage-regulator tubes are commercially available for use in the circuit design, and exact methods are known by which the necessary regulation may be economically achieved.

The voltage-regulated power supply associated with the video amplifier in television systems makes use of a cold-cathode gas-filled tube to obtain an essentially constant d-c output voltage. There are a number of such tubes that may be successfully applied in the regulator circuit, of which the VR-75, VR-90, VR-105, VR-150, 874, 876, and a number of neon tubes are typical. All the tubes listed prove useful for the purpose, since the voltage drop across each remains practically constant over a considerable current range. The operating constants of each type may be obtained from the tube manuals of the various manufacturers. A tabulation of the voltage-current characteristics of various types of VR tubes is listed in Table 4. The mean operating voltage of the series bearing the letter designation VR is always indicated by the several numerals following the two letters in the designation. Thus, a type VR-150 regulator tube has a voltage drop of 150 v. A VR-90 has a voltage drop of 90 v. across the tube. The commercially available neon lamps that are applicable to voltage-regulation circuits provide, for most types, a voltage drop of 55 v.

TABLE 4

OPERATING CHARACTERISTICS OF TYPICAL VOLTAGE-REGULATOR TUBES

Type	Minimum starting voltage	Operating voltage	Operating current, ma.
OA3/VR-75	105	75	5-40
OB3/VR-90	125	90	5-40
OC3/VR-105	135	105	5-40
OD3/VR-150 (VR-150-30)	185	150	5-40

The regulator tubes listed are only typical; others are commercially available for this application.

Two or more cold-cathode gas-filled tubes may be series-connected to regulate higher d-c potentials than would be possible with a single regulator tube. For this reason it is customary to find more than one such tube in the developed circuits.

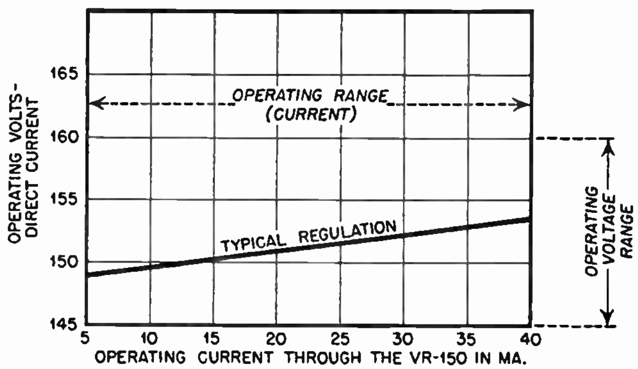
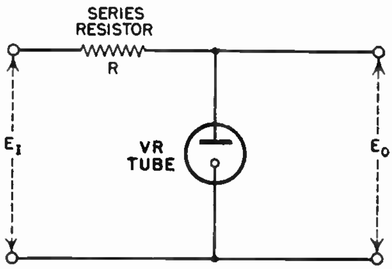


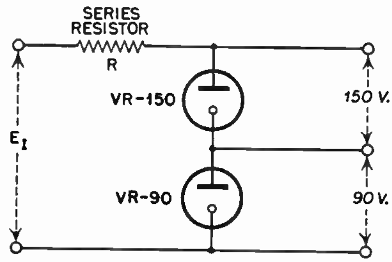
FIG. 7.1

The typical regulation characteristic of the type VR-150 is seen in Fig. 7.1. The fundamental circuit of a voltage stabilizer that makes use of a gas-filled tube is shown in Fig. 7.2. Inspection of the characteristic curve of the VR-150-30 (see Fig. 7.1) will indicate that the starting voltage, or the voltage at which the tube will fire, is considerably greater than the d-c voltage drop across the tube for normal operating conditions. Thus, it becomes essential that the input voltage to the tube be made higher than the starting voltage. This higher input voltage ensures that the tube will fire even though the line voltage be below normal. A series resistor *R* is almost always connected between the d-c line and the plate of the regulator tube so that the maximum current demanded by the tube will not exceed the maximum rating specified by the manufacturer. Generally, the current minimum must not be allowed to fall below the rated value.

Since the voltage drop across one tube is not greater than 150 v., and since the typical video amplifier requires input plate potential in the order of 200 to 300 v. d-c, two or more regulator tubes must be employed in the typical power supply (see Fig. 7.2). Voltage taps may then be had by connecting to the series connections between tubes, much as taps



FUNDAMENTAL VOLTAGE REGULATOR CIRCUIT MAKING USE OF A COLD CATHODE GAS FILLED TUBE



TWO OR MORE VR TUBES MAY BE SERIES CONNECTED AS ABOVE, TO REGULATE HIGHER VOLTAGES THAN WOULD BE POSSIBLE WITH A SINGLE REGULATOR TUBE

FIG. 7.2

are taken off a resistive voltage divider. The series resistance is determined through solution of the equation

$$R = \frac{E_I - V_R}{I_{VR} + I_L}$$

where R = series resistance connected between line and plate of the VR tube
E_I = maximum input voltage necessary to regulate the circuit
V_R = rated voltage of the VR tube
I_L = load current
I_{VR} = maximum rated current of the VR tube

Without output regulation, it has been shown that a power supply delivering 200 v. through a well-designed low-pass filter is capable of producing output fluctuations in the order of 5 v. when connected to a poorly regulated power line. The application of output regulation, employing any tube in the VR series except the VR–105, will reduce these fluctuations to approximately 60 mv. The type VR–105 tube will reduce the fluctuations to about 5 mv. The type VR–105 has proved to be the most stable of all the tubes in the VR series, and optimum operation is obtained when the tube is passing a current of approximately 15 ma. The type VR–150–30 has seen widespread use, however, owing to its greater voltage drop.

7.2 The Degenerative Voltage-Regulator Circuit. Although there are several well-known electronic voltage-regulator circuits of interest to the television engineer, the degenerative regulator is outstanding because it compensates for fluctuations in both line voltage and load current. A fundamental circuit of the degenerative regulator is shown in Fig. 7.3. As the output d-c voltage E_o increases owing to a reduction in load current or an increase in input voltage, the current through R increases. The result is increased bias voltage on V_1, and the plate current at this tube correspondingly decreases. This operates to bring the output voltage

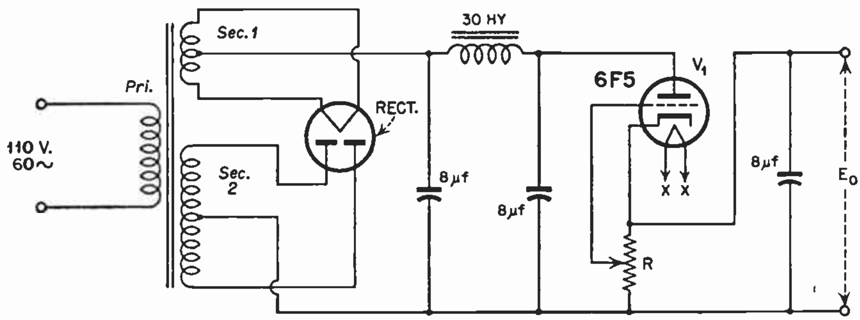


Fig. 7.3

back to its original value. With this circuit, regulation becomes optimum when tubes are employed which possess high transconductance. The use of tubes of high amplification factor limits the plate current possible at V_1 because tubes that possess high mutual transconductance pass low plate current.

It is noted that the circuit shown in Fig. 7.3 depends upon manual control of the voltage by means of the variable resistor R. When the regulation requirement is not too severe, such a circuit may be employed, utilizing such tubes as the 6B4, 2A3, or 6L6 at V_1. It is more desirable, however, to replace the voltage-control resistor with an amplifier having a high μ. Such a circuit is shown in Fig. 7.4. This circuit arrangement will result in excellent regulation of the d-c output voltage, providing compensation for both input line-voltage fluctuations and d-c load-current changes. It also has a low internal impedance, which is highly desirable in power supplies associated with video amplifiers in television.

The operation of the regulator is quite simple. Assume the value of load resistance to increase due to a change in load current, the load current changing in the negative direction. This change occurs because R_{load} equals E_{out}/I_{out}. But in the case of the degenerative regulator, the increase in output voltage brings about an increase in E_2 in direct proportion to the change in output d-c potential. This increase in E_2 effects a decrease in bias voltage at V_2; that is, the negative bias for vacuum tube V_2 becomes more positive. The result is an increase in the magnitude of plate current at this tube.

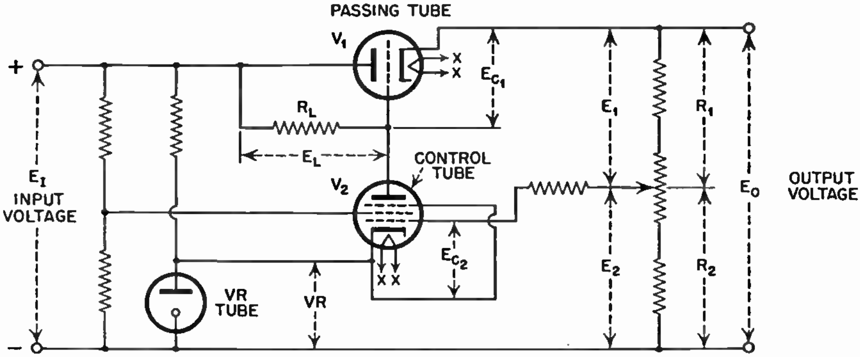


FIG. 7.4

A loop equation can be set up around the control and passing tubes to indicate that E_o (the output voltage) cannot become equal to zero.

$$E_o = -V_R - E_p - (E_{C_1}) = 0$$
$$= V_R + E_{p_2} + (E_{C_1})$$

where E_o = regulator output e.m.f.

V_R = voltage drop across a single VR tube

E_{p_2} = actual plate-cathode voltage across the amplifier or regulator tube (6SJ7)

E_{C_1} = absolute bias voltage, grid to cathode, of the passing tube

If the output voltage E_o is assumed to be equal to zero, then,

$$V_R + E_{p_2} + E_{C_1} = 0 \qquad \text{or} \qquad -(E_{C_1}) = V_R + E_{p_2}$$

However, since the voltage drop across the VR tube is constant at a positive value, it will be seen that $-E_{C_1}$ will be a positive value. This is an impossible condition of operation. Thus, the output of the supply cannot be reduced below that potential which is somewhat greater than the VR voltage present.

The minimum voltage that can be obtained from the supply shown in Fig. 7.4 may be readily determined. It is an axiom that V_2 may not be permitted to draw grid current. Thus, with $E_{C_2} = 0$ as a limit, the control-supply potential is [E_I (input voltage to the regulator) $-V_R$]. A load line is constructed for V_2 with $E_I - V_R$, whose angle with the voltage axis is $\tan \frac{1}{R_L}$. From this the value of E_{p_2} (or the actual plate-cathode potential across the amplifier or regulator tube) may be determined, i.e., from the intersection of the zero bias curve and load line. Thus,

$$E_I = E_{p1} + E_o$$

$$E_o = V_R + E_{p2} + E_{C1}$$

As an approximation, we may let

$$-E_{C1} = \frac{E_{p1}}{\mu_1}$$

where E_{C1} is the cutoff bias.

Then,

$$E_o = V_R + E_{p2} + \frac{E_{p1}}{\mu}$$

and

$$E_o = V_R + E_{p2} + \frac{E_1' - E_o}{\mu_1}$$

$$\mu_1 E_o = \frac{\mu_1 (V_R + E_{p2}) + E_I}{\mu_1 + 1}$$

It is said that the approximation $E_{C1} = E_{p1}/\mu$ will result in an error, but since E_{C1} is low compared with V_R and E_{p2}, the error is inconsequential, particularly as operation near the minimum output voltage is not very stable.

7.3 Full-Range Voltage-Regulated Power Supply. The development of a full-range regulated-voltage supply, which is variable from zero to maximum output voltage as well as capable of excellent regulation over the entire range, has been described by Hamilton and Maiman.* The schematic diagram of the supply is shown in Fig. 7.5. It may be seen that two supplies are actually necessary: one to provide the output d-c potential and one to produce bias potential for the passing tube.

In the design of the full-range supply, the required output voltage E_o and output current I_o must be determined. It is necessary to calculate the actual voltage E_{p_1} across the passing tube V_1. This voltage is the actual plate-cathode potential across the passing tube. Ordinarily, a minimum voltage drop of about 100 v. across V_1 when operating at a maximum output voltage E_o will prove satisfactory. Then,

$$E_{p1} = E_I - E_o$$

where E_{p1} = actual plate-cathode potential across V_1
E_I = input voltage to the regulator
E_o = regulator output voltage

The necessary voltage drop across R_L, the plate load for the regulator,

* Hamilton, G. E., and T. Maiman, "Voltage Regulated Power Supplies," *Communications,* November, December, 1945; January, 1946.

is equal to the sum of the actual plate-to-cathode potential E_{p1} across the passing tube V_1 and the absolute bias voltage E_{C1} on the passing tube. To achieve maximum gain from V_2, the optimum value for R_L must be chosen. The selection of optimum value is accomplished by plotting a curve of amplifier gain versus load resistance for the tube selected. The type 6SJ7 is a commonly selected tube for the application.

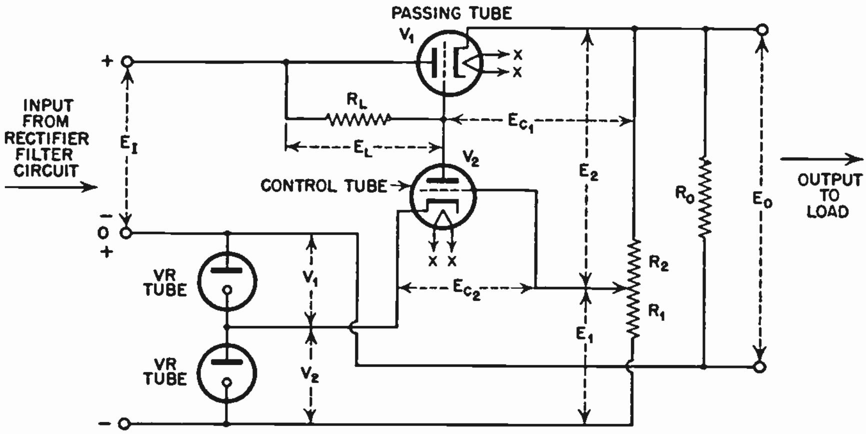


FIG. 7.5

After the value of R_L is so determined, the value of plate current through the control tube must be next found through solution of the equation

$$I_b = \frac{E_L}{R_L}$$

where E_L = voltage drop across V_2
R_L = plate load for the voltage regulator
I_b = control-tube plate current

Proper operation of the control tube is over a flat portion of the plate current–plate voltage curve. Because of the fact that the plate resistance is normally a high value, owing to the low plate current that flows, it is unnecessary to know definitely the value of plate voltage drop across the tube. Wide plate-voltage excursions result in minute changes in plate current. However, the grid voltage of V_2 necessary to fulfill the initial requirements can be determined from a family of plate characteristics plotted for low values of plate current.

Once E_C for V_2 is obtained from the curve, the ratio of R_1/R_2 must be determined after E_1, the input voltage, and E_2 are selected by the designer. Thus,

$$E_1 + E_2 = E_o + V_1 + V_2$$
$$V_2 = E_1 + E_{C_2}$$

or

$$E_1 = V_2 - E_{C_2}$$

where $E_1 + E_2$ = sum of the regulated output and bias supply voltages
$V_1 + V_2$ = bias supply of the full-range voltage
E_{C_2} = absolute biasing voltage on the regulator tube (6SJ7)

and

$$E_2 = E_o + V_1 + E_{C_2}$$

After solution for E_2, E_1 may be next determined.

$$E_1 = E_o + V_1 + V_2 - E_2$$

and

$$\frac{E_o + V_1 + V_2 - E_2}{E_o + V_1 + E_{C_2}} = \frac{E_1}{E_2} = \frac{R_1}{R_2}$$

If tubes in the regulated power supply are parallel-operated, it is necessary to include parasitic resistors in plate, screen, and grid circuits. In the case of parallel operation of tubes to satisfy the heavy current-passing capability indicated in a particular design, then each of the parallel-connected passing tubes should have resistors in the order of 50 ohms or so connected in each plate, screen, and grid circuit as close to the tube socket terminals as possible. This will prevent regeneration or oscillation of a parasitic nature developing in the regulator circuit. If such a condition does develop owing to poor design, it can be identified by observing the output d-c voltage by means of a suitable instrument and by observing the change in ionization at the VR tubes. These tubes will flicker at a steady rate, and the output voltage will be seen to fluctuate at the same instant that the flicker occurs.

Should the regulated supply "go out of regulation," it is customary first to check the output or terminal voltage to determine whether it is proper. If it is found to be satisfactory, then the bias voltage at the control tube should be investigated. A high-resistance voltmeter can be connected across control grid and cathode to measure the bias voltage, and the value should be that dictated in the particular design. It is, of course, easy to determine whether regulation is proper by varying the potentiometer in the control circuit, meanwhile observing the output or terminal voltage of the supply to ascertain whether the voltage is actually under regulation.

It is customary at television stations to check the regulation of all power supplies before going on the air for the day's operations. A maintenance technician examines each power supply for proper regulation. A high-resistance voltmeter is connected across the output terminals of the supply while the potentiometer in the control-tube circuit is varied from minimum to maximum regulation. Final adjustment results in the proper output voltage required by the equipment to which the power supply is connected.

Hum content is measured at the output of the power supply to ensure that pure direct current is being delivered to the video equipment. This measurement is made with a cathode-ray oscillograph. The vertical-axis amplifier input is connected across the output terminals of the power supply and the horizontal amplifier is adjusted for proper deflection across the face of the cathode-ray tube. With the relaxation oscillator and sweep circuit adjusted for 60 c.p.s., the amplitude of the noise voltage is directly measured. For this purpose the oscillograph is previously calibrated for use as a high-impedance voltmeter. The value of maximum permissible noise level from the power supply can be determined, and a standard set and adhered to.

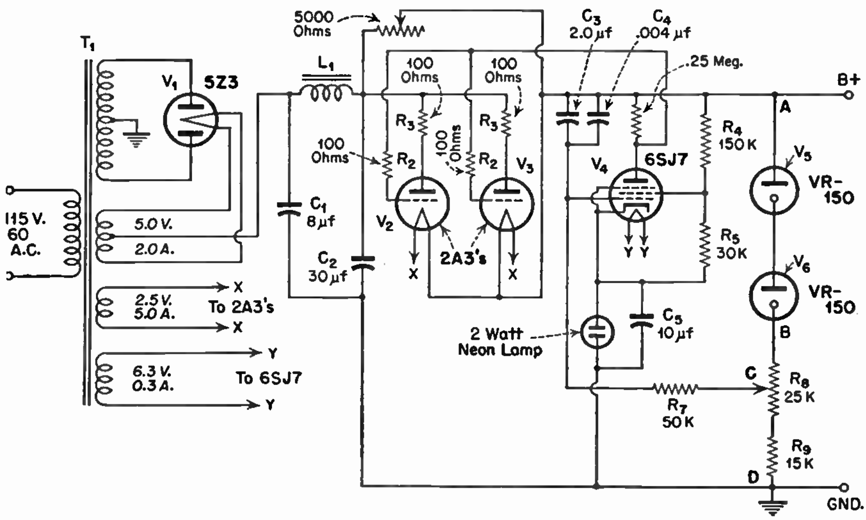


FIG. 7.6

7.4 A Practical Regulated Power Supply for Video Amplifiers. The complete schematic of a regulated power supply of the type required to provide d-c potential to the low-level video amplifiers of a television system is shown in Fig. 7.6. Two VR-150-30 gas-type regulator tubes are employed series-connected with the control potentiometer R_8. A type 6SJ7 control tube has its cathode held above ground potential by means of a 2-w. neon lamp, and the lamp is connected between cathode and ground. This neon lamp is of the type that has no resistor connected in the lamp base. Two type 2A3 passing or voltage-regulating tubes are parallel-connected in order to pass safely the current demanded of the power supply without overload. They function in the circuit as an automatically variable series rheostat.

The operation of the regulator is quite simple. Should a change in load current result at point A (at the positive output terminal), changing its potential with reference to point D (at the negative or ground terminal at the supply output), then point B (at the upper end of R_8) assumes a potential that is relative to point D by the same amount. In other words, the amount of voltage change is relatively the same. If the control potentiometer R_8 is adjusted to a position at point B, or at the end of the potentiometer winding in the direction of V_6, then the control grid of the amplifier tube V_4 receives a voltage change relative to the cathode. The cathode is held at a fixed potential above ground owing to the neon lamp being series-connected between control-tube cathode and ground. Therefore, any voltage change is transmitted at maximum amplitude to the control amplifier V_4.

If the arm or wiper of the potentiometer R_8 is set midway between points B and D, the voltage change between the potentiometer arm (point C) and ground (point D) is only one half of the voltage change, and the amplifier receives only one half the output voltage change.

The circuit is that of a degenerative voltage regulator. The control amplifier V_4 and the two parallel-connected passing or regulator tubes V_2 and V_3 may be theoretically considered as a two-stage d-c amplifier, the output of which is fed back to the input, thereby providing degeneration. The forward gain of the amplifier may be expressed as α and the feedback as β. The latter denotes the fraction of output voltage change that is fed back to the control grid of V_4.

With the arm of the control potentiometer R_8 at B, β is at maximum. When the arm of this potentiometer is at D, β approaches zero. Optimum regulation obtains when α and β are a maximum, the value of β being fixed by the circuit design. The value of β is a function of the voltage developed by the rectifier, by the desired output regulated voltage, and the voltage drop across the gas tubes employed.

Maximum output voltage is obtained when the arm of the control potentiometer is moved in the extreme direction toward D or toward ground. The ground amplifier tube V_4 then is biased at maximum, its plate current is at minimum, the drop in its plate resistor R_6 is at minimum, and the bias is reduced on the series rheostat or passing tubes V_2 and V_3. The result is that V_2 and V_3 pass the desired current with less plate voltage drop, and maximum output voltage is obtained across points A and D.

When maximum output voltage occurs, β is reduced because the arm of the potentiometer R_8 is at maximum position away from point B in the circuit. To increase β, it is essential either to raise the voltage drop across the gaseous regulator tubes or to increase the voltage entering the regulator circuit from the d-c rectifier filter section.

It is possible to bring point B in the circuit close to the cathode potential at the maximum output voltage by choosing a gaseous regulator tube demonstrating higher voltage drop for series connection between the control-tube cathode and ground. Thus, the grid may be easily operated further up potentiometer R_8. It has been pointed out that an additional advantage can be had in employing an RC combination in the grid circuit. This component operates to maintain the signal grid of the control tube close to point A or at maximum voltage insofar as rapid fluctuations in output voltage are concerned. It operates to increase β for a-c variations at the supply output. Increasing C_3 above 2 μf. or increasing R_7 above 50,000 ohms results in little improvement in regulation insofar as surges in line voltage are concerned. Low-frequency voltage variations are brought under better control as the product of R_7C_3 is increased. The capacitor C_3 must be of the low-leakage type, and an oil-filled capacitor rated at a working voltage at least 100 per cent greater than the maximum d-c output is recommended. Generous safety factors should be provided throughout the power supply in order to ensure continuous, trouble-free operation.

The filament transformer for the regulator or passing tubes must be insulated for the full d-c voltage of the power supply and with an ample safety factor. This transformer must not be used to supply current to other tubes in the associated video amplifier if filamentary-type regulator or passing tubes are employed in the circuit.

Bias for the control tube may be either a dry battery adjustable through the range of 45 to 90 v. or a gaseous regulator tube, such as the type VR75–30, in lieu of the neon tube indicated in the circuit design. If the VR75–30 or the neon lamp is employed, a negative-resistance type of oscillation is often encountered. This can be eliminated by connecting a by-pass capacitor of 0.1 μf. capacity or greater across the tube in the cathode circuit. The use of another such capacitor across the control-tube grid and cathode will assist in removing any tendency toward negative-resistance oscillation in the circuit.

The theoretical function of R_8 has been shown. The fact must not be overlooked that this potentiometer is employed practically in setting the value of regulated voltage within the operating limits dictated by the particular design. In adjusting the output voltage, a high-resistance voltmeter is connected across the output, R_8 being adjusted for the desired regulated output potential. It will be found that there is a definite range through which regulation of the output voltage may be obtained. It is well to set the regulation-control potentiometer midway between minimum and maximum regulation limits; or the supply should be adjusted so that the desired regulated output voltage falls midway between minimum and maximum limits of regulation.

It should be mentioned that the type 2A3 vacuum tube is capable of passing about 75 ma. without overload. Two such tubes, parallel-connected in the passing or regulator circuit, allow an upper limit of 125 to 150 ma. to be safely passed under commercial operating conditions. Of course, there are many other types of vacuum tubes that might be employed in the passing circuit with a minimum of change in the design. Such tubes as the 6B4 and 6L6 are commonly employed.

In the final adjustment of any regulated power supply it is important that the filament or heater supply to the regulator tubes be carefully balanced to ground. Otherwise, the a-c ripple present in the filament circuit will modulate the d-c current output, and an objectionable component of hum will be introduced in the output. Various methods of attenuating this source of hum may be used. If the filament circuit is operated above ground, with the center tap at the transformer secondary not being connected to the common ground of the supply, then one side of the filament circuit to the regulator tube sockets must be grounded. The side of the circuit to be grounded, as well as the point along the circuit where the ground is actually connected, is that point or side of the circuit at which maximum hum reduction obtains. The best point for placing the ground connection is determined through the use of an oscilloscope, the vertical-axis amplifier input circuit of which is connected at high impedance across the regulated power supply output. The sweep circuit is locked in at 60 c.p.s., and a ground is connected along the filament line to the regulator-tube sockets until the point is found where minimum ripple is observed at the power-supply output.

The filament circuit may also be balanced to ground through use of a center-tapped resistor connected across the filament circuit—usually at the filament transformer secondary terminals. If the hum voltage is balanced out in this manner, it must be determined that equivalent values of resistance are used on either side of the center tap. A check should be made with an oscillograph, as previously described, to determine if the total hum is actually balanced out of the circuit. Often a rheostat of about 100 ohms resistance is employed across the circuit at the transformer secondary, the arm of which is connected to ground. With an oscillograph connected at the regulated power-supply output, the rheostat is varied about the center position until maximum hum reduction is obtained. Then the arm is locked in place.

As with any attempted power-supply construction, less noise component will be present if a one- or two-section L-type low-pass filter of excellent design is employed in advance of the actual regulator circuit. Capacitor input to the filter, while yielding greater d-c output, will result in poorer regulation and reduced rectifier efficiency. The cutoff frequency in the low-pass filter section is equal to $\frac{1}{\pi\sqrt{LC}}$, where L represents the series inductances in each filter section and C the shunt capacitance. Therefore, the cutoff frequency is inversely proportional to the square root of the product of the capacitance and inductance of each section, and there is a definite LC product that will satisfy the design requirement. Thus, the values of capacitance called for in the design must be employed regardless of whether oil-filled, paper dielectric, or electrolytic capacitors are used. An erroneous impression has been given in certain quarters that less paper or oil-filled capacity is required in a given filter circuit, as compared with electrolytic capacity, to achieve the same ripple reduction. This is untrue.

7.5 Internal Resistance of the Regulated Power Supply. The output impedance of the regulated power supply must be considerably less than 1 ohm if line-voltage surges and variations in d-c load current are not to result in disagreeable picture bounce. It is necessary, therefore, to determine accurately the internal resistance of the regulated power supply once it is constructed and to determine whether the dynamic internal resistance is of a sufficiently low value to enable its association with high-fidelity video equipment as a source of power.

In measuring the internal resistance of the regulated power supply, a minimum amount of equipment is necessary, only two items of test equipment, in fact. One necessity is a reliable beat-frequency oscillator capable of reasonably high output at 60, 120, and 180 c.p.s. To measure the internal resistance of the regulated supply satisfactorily, a high-gain cathode-ray oscillograph of excellent sensitivity is also required. Besides these two instruments, a *blocking capacitor* of suitable low reactance at the test frequencies and with a working voltage rating of at least twice the maximum output potential of which the regulated power supply is capable and a *wire-wound power rheostat* of about 3 ohms resistance are required. A filament rheostat may be used as the variable-resistance element in the test circuit.

The apparatus is connected as shown in Fig. 7.7. It will be noted that with the circuit arrangement a signal from the beat-frequency oscillator (at 60, 120, or 180 c.p.s.) may be impressed across the output terminals of the regulated power supply, the variable rheostat of low resistance being connected in series. The blocking capacitor is employed for the purpose of preventing any d-c potential present at the output of the regulated power supply from entering the output attenuator system of the beat-frequency oscillator. It should also be noted that the output terminals of the beat-frequency oscillator must be above ground, since the series-connected rheostat is between one output terminal and ground.

The external sync terminal of the oscillograph is connected to the same output terminal of the beat-frequency oscillator as is connected to one terminal of the blocking capacitor. The internal sweep circuit of the cathode-ray oscillograph is adjusted to 60, 120, or 180 c.p.s. or to that frequency at which the measurement is to be made.

The ground terminal of the oscillograph at the vertical amplifier input is connected to ground. The other vertical input post of the oscillograph is supplied with a test lead of suitable and convenient length. A test lead with an insulated clip connected at one end is particularly convenient.

With the beat-frequency oscillator supplying a test signal at the chosen frequency into the power-supply output terminals, the test lead from the oscillograph is first connected to the positive terminal of the power supply and then to the high side of the series rheostat. R is then adjusted until

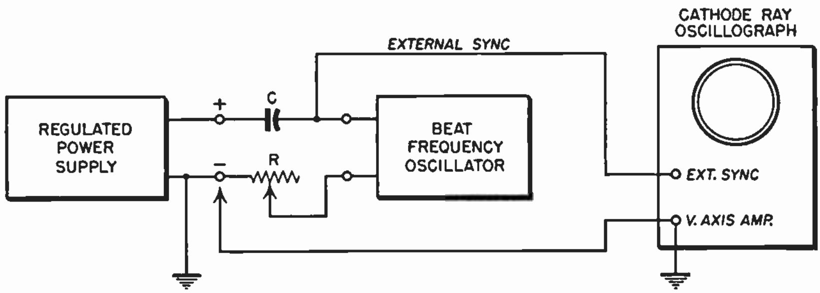


FIG. 7.7

the signal voltage across it, as observed at the previously calibrated oscillograph, is the same as that observed across the regulated power-supply output. The rheostat R is then removed from the test circuit and its resistance determined through measurement by means of a high-resistance ohmmeter or Wheatstone's bridge. The value of resistance indicated is equivalent to the internal resistance of the regulated power supply, and this, of course, should be less than 1 ohm if the regulated supply is to prove suitable for use with the video amplifier.

If it is observed that no appreciable indication is present when the measurement is undertaken across the power supply or when connected across the rheostat R, and especially if the latter is adjusted well below 1 ohm, then it can be safely assumed that the supply is of suitable low internal resistance for association with video equipment, provided, of course, that the test circuit is carefully checked and found to be proper.

BIBLIOGRAPHY

1. HAMILTON, G. E., and T. MAIMAN, "Voltage Stabilizers," *Communications,* November, 1945; December, 1945.

2. Kiver, M. S., *Television Simplified*, D. Van Nostrand Company, Inc., New York, 1946.
3. *The Radio Amateurs Handbook*, American Radio Relay League, Hartford, Conn., 1947.
4. Grob, B., *Basic Television, Principles and Servicing*, McGraw-Hill Book Company, Inc., New York, 1949.
5. Scheraga, Morton G., and Joseph F. Roche, *Video Handbook*, Boland and Boyce, Montclair, N.J., 1949.

REVIEW QUESTIONS

7-1. What is meant by (a) "voltage-regulated power supply"? (b) Describe several conventional types and their uses.

7-2. What is (a) a passing tube? (b) a regulator or control tube?

7-3. (a) Describe the operation of the VR-150-30 voltage-regulator tube. (b) What are its advantages? (c) How may several be used in series to improve the maximum output voltage which may be regulated?

7-4. How is the feedback principle employed in voltage-regulated power-supply design?

7-5. Explain how a control tube is employed to provide effective adjustment of the average voltage to be regulated.

7-6. Why are voltage-regulated power supplies essential in television applications? In what parts of the television system are they principally employed?

7-7. Explain how a voltage-regulated power supply is adjusted for optimum operation through use of an oscillograph.

7-8. How would you adjust one of these supplies for optimum regulation of the d-c voltage output?

CHAPTER 8

THE TELEVISION RECEIVER

8.1 Introduction. The design of a modern television receiver is far more complex than that found in even the most advanced radio receiver developed to operate in the AM broadcast band, i.e., the band extending from 550 to 1,600 kc. per sec. Actually, two receivers are for the most part involved: one for reception and conversion of the picture signal, and the other to receive the accompanying aural signal. For high-quality television reception, neither is more important than the other.

The design of such a receiver requires a broad knowledge of practically the entire field of radio engineering, for all the problems of very high frequency broadcast reception are encountered, as well as problems that involve application and use of the cathode-ray tube, video amplifiers, cathode followers, scanning, synchronization, and magnetic and electrostatic deflection circuits. A thorough knowledge of pulses, pulse techniques, and wave shaping is most essential. The development of the complete receiver requires a knowledge of both amplitude and frequency modulation, since the picture carrier at the transmitter is modulated in an amplitude manner, and the aural carrier is frequency-modulated. The design engineer must also have some knowledge of the television antenna, since the television receiver must obtain its signal from a special form of receiving antenna, the installation of which requires some special knowledge of the subject. A carefully designed antenna-coupling circuit must be employed if the receiver is to produce the high-quality picture and sound that we may expect according to present-day standards.

It will be noted that the television receiver employs the superheterodyne principle because this circuit is extremely sensitive, but it is a far more complex circuit than that usually found in receivers designed for the broadcast band, even though the fundamental principles are identical. The F.C.C. has adopted standards that dictate the allocation of 12 television channels, each channel occupying a bandwidth of 6 mc. Both the video and the aural signals must be transmitted within the 6-mc. channel, the picture carrier being amplitude-modulated and the sound carrier frequency-modulated. Thus, the receiver must be capable of handling both types of signals, and without interference with each other.

The superheterodyne circuit of the receiver must be capable, therefore, of accepting both the video and aural carriers, while at the same time effectively rejecting identical types of signals on adjacent channels in the spectrum. The circuit that is employed must also separate the picture and sound carrier and, through the use of a suitable oscillator and converter or mixer system, produce two intermediate frequencies—one, the result of heterodyning the video carrier, the other the result of heterodyning the aural carrier. Thus, two intermediate-frequency amplifiers are required (each usually employing several stages), the outputs of both being admitted to separate second detector circuits, one for picture and one for sound conversion. It follows that the two second detectors must be followed by separate circuits capable of constructing the picture, and for reconstructing the aural intelligence originally employed in frequency modulating the sound carrier. The detector that is a part of the sound channel is termed a "discriminator."

In addition, a special sync-separator circuit must be used to remove the synchronizing components from the visual carrier, it having been modulated with both the picture information and the signals required to hold the receiver in perfect synchronization with the transmitter. These separated synchronizing impulses must be used to drive horizontal and vertical deflection generators of the receiver, and they, in turn, provide deflection of the electron beam of the cathode-ray tube, upon the fluorescent screen of which is reconstructed the transmitted image.

Since a cathode-ray tube is employed in viewing the picture, associated circuits are required to restore the average brightness of the scene as transmitted (i.e., d-c restoration), and both the picture and aural signals require carefully designed a.v.c. or a.g.c. circuits. In the actual construction of the receiver, special techniques are required, some of which are not conventional in broadcast-receiver production. To impart a general idea of the circuit arrangement found in the modern television receiver, a simplified block schematic is shown in Fig. 8.1. It may be seen that a horizontally polarized dipole antenna picks up both the video and aural signals, these signals being normally fed over a transmission line to a common radio-frequency amplifier input system. The output of the radio-frequency amplifier is passed to a conventional converter or mixer circuit, where both carriers are heterodyned by a local oscillator. The resulting signals are separated and result in two intermediate frequencies, one for sound and one for picture. The two converted signals at intermediate frequencies are passed through two very carefully designed intermediate-frequency amplifying systems. In the case where intercarrier sound is employed, only one intermediate-frequency system is utilized. Further along in the system the two signals are demodulated. The video signal is amplified and used to modulate the grid of the cathode-ray tube, and the audio signal is amplified and used to drive a high-quality loudspeaker. It is most important that cross talk be minimized throughout the system, at the transmitter as well as at the receiver. Usually, special antenna design at the transmitter minimizes the possibility of cross talk to some extent, and the use of amplitude modulation at the picture transmitter and frequency modulation for aural modulation operates to prevent the development of such undesirable

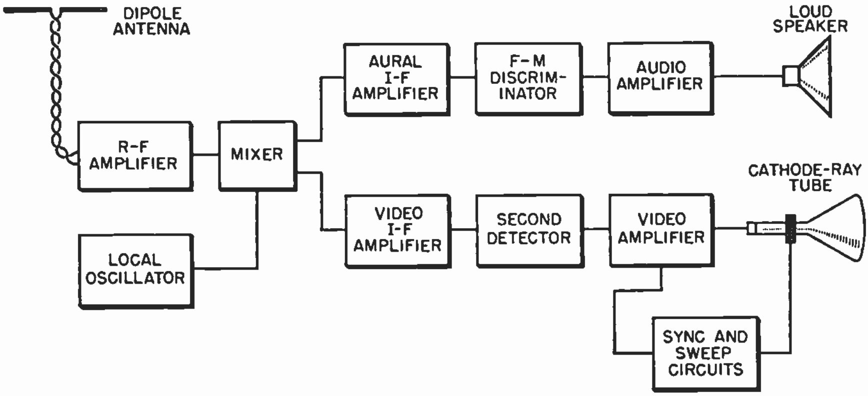


FIG. 8.1

cross talk. But precautions must also be taken elsewhere throughout the system. Very careful circuit design and the application of reasonable care in isolating the circuits of the two channels from each other will maintain such interference at the minimum.*

8.2 The Television Channel. The entire portion of the frequency spectrum allocated to AM broadcasting extends from 550 to 1,600 kc. per sec., a total of 1.05 mc. of the spectrum accommodating more than 2,000 licensed broadcasting stations that employ amplitude modulation. One television station occupies almost six times as much space in the frequency spectrum; i.e., each television channel has been specified by the licensing authority as 6 mc. wide. Altogether, 12 channels, each 6 mc. wide, have been allocated by the licensing authority for commercial television broadcasting purposes. These 12 channels occupy a total of 72 mc. throughout the frequency spectrum—almost seventy times the space allocated for AM broadcasting.

Of the 12 channels 5 are located between 54 and 88 mc. per sec., 7 are allocated between 174 and 216 mc. per sec., with additional experimental channels existing at much higher frequencies. Each of the commercial television channels 6 mc. wide contains properly spaced video and aural carriers and the picture-carrier sidebands. A chart indicating the 12 channels provided for commercial television broadcasting is shown in

* Du Mont, A. B., "Design Problems in Television Systems and Receivers," *Jour. Soc. M. P. Engineers,* Vol. 33, July, 1939, pp. 66–73.

Fig. 8.2. Of the total 6-mc. bandwidth allocated to each station, about 5.75 mc. is devoted to the video signal, about 0.25 mc. being devoted to the FM aural signal. It will be noted that the FM aural carrier is always 0.25 mc. below the upper limit of the channel, the picture carrier being placed 1.25 mc. above the lower limit of the channel. Thus, the picture carrier for channel No. 2 will have a frequency of 55.25 mc. per sec., while the FM carrier for this channel will have an assigned frequency of 59.75 mc. per sec.

THE TWELVE CHANNELS ALLOCATED TO COMMERCIAL TELEVISION BROADCASTING

Channel no.	Lower limit of channel (mc./sec.)	Video carrier frequency (mc./sec.)	Aural carrier frequency (mc./sec.)	Upper limit of channel (mc./sec.)
2	54	55.25	59.75	60
3	60	61.25	65.75	66
4	66	67.25	71.75	72
5	76	77.25	81.75	82
6	82	83.25	87.75	88
7	174	175.25	179.75	180
8	180	181.25	185.75	186
9	186	187.25	191.75	192
10	192	193.25	197.75	198
11	198	199.25	203.75	204
12	204	205.25	209.75	210
13	210	211.25	215.75	216

FIG. 8.2

The picture carrier is modulated with a composite TV signal, i.e., a signal including not only the picture information, but the necessary synchronizing signals as well. Only the audio signal is employed to frequency-modulate the aural carrier. Since the latter carrier is frequency-modulated, no attendant sidebands should be present. Vestigial sideband transmission is employed in radiating the picture signal; that is, one sideband is partially suppressed, only the full upper sideband being transmitted. The reason for the licensing authority specifying approximately single sideband transmission is due to the fact that the total frequency band required per channel is kept at the minimum, while the picture quality is not appreciably altered in any manner. In practical operation, the upper sideband of the picture carrier is allowed to extend up to slightly more than 4 mc. to ensure high-fidelity picture transmission. The lower sideband is permitted to extend approximately 0.75 mc. below the picture carrier, after which it is rather sharply attenuated. Figure 8.3 presents the idealized picture transmission characteristic shown by the F.C.C. It will be noted that only a portion of the lower sideband is transmitted, since a vestigial sideband filter is employed. The lower frequencies contained in the modulating picture signal thus add to the lower pass frequencies contained in the upper sideband. For this reason it is customary in television-receiver design to attenuate the carrier frequency by approximately 50 per cent, thus eliminating the possibility of low-frequency overemphasis.

The practical design of a television receiver to cover all 12 channels with continuous tuning has, until recently, posed a quite difficult engineering problem. The difficulties involved are recognized when we consider that in order to develop a satisfactory receiver it becomes necessary to provide simultaneously *radio-frequency circuit gain* before the signal is admitted to the mixer or converter; *proper termination* of the transmission line connecting the antenna with the receiver input circuit; and *optimum bandwidth* plus the required selectivity. In addition, the local oscillator

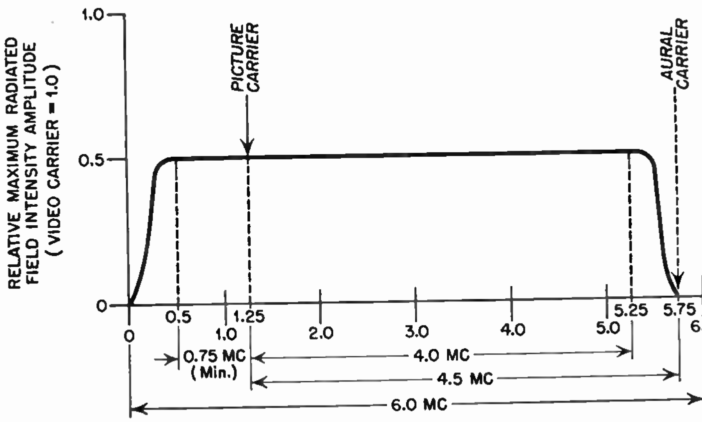


FIG. 8.3

must "track" with the other tuned circuit at the receiver input. It becomes evident at once that a variable tuning capacitor cannot be used, since, because of the very high frequencies involved, tube input capacitance and stray circuit capacitance are too high to permit a tuning capacitance to be placed in shunt with these values. A definite LC product must be maintained in the tuned circuit for each carrier frequency that will be encountered. Too high capacitance limits the value of inductance that may be used, and it is very important that to obtain a reasonable circuit gain and broad bandpass at the same time the reactance of the tuned circuits be made highly inductive.

This has resulted in the use of either push-button or rotary switch channel selection in some receivers, individual low Q iron-core inductors being employed for both radio-frequency and oscillator circuits, with separate circuits used for each channel and tuning accomplished through the use of adjustable iron cores for each inductor. The recent development of the Mallory-Ware Inductuner has brought about a practical solution to the principal problems and has made possible continuous single-dial tuning of the modern and complex television receiver. The capacitance of each tuned circuit is fixed, and a slide-wire inductance

FIG. 8.4 The Du Mont Savoy receiver. This teleset is an excellent example of post-war television-receiver design. It incorporates a 12-in. picture tube, includes an automatic record changer, and provides continuous tuning throughout both the FM and TV bands. An AM receiver is included. (Courtesy of Allen B. Du Mont Labs., Inc.)

provides a means of tuning. This new tuning system was originally developed by Paul Ware, now of Allen B. Du Mont Laboratories, and will be described more fully later in the text.

8.3 The Input and Radio-Frequency Amplifier Circuits. It must be remembered that a composite TV signal carrier and an aural carrier are both delivered to the television-receiver input from the receiving dipole, and that both carriers must be handled at the receiver-input system. For optimum results, this requirement dictates the use of a wide-band band-pass radio-frequency amplifier to precede the mixer-oscillator circuit of the receiver. At the same time the radio-frequency amplifier, to which the input signal is delivered, must provide sufficient radio-frequency selectivity to obviate the possibility of interference or cross talk from transmitters operating on adjacent channels in the same city. In some instances it has been found necessary to provide a high-pass filter at the radio-frequency amplifier input, for the purpose of eliminating the possibility of AM broadcast signal interference. This particular type of interference is most likely to develop when the receiver is operated in the vicinity of high-power AM broadcast stations. The provision of a tuned circuit between the receiver input and the grid

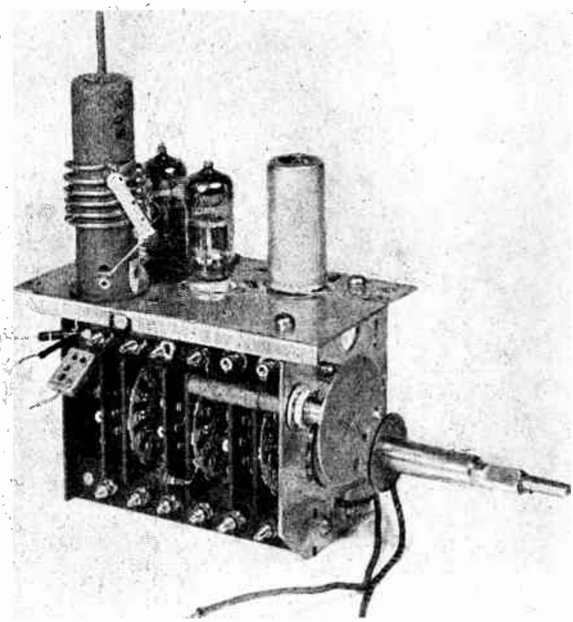


FIG. 8.5 External view of an R.C.A. Victor television tuning unit showing switch wafers and coils. Unit contains circuits tuned to cover each of the channels assigned by the F.C.C. to commercial television. (Courtesy of Radio Corporation of America.)

of the first tube, even though an input radio-frequency amplifier is not employed, results in voltage gain, owing to the resonant rise of voltage produced in such a circuit, and this gain may be, in most instances, sufficient to override noise due to shot effect and the thermal agitation in the first tube and circuit.

A radio-frequency input amplifier must be capable of amplifying the picture and sound carriers without the introduction of objectionable frequency, phase, or amplitude distortion. To achieve all these desirable functions remains one of the most difficult tasks that confronts the television-receiver design engineer. Before entering into the actual design of the radio-frequency amplifier, let us consider the transmission line over which the television signal is conducted from the receiving dipole to the receiver input. Ordinarily, a half-wave dipole antenna is employed. The resistance of such an antenna is approximately 75 ohms. To obtain the maximum transfer of energy, the tuned circuit at the input to the first tube in the system must reflect the same impedance back into the transmission line. An important fact to note is that the receiver input terminus of the transmission line cannot be simply shunted with a resistor of the necessary value, since there must be an efficient transfer of energy to the radio-frequency amplifier input. Thus, for practical consideration of the circuit requirements, a radio-frequency transformer may be assumed to be the transfer medium. The primary of the transformer may be connected across the transmission-line terminus, the secondary being connected in series between the control grid of the radio-frequency amplifier and ground. The inductance of the secondary, together with the input and stray circuit capacitance, may be assumed to provide the necessary LC product for resonance at the desired carrier frequency. Thus, the impedance of this tuned secondary circuit is reflected back into the transmission line because of the mutual inductance between the primary and secondary windings of the transformer.

It follows that the Q of the input tuned circuit must be made very low. Q is a direct function of the inductive reactance of the tuned secondary circuit. At the carrier frequencies involved in television, very low values of inductance are commonplace in such circuits. Thus, the amount of resistance found in the circuit is very large compared to the circuit inductance, the resultant Q being very low. A circuit gain of about 2 in double tuned circuits is generally considered very good, even though it may appear extremely low as compared with the Q present in AM broadcast circuits.

In order to terminate effectively the transmission line at the receiver input, the circuit constants must be such that

$$X_m = \omega_o M = \sqrt{RR_a}$$

$$m = \frac{X_m}{\omega_o}$$

where $\omega_o = (2\pi f_o)$ = the resonant frequency of L and C in the input circuit.

It has been shown that to provide the optimum coupling for proper termination of the transmission line to the receiver, it is considered by some authorities the best procedure to employ separate sets of coils for each of the television channels, because the coupling reactance X_m is a direct function of the square root of the product of R and R_a, while the mutual inductance M is an inverse function of frequency. X_m remains constant (or approximately so) over the entire frequency range where R and R_a are constant, M being an inverse function of frequency.

Mountjoy* has shown that the gain at the center frequency g_o may be expressed by the following equation:

$$g_o = \frac{\sqrt[4]{\frac{1}{P^2} - 1} - \frac{\Delta\omega}{\omega_o}}{\sqrt{2\Delta\omega C R_a}}$$

where $P = \frac{g_1}{g_0}$

= relative gain at f_c as compared with the gain at f_o

when f_o = center frequency
f_c = cutoff frequency
C = tuned-circuit capacitance
R_a = antenna resistance
$\omega_o = 2\pi f_o$
$\Delta\omega = 2\pi f$

In applying this equation in actual circuit design, the center frequency f_o is chosen halfway between the picture and sound carriers. Thus, for channel 10, where the picture carrier is fixed at 193.25 mc. per sec. and the aural carrier at 197.75 mc. per sec., the center frequency f_o will be 195.5 mc. per sec.,

$$f_o = C_V + \left(\frac{C_{FM} - C_V}{2}\right)$$

where C_{FM} = aural carrier
C_V = picture carrier

The frequency band to be passed is 4.5 mc. wide, since about 2.25 mc. exist both above and below the center frequency f_o. The antenna resistance R_a may be assumed to be 75 ohms where a half-wave dipole is employed. The tuned-circuit capacitance may be measured or assumed. This capacitance must be kept to the minimum by every conceivable means, since, when the reactance of the tuned circuit is made predominantly inductive, greater gain is obtained. The reason is that the gain is an inverse function of C, as may be seen in an examination of the equation for determining g_o. As the amount of circuit C is increased, the gain is effectively decreased. In some instances, the designer prefers to choose 6.0 mc. as the band to be passed.

The gain in the input circuit is also a function of bandwidth, the gain being reduced as the bandwidth is increased. In judicious circuit design, it is common practice to assume 0.9 g_o at the edges of the anticipated band-

* Mountjoy, G., "Television Signal Frequency Circuit Considerations," *R.C.A. Review*, October, 1939.

width. In other words, it is not necessary to anticipate full gain at both picture and carrier frequencies, and the design in some cases is made such that maximum gain obtains at g_o, the center frequency, and 90 per cent of this gain is sought at the picture and the carrier frequencies.

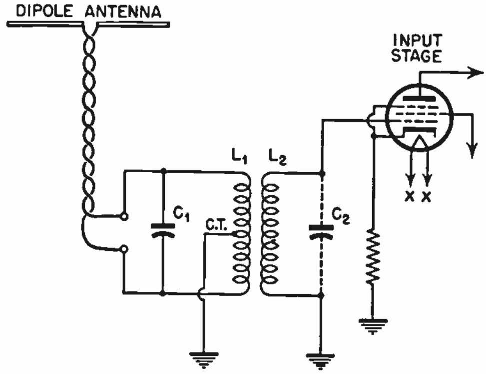


FIG. 8.6

It is common practice to use double-tuned circuits at the receiver input to obtain greater gain and improved selectivity. Such a circuit is shown in Fig. 8.6. The two tuned circuits now comprise a band-pass filter, which couples the transmission line to the control grid of the input radio-frequency amplifier. When such a circuit is used, the gain at the center frequency may be determined through use of the equation

$$g_o = \frac{1}{2\sqrt{\Delta\omega C R_a}}$$

In this circuit, i.e., a double-tuned circuit, the circuit gain is not particularly a function of the primary circuit inductance or capacitance (L_1C_1). In circuit design, L is made as low as possible to still ensure adequate M. The value of the primary shunt capacitance C_1 is increased by the same proportion that the primary inductance L_1 is reduced. The result is that tuning is simplified; that is, small variations of circuit capacitance do not greatly affect the resonant frequency f_r of the circuit.

The primary and secondary circuits are both made resonant at the center frequency f_o; that is

$$\frac{1}{2\pi\sqrt{L_1C_1}} = \frac{1}{2\pi\sqrt{L_2C_2}}$$

It is seen that the mutual inductance M is made equivalent to the product of $\sqrt{L_1L_2}$ and the ratio f/f_o. Thus, the broader the band f to be passed for the desired value of center frequency f_o, the tighter the coupling is made, i.e., the greater the value of M required.

In determining the value of components to be used, the following equations may be employed:

$$L_2 = \frac{1}{\omega_o^2 C} \qquad L_1 = \frac{1}{\omega_o^2 C}$$

$$M = \frac{f}{f_o}\sqrt{L_1 L_2} \qquad \omega_o = 2\pi f_o$$

If the resistance of the secondary tuned circuit R and the value of antenna resistance (R_a) are known, the required value of M may be determined by the following equation:

$$M = L_1\sqrt{\frac{R}{R_a}}$$

With the value of M known, the necessary circuit resistance required to load the transmission line for a given antenna resistance may be determined by

$$R = \frac{R_a M^2}{L_1^2}$$

A typical radio-frequency amplifier as employed in a television receiver is shown in Fig. 8.7. It may be seen that the signal is delivered through

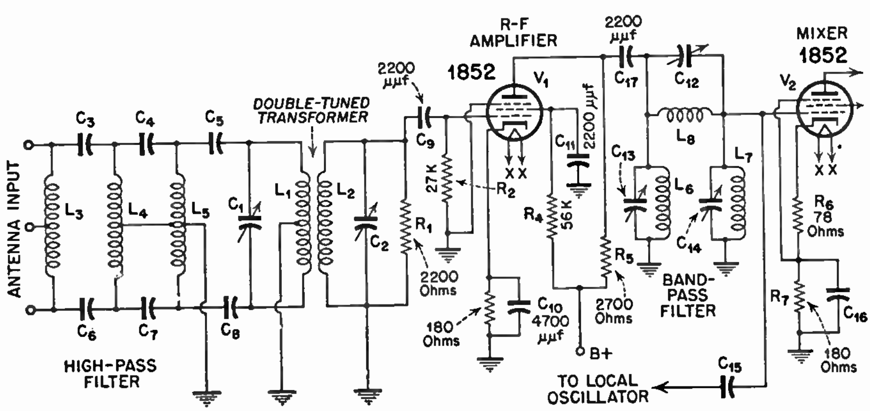


Fig. 8.7

a high-pass filter to the radio-frequency input-amplifier coupling transformer. The input high-pass filter is designed to have a cutoff frequency such that low-frequency signals, which might create undesirable interference, are rejected at the receiver input. It is sometimes possible for strong signals of near-by stations to enter the receiver, creating interference with the picture signal, particularly when the signals are either directly or harmonically related to the video intermediate-frequency amplifier frequencies.

In Fig. 8.7 a double tuned-input radio-frequency transformer is used, which results in increased gain and selectivity and is designed for broad band pass as well. The center frequency of these tuned circuits is chosen halfway between the picture and FM carriers for the particular channel. Of course, there exists a separate set of tuned circuits for each television channel. L_1C_1 comprises the primary tuned-input circuit, whereas L_2C_2 makes up the secondary tuned circuit, and the resistor R_1 is employed to broaden the response of the secondary tuned circuit. R_1 also reduces the capacity effect between L_1 and L_2, and it is assumed that a twisted-pair transmission line is used in this arrangement, since a coaxial line

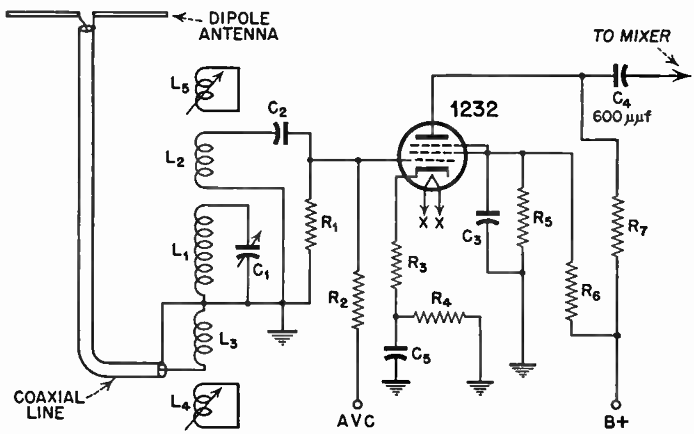


FIG. 8.8

is unbalanced, and a somewhat different circuit arrangement is required.

The output of the radio-frequency amplifier is coupled to the mixer or converter stage through a wide band-pass filter circuit. This circuit provides more uniform frequency response and greater gain than would otherwise be possible. A separate band-pass filter is switched into the circuit for each television channel that the receiver is designed to accommodate, the switching being accomplished simultaneously with selection of radio-frequency amplifier input and local oscillator tuned circuits, a ganged rotary switch providing the selection in some commercial receivers.

Another radio-frequency amplifier circuit utilized in a postwar television receiver is shown in Fig. 8.8. The input radio-frequency transformer incorporates three windings. Maximum transfer of energy from the antenna is assured through a primary winding of low impedance, which provides a match of the antenna through the coaxial line. A tertiary winding is adjusted for resonance at the center frequency by means of a variable capacitor. The grid inductance is resonated by the lumped capacitance due to distributed coil capacity, stray wiring capacity, and the input capacity of the tube. It is tightly coupled to the primary inductance. A double peaked-response curve is obtained, since the tertiary winding serves to increase the coupling between the grid winding and the primary winding.

At the ends of the coil are placed two adjustable brass rings, which are, in effect, shorted turns of inductance. Adjustment of these rings provide adjustment of the primary and secondary inductances. They are adjusted until the two required resonant peaks are obtained, separated by 6 mc. The dip, appearing midway between the two peaks, occurs at the center frequency and is 30 per cent down.

The radio-frequency amplifier tube operates as a conventional tetrode, except that the cathode resistor is not by-passed, and a small amount of degeneration is developed which improves the frequency response of

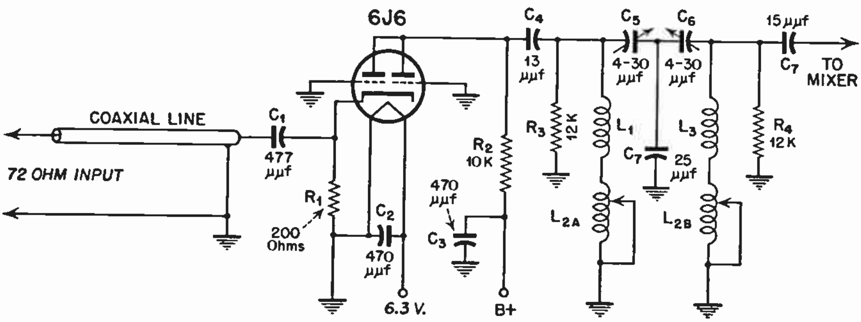
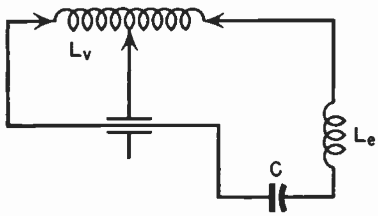


Fig. 8.9

the amplifier. An a.v.c. voltage is provided through a voltage divider R_1R_2. The a.v.c. bias of the amplifier is reduced because the divider arrangement, which results in the amplifier operating at high gain, effects an improvement in signal-to-noise ratio. Any improvement in signal-to-noise ratio that can be obtained in the input radio-frequency amplifier stage is highly desirable, since the signal level is very low at the receiver input. It is in the input system that great care must be exercised to maintain the noise level at a low value.

A late input coupling system is shown in Fig. 8.9. This system constitutes a part of the Mallory-Ware Inductuner, the complete operation of which will be later described in the text. It is a cathode-coupled system, the signal input from the coaxial transmission line being introduced directly across the cathode resistor at low impedance. The input coupling stage is followed by a broad band-pass inductively tuned filter circuit, a sequence that produces improved gain and selectivity. The cathode-coupled input stage has proved to be a very convenient and effective means of coupling a fixed-line impedance to a wide tuning ratio wide-pass circuit. Single-dial control of FM and television bands is afforded, since continuous tuning is provided.

The basic inductively tuned circuit is shown in Fig. 8.10 and has been described in the literature by Paul Ware,* its originator. The system incorporates a variable coil, a fixed coil, and a fixed capacitance series-connected. The tuner covers all the 12 television channels and the FM band as well. It provides continuous tuning from 54 to 216 mc. per sec. Theoretically, the system's upper frequency limit can be made as great as 500 to 1,000 mc. per sec. Instead of making use of a small



TUNING RATIO $\frac{f_2}{f_1} = \sqrt{\frac{L_V(\text{max.}) + L_e}{L_e}}$

FIG. 8.10

portion of the variable coil L_V to reach the uppermost desired frequency, a trolley contact, which determines the number of turns used in the circuit and, consequently, the amount of inductance inserted, is operated out to the limit, and the separate end inductance L_e is made use of.

The trolley contact divides each coil into a used and unused portion. That is, the variable inductance is shorted out, turn by turn, as the trolley travels in the direction of the fixed coil L_e. The variable inductance is a 10-turn coil, having an inductance of approximately 0.02 to 1 μh. The result is that the total inductance of the variable coil is short-circuited for high-frequency resonance, only the end coil being utilized. The reason for this lies in the ability of this system to produce higher Q in an end coil than can be obtained in a stopped-off portion of the variable coil. As the circuit is tuned from minimum (f_1) to maximum (f_2) resonance, the Q is increased at the higher frequencies when the end coil comes into use. Without the use of the inductance, the Q would decrease at the higher frequencies.

In such a tuned circuit, where the capacitance is fixed and the inductance is made variable, the paralleled impedance is approximately expressed by the equation

$$Z = \frac{Q}{2\pi FRC}$$

* Ware, Paul, "A New Inductive Tuning System." *Proc. Radio Club of America*, Vol. 15, No. 1 (February, 1938); "A New System of Inductive Tuning," *Proc. I.R.E.*, Vol. 26 (March, 1938).

Therefore, Q should theoretically vary as f, where Z and C are constant. The circuit provides an approach toward constant impedance, which would be completely realized if Q varied directly with frequency.

Because of the fact that a length of wire can be reduced to a smaller relative value of reactance than can a variable capacitance, wider tuning ranges are possible in a fixed capacitance–variable inductance resonant circuit. Of great importance is the reduction in inductance with increased frequency, since the losses are decreased to proportion, resulting in improved circuit Q.

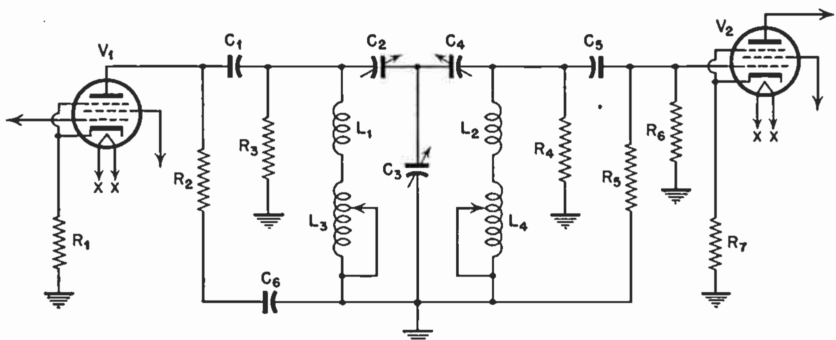


FIG. 8.11

For high-quality television reception it is desirable to have bandwidths of 5 to 6 mc. To achieve this, two adjacent sections of the Inductive Tuner may be overcoupled, as indicated in Fig. 8.11, since it is possible with such an arrangement to track throughout the entire range of television frequencies. In the television receiver it is more desirable to obtain a constant bandwidth in megacycles throughout the range of tuning than a constant percentage bandwidth. The constant bandwidth is attained, as demonstrated by Paul Ware, through a combination of capacitive and inductive coupling as shown in Fig. 8.11 and 8.12.

In applying variable-inductance tuning in television receivers, many efficient circuit arrangements are possible. The usual application involves the use of a standard unit comprising three variable inductors. These inductors provide the basic tuning elements for the radio-frequency, mixer, and oscillator stages. Grounded grid amplifiers, designed for wide bandpass and employing the Inductuner, are exceptionally effective. Reflections are eliminated to a great extent by matching the impedance of the incoming transmission line at the cathode circuit of the grounded grid amplifier. A practical commercial application of such a circuit arrangement is shown in Fig. 8.18.

So that the recommended bias value for the grounded grid amplifier is not exceeded, it is not always possible to obtain an absolute impedance match with the transmission line, although the mismatch cannot be noted when viewing the reproduced image, since the reflections are not apparent to the eye.

Ordinarily, one variable-inductance element is utilized as the principal element of the local oscillator-tuned circuit, the other two variable inductors being used as elements of a bandpass circuit. Bandwidth can be made quite broad through overcoupling the end inductors and overcoupling capacitively. Essentially, constant bandwidth is possible throughout the desired tuning range by means of opposite coupling of the end inductors.

FREQUENCY mc/s	BANDWIDTH mc
54	5
100	6
150	7
200	6

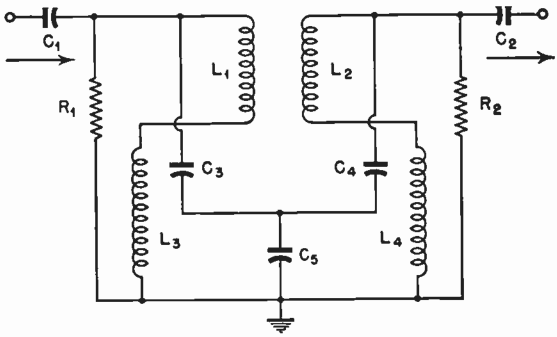


FIG. 8.12

In a test on a variable-inductance tuning arrangement reported by M. F. Melvin, of P. R. Mallory and Co., a grounded-grid input amplifier was used, employing one half of a 6J6 miniature dual triode. A type 6AK5 was employed as the converter, and a type 6J6 tube as the local oscillator, the grids and plates being parallel-connected. The gain was determined as approximately 10, measured at the grid of the first intermediate-frequency amplifier, the test signal being introduced between cathode and ground of the grounded grid 6J6 input radio-frequency amplifier. The gain was quite constant over a range of tuning extending from 50 to 170 mc. per sec., some increase being noted in the higher frequency range. The bandwidth varied from 5.25 mc. at 50 mc. per sec. to 6 mc. at 220 mc. per sec. The maximum bandwidth was obtained at 150 mc. per sec., where the measured bandwidth was 7 mc. It can be seen that insofar as bandwidth is concerned, the Inductuner meets all the requirements with respect to proper transmission of the energy contained in the intercepted video carrier. The advantage of single-dial control for the television receiver cannot be overlooked, since simplification of television-receiver tuned-circuit design is considered essential toward proper development of the television art.

Another disadvantage of more complicated circuit-tuning arrangements in television receivers has been the noise developed in the tuned circuits themselves at that part of the receiver system where signal voltages are extremely low. In the design of the Inductuner, special alloys of wire, trolley guides and end rings, together with careful design of the nib contactor have served to bring about a reduction in tuner noise so that it is below that of tube noise. In the development of such inductive tuning systems, another problem encountered was that of reset error. Such a problem can be serious in high-frequency circuits of the kind found necessary to tune through the higher-frequency television channels. The Inductuner has been so designed that a maximum reset error of 0.025 per cent obtains at 200 mc. per sec., or an error of 100 kc. per sec. This makes it possible to tune the unit by means of a motor drive as well as by a mechanical push-button arrangement. Motor drive has been incorporated in some postwar Du Mont Telesets and makes for more simplified and effortless operation on the part of the set owner.

In the design of radio-frequency circuits employing the Inductuner, the optimum proportions of a particular circuit for a proposed tuning range are achieved when the optimum selection of L, C, and R is obtained near—but not directly at—the upper frequency limit of the circuit. The reason for this lies in the fact that circuit performance is not altered in adding inductance to permit operation at the lower desired frequencies.

8.4 The Mixer, Converter, and Local-Oscillator Circuits. Once the incoming television signal, containing both the video and the aural carriers, has been amplified, it becomes necessary to heterodyne the signal with a local oscillator to produce suitable video and sound intermediate frequencies. The circuit in which conversion takes place is termed a "mixer," or "converter." The design of the oscillator-converter circuits is no less important than the design of the input system for the receiver, and a number of considerations are important.

The tube selected, i.e., the mixer tube, must have low input capacitance. Low input capacitance is an important factor when we consider that at the high frequencies encountered at the tube input most of the tuned-circuit capacitance is, in effect, the input capacitance of the tube itself. The conversion transconductance of the selected tube is of equal importance. This factor is equal to the intermediate-frequency current in the primary of the intermediate-frequency transformer divided by the radio-frequency voltage applied to the control grid of the converter tube, which results in the measured value of intermediate-frequency current. The conversion transconductance G_c is used in determining a figure of merit for converter tubes, which is equivalent to the ratio of G_c to the sum of the input and output capacitances of the tube. Thus,

$$\text{Figure of merit} = \frac{G_c}{C_{\text{in}} + C_{\text{out}}}$$

From the above discussion it will be seen how all the factors described influence converter operation. The greater the figure of merit for a particular tube, the greater the intermediate-frequency signal at the converter-tube output as compared with the signal introduced from the preceding radio-frequency amplifier. The lower the input capacitance of the selected tube, the greater the circuit gain; and the lower the output capacitance of the tube selected, the larger the value of inductance which may be used in the primary of the first intermediate-frequency transformer, and with a consequent improvement in gain. Some tubes particularly suitable for converter, or mixer, use are the types 1852, 1232, and 6AK5. It is important to select tubes demonstrating high G_c, since with high-gain tubes the signal-to-noise ratio becomes more favorable.

It is well to point out here that although the terms "mixer" and "converter" are used interchangeably, the term "mixer" correctly applies when a separate local oscillator is employed, whereas the term "converter" applies to a special application of a pentode for generating the intermediate frequencies. In the latter case the oscillator voltage is produced and the incoming signal is heterodyned within the same envelope; i.e., the one tube provides both the function of the local oscillator and the function of a mixer.

An important factor that must be considered in the design of the local oscillator is that of frequency stability. The stability and output of the usual type of oscillator circuit decrease as the frequency is increased. Thus, in selecting a tube for a particular oscillator design, it is important to use a type which oscillates copiously at the upper required frequency. At the same time the tube must possess acceptable gain (μ) and high mutual conductance (G_m). Such tubes as types 6J5, 7A4, and 6J6 have been used successfully in commercial television receivers.

How important frequency stability really is will be realized if we consider a few facts with reference to receiver operation. The video intermediate-frequency channel is relatively broad, sometimes exceeding 5 mc. with good circuit design. So, insofar as the picture is concerned, a slight drift in oscillator frequency is not of great importance. Such is not the case with respect to the aural signal. In order to obtain the required gain per stage in the aural intermediate-frequency amplifier, and to obtain excellent attenuation in the accompanying channel, sound rejector circuits must be employed to prevent the sound carrier from entering the video intermediate-frequency channel. Thus, it is important that these circuits be adjusted for narrow band pass. The sound intermediate-frequency channel is adjusted for a band pass or bandwidth of 50 to 100 kc. per sec., which dictates that the maximum oscillator drift from one extreme of the channel to the other cannot become greater than 0.05 to 1 mc. per sec. The rigidity of this requirement poses a difficult design problem at the higher television channel frequencies.

Two of the factors found to affect oscillator frequency stability are temperature rise and supply voltage. The ambient gradient surrounding the capacitors, coils, and other components in the oscillator circuit produces a change in the electrical constants of these components. And this change can be particularly serious when it affects those parts related to the oscillator tuned circuit. A slight drift in oscillator tuned-circuit capacitance can result in a considerable frequency change at the higher frequencies. Numerous methods have been devised to make such drift inconsequential. One recommended procedure is to locate the inductance of the oscillator tuned circuit near a circuit resistor, which, after attaining operating temperature, tends to stabilize the temperature of the circuit inductor. It is good practice to apply negative temperature coefficient capacitors in the oscillator circuit. Also the use of a high ratio of capacitance to inductance in the tuned circuit has proved helpful. When a large value of capacitance is used, small changes in capacitance due to temperature gradient constitute a small percentage of the total capacitance of the circuit. The use of the Mallory-Ware Inductuner has also proved useful for oscillator tuned-circuit installation, tests at 100 mc. per sec. indicating that the required frequency can be held to within 500 c.p.s. per °C. after a brief warm-up period. In superheterodyne circuits there has been no difficulty in maintaining the injection-voltage amplitude within a variation of 2 : 1 over a very wide range, as applied to the mixer tube.

As has been pointed out, it is important in television-receiver local-oscillator design to select a tube that will oscillate very strongly throughout the entire desired frequency range. It is customary to operate the oscillator at a frequency higher than the radio-frequency carriers to be heterodyned. This requires oscillator operation at even higher frequencies than are encountered elsewhere in the television receiver, which serves to complicate the oscillator-design problem. Not too many of the available tubes are found satisfactory for use in the local oscillator. Supply voltage to the oscillator tube must be relatively constant, since variation in the supply voltage produces a change in the electrical characteristics of the tube.

Some oscillator circuits are basically more stable than others. In commercial television receivers, the Hartley, the Series Fed Hartley, and the Tuned Grid Tickler circuits, or variations of these circuits, have been found suitable for use. These are shown in Fig. 8.13. It is possible to switch in separate coils; to add inductances, capacitances, or both, to afford operation throughout the 12 television channels. The Hartley circuit is particularly suitable, since the entire tube capacity, grid to plate, is effectively in shunt with the oscillator tuned circuit, resulting in small changes in input capacity having a very slight effect on total tube capacity. The Hartley oscillator is also capable of supplying sufficient output, even at the higher desired frequencies.

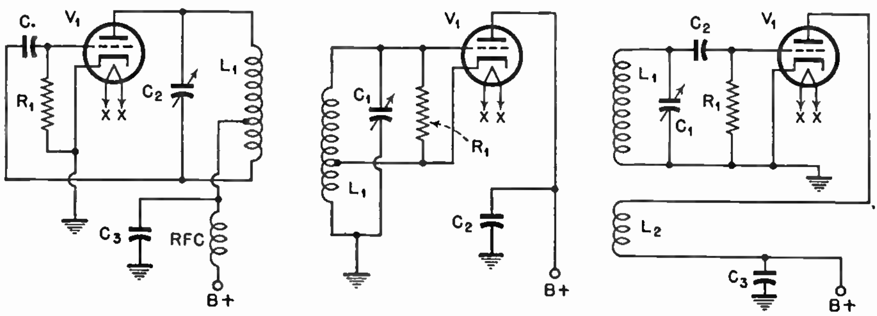


Fig. 8.13

A circuit indicating use of a Hartley oscillator in a commercial type of receiver is shown in Fig. 8.14. For multiband operation a separate coil can be switched in the oscillator circuit for each channel, and a separate radio-frequency input circuit, connecting transmission line to mixer input, must be switched in for each channel that it is desired to cover. The radio-frequency input circuits are double tuned in this receiver, L_1C_1 constituting the primary tuned circuit. Here, a large value of capacitance is utilized, being shunted with a single, small partial turn of inductance. The secondary of the input transformer is permeability-tuned, which for each band achieves resonance through the input capacitance of the mixer tube, the latter capacitance providing the other reactive component of the tuned circuit. In the design of this secondary tuned circuit, consideration must be given the fact that the capacity reactance is fixed by the input-tube capacitance, the inductance of L_2 being adjusted for resonance at the desired channel center frequency. To reflect the proper resistance back into the transmission line, to provide termination of the line at the antenna resistance, the coupling is adjusted between L_1 and L_2.

The oscillator circuit is of the Hartley type. A single turn of low resistance L_4 is connected directly to the socket terminals. The negative temperature coefficient capacitance C_7, which shunts the inductance L_4, is also soldered directly to the socket terminals. The inductance and capacitance of L_4C_7 are the reactive components of the tuned circuit of the Hartley oscillator. A small variable capacitance C_8 is used to center the sound carrier precisely on the rejector intermediate-frequency circuits. Plate voltage for the oscillator circuit is applied through a filter, and enters the circuit at the center tap of L_4.

It is interesting to note that the parallel resonant frequency of L_4C_7

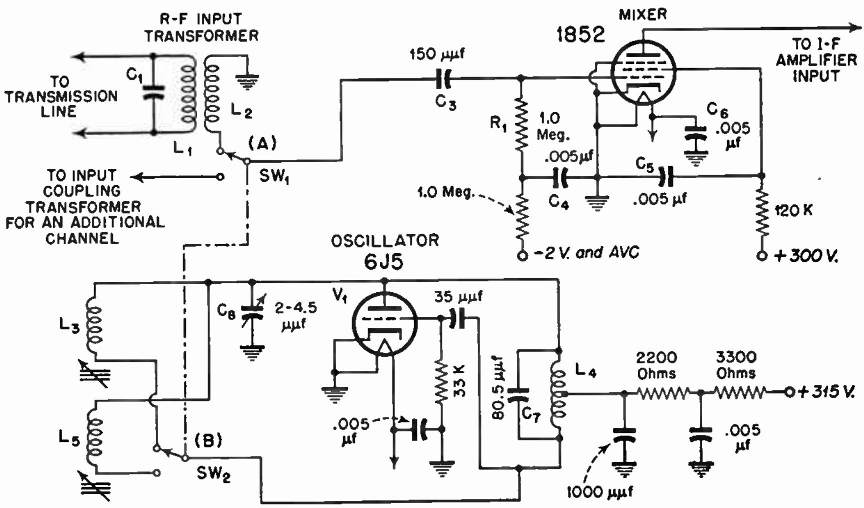


FIG. 8.14

is made less than that required for the particular channel. A separate permeability-tuned shunt inductance L_3 is switched in parallel with L_4 for each channel to be covered. This arrangement effectively reduces the total effective circuit inductance, the smallest value of L_4 being switched in for the highest frequency channel to be covered, and high Q and low circuit resistance are obtained at the same time. Everything taken into consideration, this makes for a very efficient circuit arrangement.

A most efficient method is employed to couple the oscillator output to the grid input of the mixer. A band switch is used to switch in coils at points A and B in the circuit. The capacity that exists between the plates of the band switch effects the necessary coupling. Thus, the oscillator output is capacitively coupled to the input circuit of the mixer.

A rather simple type of radio-frequency circuit, which has been made use of in a table model television receiver, is shown in Fig. 8.15. For purposes of illustration the radio-frequency circuit for one channel only is shown, although a separate antenna primary inductance, preselector, radio-frequency input, and oscillator coil are used for each of the television channels. The oscillator voltage is inductively coupled to the type 1852 mixer, the local oscillator making use of a type 6J5 vacuum tube. A small variable capacitor in the oscillator circuit allows precise tuning of the oscillator resonant circuit. Coupling between the oscillator and the secondary inductor (in shunt with the mixer input) is adjusted to produce about 5 v. peak of induced oscillator voltage. With

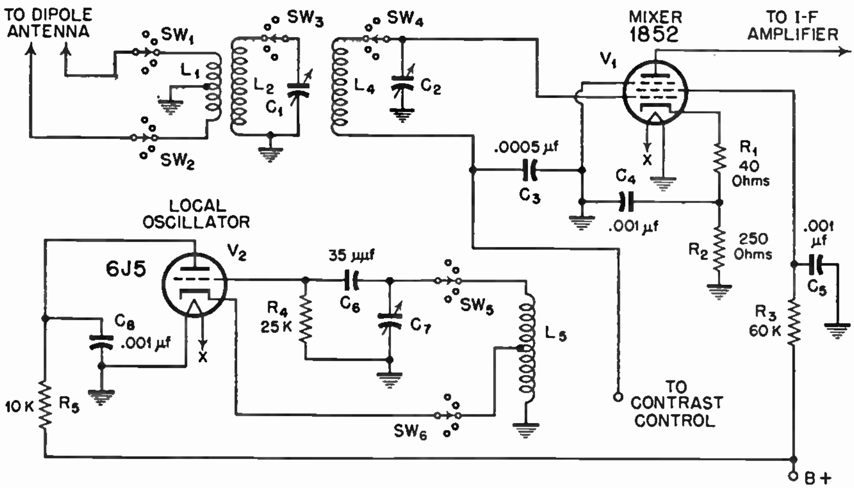


FIG. 8.15

the type 1852 tube employed in the mixer circuit, since it is provided with optimum bias of −5 v. by means of a 40-ohm cathode resistor (not by-passed), the 5 v. of induced oscillator potential provides maximum conversion conductance.

The sound intermediate frequency is coupled out of the plate circuit by means of a 2$\mu\mu$f. mica capacitor to the control grid of a type 1853 vacuum tube, which is employed as the first sound intermediate-frequency amplifier. The input circuit of this amplifier is tuned to the intermediate frequency by means of an adjustable iron-core inductor. A portion of the cathode resistor (the 250-ohm section) is not by-passed in the normal manner, so that a.v.c. potential variations will not materially affect the input capacitance with bias change.

The plate output of the type 1852 mixer is inductively coupled through a conventional video intermediate-frequency input transformer to the grid input circuit of a type 1852 tube, the 1852 tube being employed as the first picture intermediate-frequency amplifier. A series resonant trap circuit is connected between the first picture intermediate-frequency amplifier control grid and ground to prevent the sound intermediate-frequency carrier of the next lower channel from coupling into the picture signal.

An advanced type of mixer and local oscillator circuit described by Philco engineers is shown in Fig. 8.16. The video and audio carriers, after passing through a single stage of radio-frequency amplification are capacitively coupled by means of a 600-$\mu\mu$f. capacitor to the control grid of a type 1232 vacuum tube employed as a mixer and through the sec-

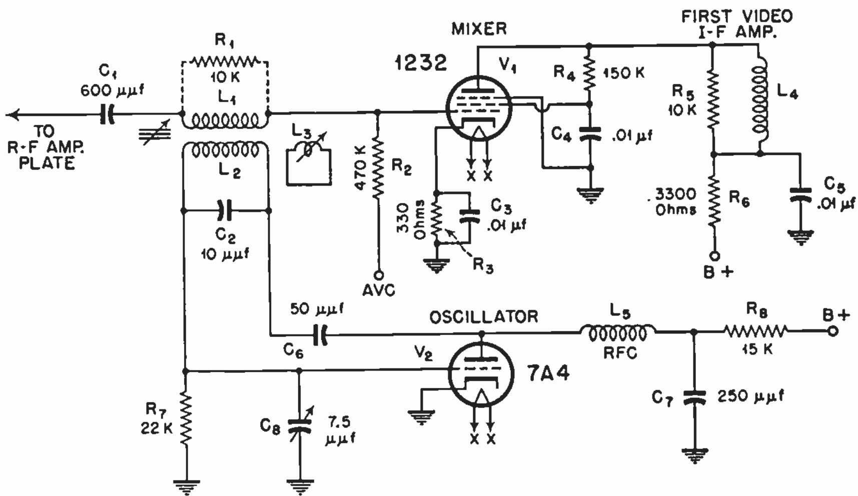


FIG. 8.16

ondary of the local oscillator output transformer. The oscillator section of the channel selector switch of this receiver operates to connect the oscillator output transformer into the mixer input circuit as shown when channels are selected in tuning. Thus, oscillator voltage, at the requisite frequency, is introduced into the mixer input along with the video and aural carriers.

The oscillator coupling transformer is of special design. The primary of the transformer is a part of the oscillator tank circuit, being brought to resonance by means of the fixed capacitance in shunt with the primary, as well as by permeability tuning of the core. It is seen that the oscillator voltage at the required frequency is transformer-coupled to the mixer input. The dual purpose of the secondary is to provide a peaked resonant circuit to couple the preceding radio-frequency amplifier to the control grid of the type 1232 mixer tube. Precise tuning of the secondary is obtained by varying the primary to secondary coupling for optimum M, and by the adjustment of a brass ring adjacent to the secondary winding (i.e., a shorted turn) until the circuit peaks at the center of the band. At this peak the amplitude will be 30 per cent greater than at other points 3 mc. on either side of center frequency.

The reason for adjustment of the center-frequency response for an amplitude 30 per cent above the amplitude at 3 mc. either side of center frequency is to compensate for response effects in the preceding radio-frequency amplifier. The secondary is shunted with a resistor on channel 2 to compensate for the greater Q of the coil at the lower frequencies. As illustrated, there are voltages at three frequencies introduced to the control grid of the type 1232 mixer tube. One induced potential is at the video carrier frequency, the second at the aural carrier frequency, and the third at the frequency of the local oscillator, which is arranged as a modified Colpitts oscillator.

A small tuning capacitor, connected between the control grid of the oscillator and ground, permits precise tuning of the oscillator resonant circuit. The principal tuning is accomplished through permeability tuning of the transformer core and by means of the fixed capacitance in shunt with the transformer primary. The small trimmer capacitor is effectively in shunt with the interelectrode capacitance of the type 7A4 vacuum tube employed as the oscillator.

The output of the type 1232 mixer tube includes voltages at not only the three original frequencies introduced, but also at the two desired intermediate frequencies—one for introduction to the sound intermediate-frequency channel and one for introduction to the picture intermediate-frequency channel. Each intermediate-frequency voltage contains information identical with that supplied to the mixer input before heterodyning by the local oscillator. Only the frequencies of the two input signals have been converted.

8.5 Crystal Control of Local Oscillators in Television Receivers. Chalfin* has described a crystal-controlled local oscillator for television receivers that provides precise control of the local oscillator by means of selected quartz crystals. It is a well-known fact that distortion of the picture is quite likely to take place as a result of oscillator drift, particularly at the higher channel frequencies. The drift of the local oscillator will bring about changes in contrast, and a considerable change in local oscillator frequency will affect brightness and focus. To eliminate these effects, it is sometimes necessary to make frequent readjustments of oscillator tuning in order to maintain the delivered oscillator voltage at the required frequency for conversion to the desired intermediate frequencies at the mixer output.

Conventional local-oscillator design, as applied in television receivers for operation within the present assigned spectrum, requires not only

* Chalfin, N. L., "Crystal Stabilization of Television Receivers," *Radio News*, May, 1946.

careful mechanical compensation arrangements but the use of negative temperature coefficient electrical components as well. Ambient gradient of temperature must be compensated for if the local oscillator is to supply voltage to the mixer tube that is precisely controlled as to frequency. It has been shown that the temperature coefficient of copper is such, for example, that its expansion and contraction in an oscillator coil has resulted in a frequency change of 24 kc. per sec. at 100 mc. per sec. for a 30°F. temperature change. Compensation for temperature change in the conventional type of oscillator circuit is, therefore, an expensive undertaking.

The R.M.A. standards for television intermediate frequencies have been set as 21.25 mc. per sec. for sound and 25.75 mc. per sec. for video. Chalfin* has investigated the requirements of a local oscillator of requisite stability to maintain these intermediate frequencies. Considering channel 5 (76 to 82 mc. per sec.), the oscillator frequency becomes 103 mc. per sec. It is seen, therefore, that since the intermediate-frequency bandwidth is plus or minus 100 kc. per sec. for the aural system, a frequency drift at the local oscillator by a factor of 10^{-3} (1/1,000) will take the center of the aural intermediate-frequency carrier completely outside the band. It is necessary to maintain oscillator frequency stability at about 3×10^{-5} at 100 mc. per sec., or to approximately 0.003 per cent, which is equivalent to 30 c.p.s. per mc.

Quartz crystals for oscillator stabilization are considered by some authorities to be more economical than the stabilization required for each channel where self-excited local oscillators are used. Stabilities in the order of 0.001 per cent of nominal oscillator frequency are possible in factory production of quartz crystal units, and low temperature coefficient crystals at frequencies below 6 mc. per sec. are possible on a production basis with ±0.0001 per cent to ±0.0005 per cent per °C. accuracy.

Harmonic oscillators or harmonic accentuators are best adapted for use in direct control of oscillators above 50 mc. per sec. Two such circuits are illustrated in Fig. 8.17. The circuit incorporating the type 6AC7 vacuum tube will deliver less power than that using the type 6AG7 tube. The tuned plate circuit of the oscillator *LC* may be adjusted to any harmonic of the fundamental crystal frequency, the greater the harmonic frequency chosen, the more reduced the output voltage of the oscillator. In the design of such an oscillator it is customary to switch in suitable crystals for each channel to be covered, a harmonic of the fundamental crystal frequency being used to generate the desired local-oscillator frequency. For the first five channels allocated to commer-

* *Ibid.*

cial television, the crystal frequencies presented in Table 5 have been suggested by Chalfin.*

It is pointed out that choice of electrical components for use in either of the suggested circuit arrangements is of great importance. The posi-

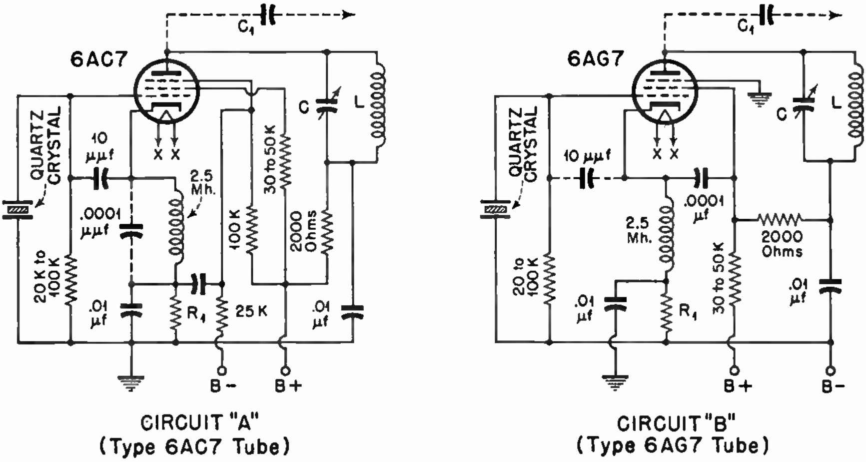


FIG. 8.17

tive potential applied to the suppressor electrode of the vacuum tube may be varied from 20 to 25 v. to approximately 150 v. The greater the voltage is made, the more acceptable the operation of the emphasizer

TABLE 5

Channel, mc. per sec.	Fundamental crystal frequency, kc. per sec.	Selected harmonic	Local-oscillator frequency, mc. per sec.	Intermediate frequencies, mc. per sec.
54–60	9,000	Ninth	81	21.25 and 25.75
60–66	8,700	Tenth	87	21.25 and 25.75
66–72	9,300	Tenth	93	21.25 and 25.75
76–82	9,363.636	Eleventh	103	21.25 and 25.75
82–88	9,083.333	Twelfth	109	21.25 and 25.75

tuned circuit in the anode circuit of the tube becomes as frequency is increased. A high-Q tank circuit is essential, and the inductance in the cathode circuit of the crystal oscillator should be made resonant at some low frequency. A 2.5-mh. choke, with air core, and of pie-wound construction, has been found suitable at operating frequencies approach-

* *Ibid.*

ing 90 mc. per sec., the choke not being by-passed. Consideration in the choice of crystal frequencies should be instituted, so that no harmonic of the selected crystal frequency falls within the 6-mc. band for intermediate frequencies lying between 20 and 26 mc. per sec. or for any single channel within the carrier transmission channel itself. This indicates that crystal frequencies lying between 8.6 and 10 mc. per sec. or above 26 mc. per sec. are the only suitable frequency ranges.

It should be noted that the circuits illustrated in Fig. 8.17 can be used to emphasize harmonic frequencies bearing any integral relation to the fundamental crystal frequency. The circuits do not favor either odd or even harmonics, a characteristic peculiar to certain other frequency-multiplier circuits or systems. As much as 15 v. has been obtained at the plate tank at the twelfth harmonic when the 6AC7 circuit was employed. Less output, of course, is to be had at the higher-order harmonic frequencies.

Coupling from the plate circuit of the crystal-controlled local oscillator to the mixer stage may be attained by any of several circuit arrangements. Link coupling may be employed between the oscillator plate tank and the antenna band-pass coil of the receiver. Inductive coupling may be used through winding the crystal-oscillator tuned tank on the same form as the antenna coil or grid coil or the combined antenna and grid coil of the mixer tube. Capacitive coupling may be employed between the plate end of the oscillator tank coil and the control grid of the mixer tube. Inductive coupling has proved most satisfactory. The two other methods require careful dressing of leads to eliminate the possibility of extraneous coupling with other circuits and the excessive loading of the circuits when capacitive coupling is made use of.

8.6 The Du Mont Radio-Frequency Input System. The Du Mont radio-frequency input system is unique in that it makes use of the Mallory-Ware Inductuner. In Fig. 8.18 it may be seen that the input system employs a type 6J6 vacuum tube (V1) as a radio-frequency amplifier, a type 6AK5 tube (V2) as a mixer, and a type 6J6 tube as the local oscillator (V3). Three variable inductors are incorporated in the Mallory-Ware Inductuner, two in the broad band filter that couples the output of the radio-frequency amplifier, and one in the local-oscillator tank circuit. These three separate inductors are engineered to cover the range of 54 to 216 mc. per sec. without band switching.

In examining the circuit and components associated with V1, it may be seen that the 72-ohm coaxial transmission line (type RG–59U) is coupled into the cathode circuit of the input radio-frequency stage, and the inner conductor of the line is coupled through a 470-$\mu\mu$f. capacitor to the upper end of the 200-ohm cathode resistor. Thus, the line terminal is effectively in shunt with the cathode resistor. The symmetrical grids of the 6J6 are grounded at the tube socket, and V1 operates in all respects as a grounded grid amplifier. Resistor R_2 (10,000 ohms) is the plate-load resistor for the amplifier. The use of coaxial cable between the antenna and the input of the amplifier results in the reduction of noise pickup by the transmission line.

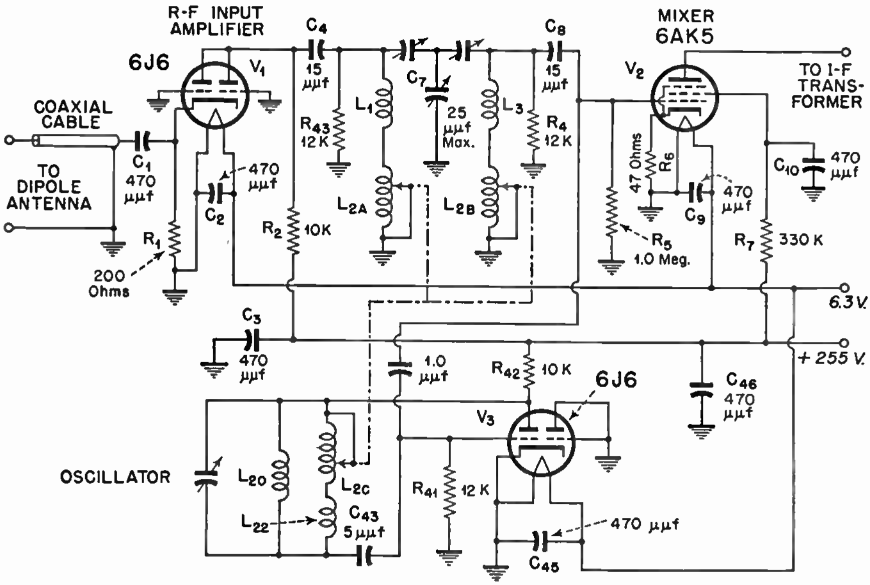


FIG. 8.18

The output of the radio-frequency stage is coupled through a unique broad band-pass filter to the control grid of the 6AK5 mixer tube. It will be noted that the capacitance in the broad band-pass filter is held constant (except for preliminary tuning adjustments), circuit tuning being normally carried out through adjustment of the circuit inductance of *L2A* and *L2B* (in the broad band-pass filter network), and through adjustment of *L2C* in the local oscillator tank circuit. Adjustment of all the coils is carried out simultaneously by means of a single control, and tuning is accomplished in this manner throughout the tuning range of 54 to 216 mc. per sec. No band switching is required.

The three coils or inductors of the Mallory-Ware Inductuner are housed in a square-section die casting. Figure 8.19 indicates the general external appearance of the system, and Fig. 8.20 illustrates the unit with the cover removed. The general arrangement of the three coils on a ceramic shaft with nibs may be seen and the placement of an accumulation stop at the end of the shaft to eliminate the possibility of mechanical damage if the shaft should be operated too far in either a clockwise or counterclockwise direction. Each of the three inductors, two for the band-pass filter coupling the input radio-frequency stage to the mixer and one for the local-oscillator circuit, may be tuned continuously through

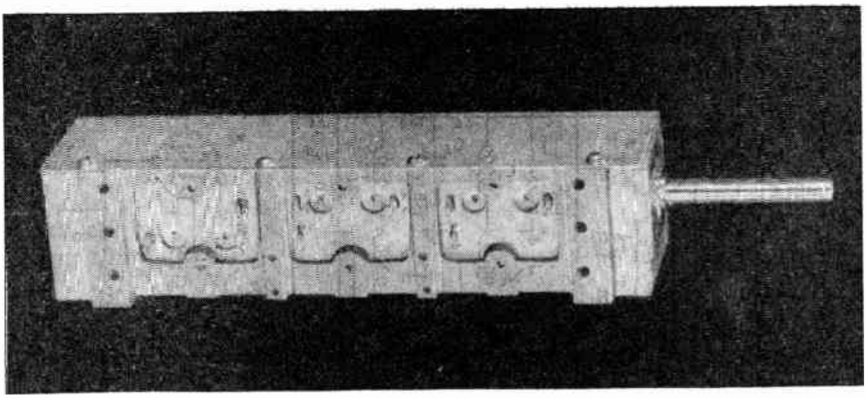


FIG. 8.19 The Inductuner is enclosed in a die-cast housing. The external connections to each coil assembly may be seen. The coils are not grounded. (Courtesy, Allen B. Du Mont Labs., Inc.)

10 turns. This represents an inductance range of approximately 0.02 to 1 μh.

In the circuit diagram in Fig. 8.18, it may be seen that turns of inductance are short-circuited in resonating *L2A*, *L3A*, or *L2C*. The low-fre-

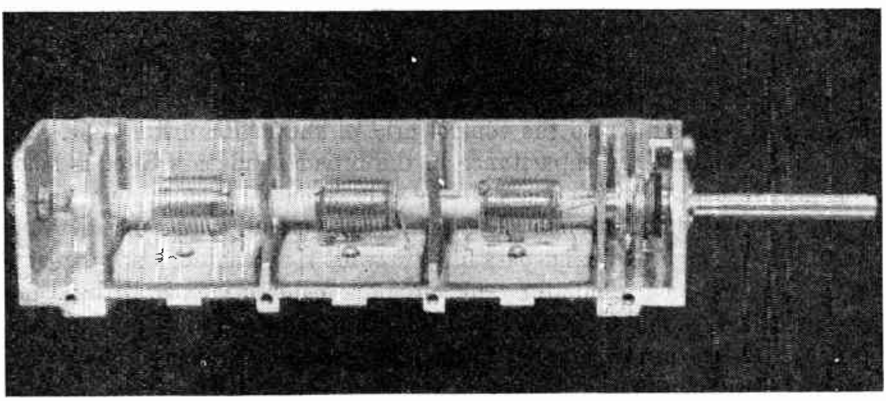


FIG. 8.20 The Inductuner is shown with the cover removed. It will be noted that the No. 2 and No. 3 inductors are wound in opposite directions so as to facilitate close positioning of the end inductors. (Courtesy, Allen B. Du Mont Labs., Inc.)

quency end of each coil is shorted to the nib, thus increasing the natural frequency of the unused portion, since it attains a minimum when the nib is nearest the high-frequency limit of travel. Where the Inductuner is employed in wide band-pass filter design to couple adjacent stages, such as the output of the radio-frequency amplifier to a following mixer input, two adjacent sections of the inductive tuner may be overcoupled and caused to track throughout the entire tuning range. The goal is a constant bandwidth in megacycles rather than a constant percentage bandwidth. This constant bandwidth is obtained by combined capacitive and inductive tuning as shown in Fig. 8.21. The tabulation by Paul Ware shown in Fig. 8.12, indicates the approximate bandwidth variation with frequency that may be obtained with this system. It is seen that the possible bandwidth increases with increasing frequency. It is interesting to note, also, that the circuit Q of the inductive tuner increases with frequency. The increase is a very desirable feature, since circuit losses increase with frequency. The result is more efficient high-frequency operation insofar as the tuned circuits are concerned.

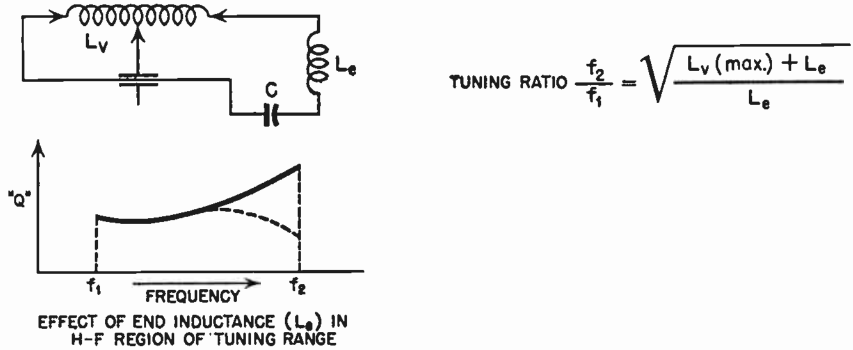


Fig. 8.21

In Fig. 8.18 again, it will be noted that the oscillator voltage is coupled to the mixer control grid by means of a 1-$\mu\mu$f. zero temperature coefficient capacitor. Thus, the oscillator voltage at the heterodyning frequency is injected into the mixer grid along with the signal voltages at the aural and picture carrier frequencies present at the output of the band-pass filter. In the output of the mixer, therefore, are both sound and picture intermediate-frequency voltages, which are fed to the two respective intermediate-frequency amplifier channels.

8.7 Production of the Picture and Sound Intermediate-Frequency Carriers. Before discussing the remaining circuits of the television receiver a description of the production of the intermediate-frequency signals should be given. For purposes of illustration channel 5 will be analyzed. Here, the picture carrier radiated by the television transmitter is 77.25 mc. per sec., and the aural carrier has a frequency of 81.75 mc. per sec. Both carriers are present at the mixer input which succeeds the radio-frequency amplifier, and both carriers must be heterodyned by the local oscillator. The local oscillator must develop a voltage, the frequency of which is always above the video and sound carrier frequencies. Since a video intermediate frequency of 25.75 mc. per sec. represents the choice of the R.M.A. Committee that has proposed the standards, the oscillator frequency required to develop this intermediate frequency will be 77.25 + 25.75 mc. per sec., or 103 mc. per sec. Considered in another manner, the numerical difference between the picture-carrier frequency and the local-oscillator frequency yields the video intermediate frequency. Thus, 103.0 — 77.25 mc. per sec. = 25.75 mc. per sec. It may be seen that the difference between the sound carrier frequency of 81.75 mc. per sec. and the local-oscillator frequency of 103.0 mc. per sec. yields the required aural intermediate frequency of 21.25 mc. per sec. Therefore, at the

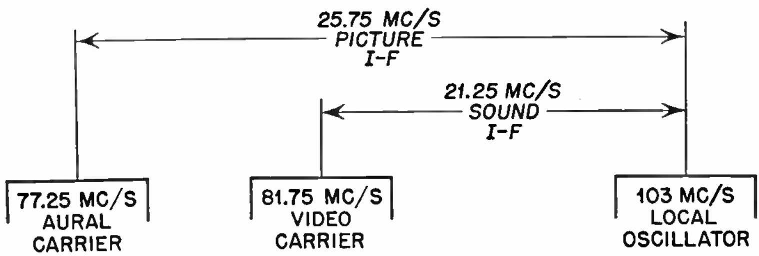


FIG. 8.22

output of the mixer stage, two signal voltages are present at intermediate frequencies, namely, the 25.75-mc. per sec. picture intermediate-frequency carrier and the 21.25-mc. per sec. aural intermediate-frequency carrier. The frequency relations that exist are indicated in Fig. 8.22.

An idealized intermediate-frequency response curve is shown in Fig. 8.23. It may be noted that 50 per cent response is sought at the picture intermediate frequency of 25.75 mc. per sec.

The purpose of this discussion is to present a brief summation of the radio-frequency and intermediate-frequency signal system, together with the relations of carrier and intermediate frequencies, before treatment of the intermediate amplifier systems is undertaken.

A discussion of the intercarrier or carrier-difference system of television sound reception has not yet been presented, since it will be discussed in some detail later (pages 406 to 409). However, in examining the intermediate-frequency response characteristics of conventional and intercarrier receivers, as illustrated in Fig. 8.23, it will be seen that both systems are considered.

In the conventional television receiver, the pass bands of the intermediate-frequency systems are shown in the figure. The picture intermediate-frequency amplifier possesses substantially zero sensitivity (actually an average of 45-db. attenuation at the associated sound channel frequency).

The sound carrier pass band is eliminated in the intercarrier system, since no sound intermediate-frequency channel is employed, as will be later discovered when the intercarrier system is described in the next section. With the sound carrier pass band eliminated, the picture intermediate-frequency pass band is extended slightly to produce greater gain at the sound carrier. This extension of the pass band is indicated by the dashed-line extension of the picture pass band in Fig. 8.23.

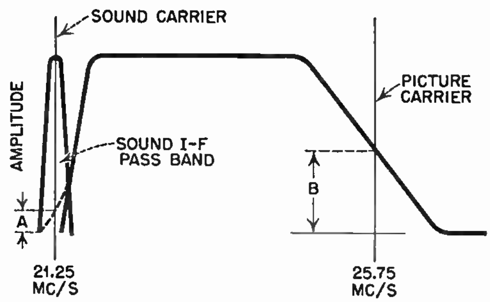


FIG. 8.23

S. W. Seeley of R.C.A. has shown that the percentage response of this extended curve at the sound carrier frequency to be equivalent to the dimension A, for the case where intercarrier sound is made use of. He has indicated that this dimension should never be made greater than 10 per cent of the carrier level (dimension B) in linear units, assuming that the sound and picture carriers are of equal amplitude when received. Seeley gives a more conservative figure of 3 per cent of dimension B for A when intercarrier sound is employed. This more conservative figure is recommended, since differential-attenuation and wave-interference effects, functions of receiver location, are likely to occur in actual practice.

When conventional television-receiver intermediate-frequency systems are employed, it will be noted that the picture and sound intermediate-frequency carriers are separated by 4.5 mc., just as the radio-frequency carriers of the picture and sound transmitters (both constituting the television transmitter proper) are separated by 4.5 mc.

8.8 The Receiver Intermediate-Frequency System. It may have been noted that signal voltages at both the video and intermediate frequencies are present in the mixer plate circuit of the television receiver. It is the function of the intermediate-frequency amplifier system following the mixer to accept and amplify these voltages. In some systems the first video intermediate-frequency amplifier must accept and amplify both the video and audio intermediate-frequency signals, at the same time rejecting adjacent-channel intermediate-frequency signals and passing along to succeeding intermediate-frequency amplifier stages the picture intermediate-frequency carrier alone, the picture carrier having been separated from the aural intermediate-frequency carrier in the first stage. The aural intermediate-frequency carrier is fed to another and separately operated amplifier system. In other modern television receivers, the picture and sound voltages at intermediate frequencies are taken off directly at the mixer output, both signals being thereafter separately amplified through the individual sound and picture intermediate-frequency channels. In any case there must always exist two multistage intermediate-frequency amplifiers: namely, one for the picture intermediate-frequency signal and one for the audio intermediate-frequency signal, except in the case where an intercarrier sound system is employed at the receiver. It follows that there must be included in the picture intermediate-frequency system, sharply tuned rejection circuits to ensure against the associated- and adjacent-channel aural intermediate frequencies passing through the video channel. In one well-known receiver the first picture intermediate-frequency amplifier functions as both a signal intermediate-frequency amplifier and a video and sound intermediate-frequency signal separator, so that with the aural intermediate-frequency signal effectively rejected in this first stage, only the picture and synchronizing signals appear at the cascaded amplifier's output. These two signals eventually reach the input of the video second detector where demodulation occurs.

It is fairly common practice to afford separation of both the picture and audio intermediate-frequency signals directly at the mixer output, and a number of circuits are conventionally employed for this purpose. Several systems will be discussed later. But, regardless of the circuit employed, the fundamental requirements are basically the same, i.e., the two incoming carriers must be heterodyned to produce the two desired intermediate-frequency carriers, and these two carriers with attendant sideband information must be separated, amplified, and then demodulated.

The standard picture intermediate frequency has been set at 25.75 mc. per sec., whereas the audio intermediate frequency has been standardized at 21.25 mc. per sec. The video signal is something less than 4.5 mc. wide, requiring wide band-pass coupling systems of one type or another between the intermediate-frequency stages, which are in cascade. The audio intermediate-frequency amplifiers must demonstrate a uniform response of only about 50 to 100 kc. per sec. This latter requirement is not difficult to obtain by conventional means. Since limiters are employed in the audio intermediate-frequency amplifier channel, any amplitude-modulated picture signal that might cross-talk into the audio intermediate-frequency channel is effectively prevented from passing through. The problem of preventing the audio signal from entering the picture intermediate-frequency system, however, presents more of a problem from the designer's point of view.

In the modern television receiver the picture carrier lies only 1.5 mc. above the sound carrier of the adjacent channel. Thus, if we consider channel 3, where the picture carrier is located at 61.25 mc. per sec. and the sound carrier at 65.75 mc. per sec., as an example, it is at once apparent that the sound carrier of channel 2 will lie at 59.75 mc. per sec., since the two carriers are separated in the spectrum by 1.5 mc. The channel 2 sound carrier is only 1.5 mc. below our channel 3 picture carrier of 61.75 mc. per sec. At the same time we must maintain relatively flat wide-band response over an upper sideband width of about 4 mc. The cutoff at each end of the band must be rather sharp. Ordinary transformer coupling between adjacent picture intermediate-frequency stages, even though extremely tight coupling and resistance damping (to provide lower Q) are employed, will not suffice. It becomes necessary to use highly refined band-pass filters in coupling adjacent stages of the cascaded video intermediate-frequency amplifier. In addition, high-Q rejector circuits, either series- or parallel-tuned, must be included to ensure adequate rejection of the accompanying and adjacent sound intermediate-frequency carriers that are present.

As opposed to transformer coupling (where two coils are inductively coupled to transfer the signal from one stage to another), band-pass coupling involves the use of interstage filters to provide a transfer of the intermediate-frequency signal, together with a rejection of related and undesired signals that might otherwise be passed. Fundamentally, the intermediate-frequency band-pass filter combines a low-pass and a high-pass filter, the elements of the filters being so selected through judicious design that the filter impedance remains constant over the broad desired band of pass frequencies and quite sharp attenuation obtains at both extremes of the pass band. It is at once evident that a combination of both a high-pass and a low-pass filter offers these desirable characteristics, provided that the design is adequate. The low-pass filter will pass a band of frequencies that lie below some selected cutoff frequency, and the network provides sharp attenuation of signals at all frequencies above the cutoff frequency. The high-pass filter has the opposite characteristic; it will, with good design, pass a band of frequencies above some selected lower cutoff frequency. The composite of the two is a broad band-pass filter, affording sharp cutoff at the two extremes of the desired pass band.

Because of the desirability for sharp cutoff beyond the pass band of the coupling networks, in order to suppress adequately the adjacent sound carrier interference, an M-derived filter is preferable in television intermediate-frequency amplifier coupling systems. It most fully satisfies the requirements outlined above. Since the M-derived filter comes from a constant K type of structure, it is necessary to investigate this latter type of filter before entering the discussion of a typical television-receiver intermediate-frequency system employing M-derived coupling networks.

Before proceeding with discussion of the constant K filter, some consideration should be given the *intercarrier sound system,* which has found

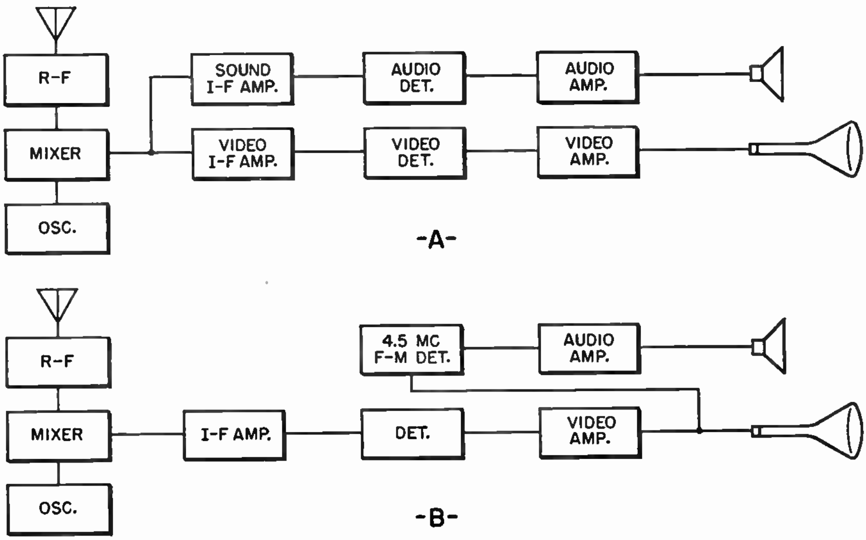


FIG. 8.24

some acceptance in television-receiver design, and which promises to be more widely used as the trend toward reduced receiver cost gains impetus.

The intercarrier, or carrier-difference, system for the reception and reproduction of TV sound uses the frequency difference between the picture and sound carriers, as transmitted by the television station. The TV receiver employing intercarrier sound does not depend upon any precise local-oscillator frequency for its proper operation. The high-frequency signal that is finally to be detected is the difference between the picture and sound carrier frequencies. This frequency difference is 4.5 mc., according to the present standards in the United States, for television stations operating in the region between 54 and 216 mc. per sec.

The television receiver employing intercarrier sound is constructed in the conventional manner, except that only one intermediate-frequency channel is used (see the block diagram in Fig. 8.24). The single intermediate-frequency channel, however, must be made sufficiently broad to pass both the picture and sound carrier, plus the sideband power that is present.

In order that the wave applied to the second detector may be predominant with respect to the picture intermediate-frequency carrier and thus may satisfactorily demodulate the sound intermediate-frequency carrier, it is necessary to provide some attenuation for the sound intermediate-frequency signal. The use of at least two absorption trap circuits, coupled to the intermediate-frequency coils, will result in an intermediate-frequency response characteristic that is identifiable by a shelf several hundred kilocycles in width, with its center about the mean sound intermediate-frequency. This has been shown in Fig. 8.23 of the preceding section.

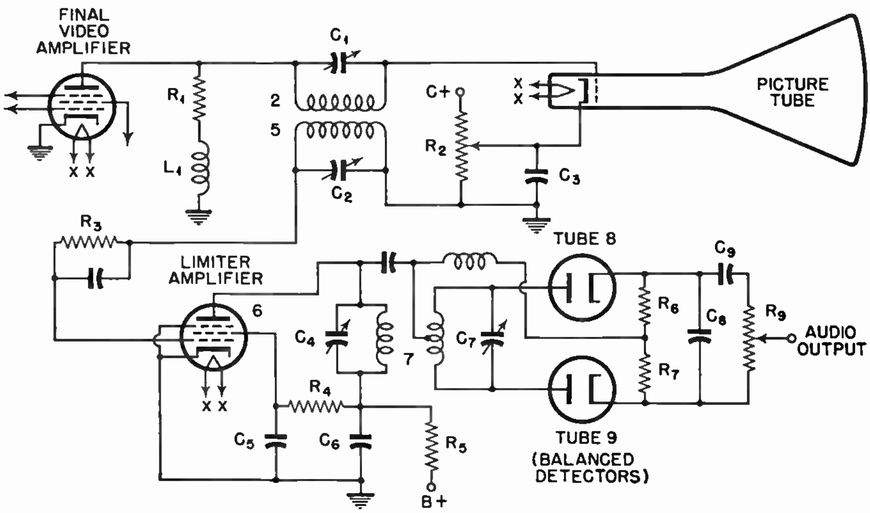


Fig. 8.25

The circuit of the receiver using intercarrier sound, suggested by R. B. Dome of General Electric, is shown in Fig. 8.25. A transformer has its primary circuit (2) connected between the final video amplifier stage and the modulating grid of the cathode-ray picture tube of the receiver. The primary circuit (2) is tuned to the difference frequency of 4.5 mc. per sec. This tuning will obviate the possibility of that frequency appearing as picture modulation on the cathode-ray tube screen. It provides, simultaneously, a circulating current of some magnitude in the primary. The current amplitude is sufficient to induce a 4.5-mc. per sec. wave in the secondary (5), which is tuned to 4.5 mc. per sec. The secondary is connected to a tube (6) that operates as a limiter-amplifier to feed the discriminator transformer (7) and balanced detectors (8) and (9). The tubes serve to detect the frequency modulation present on the 4.5-mc. per sec. wave. The resulting audio output is fed to a loudspeaker for reproduction of the sound.

A small amount of drifting of the local-oscillator frequency is of negligible concern, since the 4.5-mc. per sec. frequency has been originally determined by quartz crystals that are temperature-controlled at the television transmitter. Hum modulation or microphonics at the local oscillator are of no consequence, since any appreciable change in sound intermediate frequency is accompanied by an equal change in picture intermediate frequency, the difference frequency being undisturbed by the local oscillator. It is important, of course, that the level of the sound and picture carriers be approximately equal at the receiver location, and both carriers must, of necessity, be present for the system to operate properly. It is also very important that the modulation level be held proper at both transmitters (sound and picture), the modulation level not exceeding about 85 per cent for optimum operation of the system.

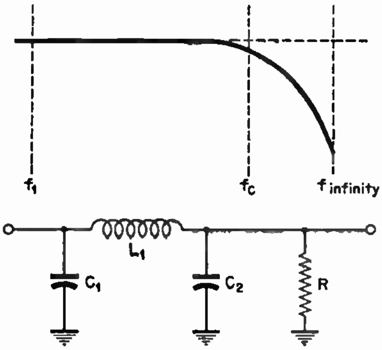
It is readily apparent that such a system offers many advantages other than the elimination of the receiver sound intermediate-frequency system. The trend toward simplification of television receivers is gaining, and with the combining of several tube functions within a single envelope (through the use of multipurpose tubes), a really simple yet efficient carrier-difference sound system can be engineered. Progress in this direction has been accelerated by the recent announcement of the General Electric type 6BN6 tube, which was especially developed for application in intercarrier systems. It is not possible to elaborate upon its characteristics or application here, but the reader is referred to the General Electric Company for specific information concerning its use.

8.9 The Constant-*K* Band-Pass Filter. In Fig. 8.26 is shown the circuit arrangement of a typical low-pass filter, which is identical in every respect with such filters as those employed for the suppression of ripple in transmitter and receiver d-c power supplies.* A series inductance, L_1 and two shunt capacitors C_1 and C_2 are used. The cutoff frequency of such a filter f_c is equivalent to $\frac{1}{\pi\sqrt{L_1C_{1\text{ and }2}}}$ where L_1 is the series inductance employed and $C_{1\text{ and }2}$ is equivalent to the combined capacitance of C_1C_2. In the design of such a filter, C_1 and C_2 are made equivalent with respect to capacitance, one half of the total capacitance for the required cutoff frequency f_c being allowed in each shunt capacitive element.

The terminating resistance R is equivalent to μf_cL, and where R is known, $L = R/\pi f_c$. The band-pass characteristic of such a filter is shown in the accompanying diagram.

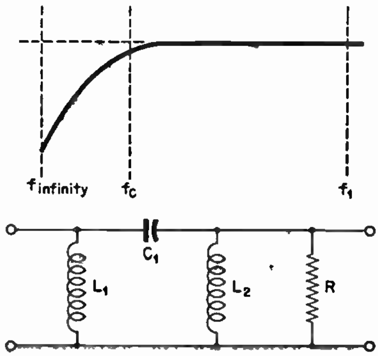
* Helt, Scott, "Design of High Voltage Plate Power Supply Using Mercury Vapor Tubes," *Communications*, April, 1943.

Figure 8.27 indicates the electrical structure of a high-pass filter. Here, a series element of capacitance is employed and two shunt inductive elements. This arrangement of elements is just the opposite of that in the low-pass filter. From the accompanying curve, indicating the transmission characteristic of such a filter, it may be seen that a band of desired fre-



LOW PASS FILTER AND CURVE INDICATING TRANSMISSION CHARACTERISTIC

FIG. 8.26



HIGH PASS FILTER AND CURVE INDICATING TRANSMISSION CHARACTERISTIC

FIG. 8.27

quencies above the cutoff frequency f_c is passed, all frequencies below f_c being sharply attenuated. In this type of structure

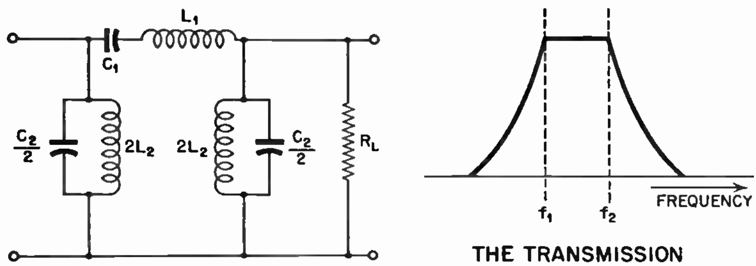
$$f_c = \frac{1}{4\pi\sqrt{LC}} \qquad \text{and} \qquad L = \frac{R}{4\pi f_c}$$

In the design of such a filter, twice the value of L, as determined by the equation just given, is incorporated in each shunt inductive arm. Thus,

$$L_1 = 2\left(\frac{R}{4\pi f_c}\right)$$

The same value of inductance is employed for L_2, since $L_1 = L_2$.

It will be noted that the characteristics of both the low-pass and high-pass filters are combined in Fig. 8.28 to take advantage of the transmission characteristics of both, the composite low-pass and high-pass curves being superimposed to provide a broad band-pass characteristic typical of this constant K type of structure. In the circuit arrangement of the constant K type of filter, both the series L and two shunt capacitive elements of the typical low-pass filter are present, as well as the series capacitance and the two shunt inductive elements of a conventional high-pass filter. Hence, the transmission characteristics of both filters are effectively combined to produce the band-pass characteristic shown in Fig. 8.28. Instead of this type of structure having a single cutoff frequency f_c, two are indicated: f_1, which is the lower cutoff frequency, and f_2, which is the upper cutoff frequency. Thus, in typical design, these two values of cutoff frequency are predetermined by the band desired to be passed.



THE CONSTANT K FILTER

THE TRANSMISSION CHARACTERISTIC OF THE CONSTANT K BAND PASS FILTER

FIG. 8.28

The values for the various elements of the constant K network may be determined through use of the following equations:

$$L_1 = \frac{R}{\pi(f_2 - f_1)}$$

$$C_1 = \frac{(f_2 - f_1)}{4\pi f_1 f_2 R}$$

$$L_2 = \frac{R(f_2 - f_1)}{4\pi f_1 f_2}$$

$$C_2 = \frac{1}{\pi(f_2 - f_1)R}$$

where R = resistance in which the network is terminated in ohms
L = inductance in henrys
C = capacity in farads
f = frequency in cycles

The impedance of the series arm C_1L_1 is expressed as Z_1, and Z_2 represents the impedance of the shunt arm. Then, $K = \sqrt{Z_1Z_2}$, and K_2 equals Z_1Z_2 equals L_1/C_2 equals L_2/C_1.

In the application of the constant K type of filter in coupling vacuum-tube circuits, the input and output capacitances of the two vacuum tubes, one at the filter input and one at the output, combine with the distributed capacitance of each corresponding coil (the input or output shunt inductance) to form the circuit element $C_2/2$ at each filter terminus. The two values of $C_2/2$ must be made approximately equivalent. Should the input tube capacitance plus the distributed and stray capacitance at the output of the filter not provide a value of shunt capacitance equal to that present at the filter input, then it becomes necessary to add a small value of capacitance in shunt with $2L_2(C_2/2)$ to make it so. This can be made variable for accurate circuit adjustment. It is at once evident that the preponderant portion of the lumped capacitance in the case of either the input or output shunt capacitance is a function of the input and output interelectrode capacitances of the tubes selected. The two cutoff frequencies f_1 and f_2 are a function of the required bandpass desired.

The terminating resistance R_L may be determined by the following equation:

$$R_L = \frac{1}{C_{2\pi}(f_2 - f_1)}$$

In television picture intermediate-frequency amplifiers, it is universal practice to employ pentode vacuum tubes, and the gain becomes a function of R when such tubes are made use of. The gain may be expressed as

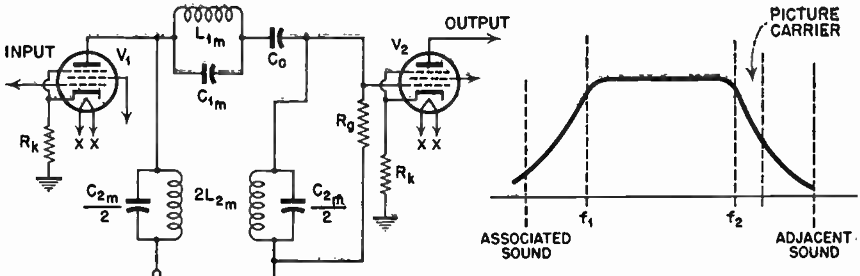
$$g_o = G_m Z_L$$

where Z_L may be considered as R. When R is decreased as the difference $f_2 - f_1$ increases, additional stages of amplification are employed in cascade to obtain the desired total gain. The total amount of gain required through the picture intermediate-frequency amplifier, the second detector, and the video amplifier that follows is a function, in turn, of the amplitude of voltage required at the grid or modulating electrode of the picture cathode-ray tube.

8.10 The *M*-Derived Type of Band-Pass Filter. The constant K type of filter network has sharper cutoff than either of the simple forms of low-pass or high-pass filters already described, but because of the much sharper cutoff of the M-derived structure at either f_1 or f_2, it is more applicable in the design of coupling networks for picture intermediate-frequency amplifier systems. Such a filter is illustrated in Fig. 8.29. It will be seen that there has been added a series-impedance element $L_{1m}C_{1m}$, which results in infinite attenuation developing at some desired frequency beyond cutoff. This provides more abrupt cutoff and, in consequence, greater discrimination to unwanted sound carriers which might otherwise result in serious interference. It is still true, however, that the previously described constant K filter is still superior in this regard to a transformer-coupled intermediate-frequency amplifier incorporating shunt resistance for purposes of damping.

Each impedance element of an M-derived filter bears a relation to those which make up a constant K section by a factor that is a function of two constants M_1 and M_2, or of a single M constant. Each value of M is a function of the ratios that exist between the frequencies of infinite attenuation f_{1i} and f_{2i} and the two upper and lower cutoff frequencies f_1 and f_2.

In Fig. 8.29 the transmission characteristic of a typical M-derived structure may be seen. In this particular filter network C_c is a large value of coupling capacitance and is employed to prevent the direct current present at the plate of V_1 from reaching the control grid of V_2. Its



THE M-DERIVED FILTER AS EMPLOYED IN COUPLING VIDEO I-F AMPLIFIER STAGES

TYPICAL BAND PASS CHARACTERISTIC OF THE M-DERIVED FILTER

FIG. 8.29

presence in the circuit has no part in the electrical development of the filter structure and is not considered in the design calculations. The selection of C_c is important, however, from the standpoint of its ability to block the d-c voltage, and for that reason it must have excellent dielectric material. A mica dielectric is preferred in order to ensure low leakage; otherwise, d-c leakage reaching the control grid of V_2 may upset the bias of this amplifier and in turn destroy the amplifier's desired operating characteristic.

The following equations may be employed in the practical design of such a filter for application in video intermediate-frequency coupling systems:

$$m_1 = \sqrt{\frac{1 - (f_2/f_{2i})^2}{1 - (f_1/f_1d)^2}}$$

$$m_2 = \frac{f_1}{f_2} m_1$$

$$L_{1m} = \frac{4m_1^2}{C_2m(1 - m_2^2)}$$

$$L_{2m} = \frac{1}{C_2m(2\pi f_1)^2}$$

$$C_{1m} = C_2m\left(\frac{1 - m_1^2}{4m_1^2}\right)$$

$$R = \frac{m_1}{C_{2m}\pi(f_2 - f_1)}$$

In the practical development of such an amplifier, the lower cutoff frequency f_1 may be taken as 22.4 mc. per sec., and the upper cutoff frequency f_2 may be taken as 25.25 mc. per sec. The upper frequency of infinite attenuation f_{2i} may be taken as 27.25 mc. per sec. It is not necessary that a lower frequency of infinite attenuation be considered in actual circuit design. Thus,

$$m_1 = \sqrt{\frac{1 - (f_2/f_{2i})}{1 - (f_1/f_{2i})}}$$

$$m_2 = \frac{f_1}{f_2} m_1$$

$$L_{1_m} = \frac{4(m_1)^2}{\frac{C_{2m}}{2}(1 - m_2^2)(2\pi f_1)^2}$$

$$L_{2_m} = \frac{1}{\frac{C_{2m}}{2}(2\pi f_1)^2}$$

$$C_{1_m} = \frac{C_{2m}}{2}\left(\frac{1 - m_1^2}{4 \times m_1^2}\right)$$

$$R = \frac{m_1}{\frac{C_{2m}}{2}(f_2 - f_1)\pi}$$

It should be remembered that the sound intermediate-frequency carrier is at 21.25 mc. per sec. and the picture carrier is at 25.75 mc. per sec. These carrier frequencies for intermediate-frequency signals have been standardized. It is therefore necessary to "shape up" the response between f_2 and f_{2i}. This is accomplished by employing the M-derived filter as described between alternate stages of the picture intermediate-frequency amplifier, the intermediate-frequency coupling network interposing being engineered to result in the desired over-all intermediate-frequency response characteristic. "Stagger" tuning of the stages is sometimes resorted to in order to achieve this end, alternate coupling networks being tuned somewhat differently, so that the over-all response is the one desired.

8.11 Overcoupled Tuned Circuit for Picture Intermediate-Frequency Stages. In some commercial television receivers overcoupled tuned circuits have been resorted to in obtaining an approach to essentially broad band pass, though not with the much to be desired flat intermediate-frequency response characteristic. It is a well-known fact that when two resonant circuits, both tuned to the same center frequency, are inductively coupled with each other, the over-all response curve is rather sharp up to critical coupling, the energy transferred from one tuned circuit to the other indicating increased amplitude as critical coupling is approached. An entirely different characteristic obtains after critical coupling is passed. It will be found that the curve then expands, with two charac-

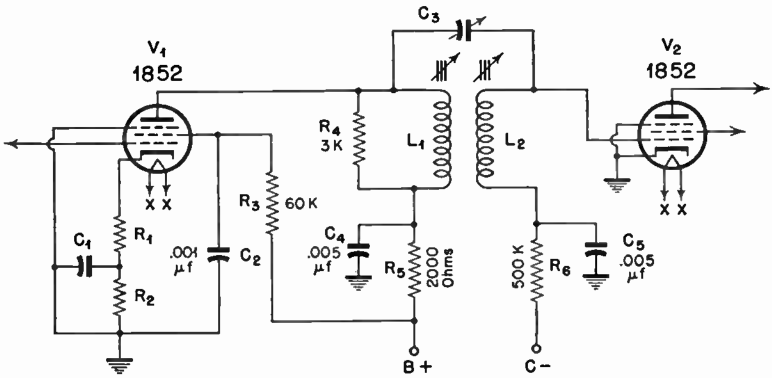


FIG. 8.30

teristic humps developing. A dip in response occurs between the upper and lower frequencies at which the two peaks or humps occur. The more critical coupling is exceeded, the more pronounced the "dip" will become,

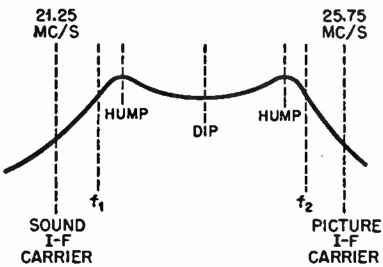


FIG. 8.31

as well as the more pronounced will appear the two humps. Hereafter, the lower hump will be described as f_1, the upper hump as f_2.

A commercial picture intermediate-frequency system in which this overcoupled type of interstage coupling has been used is shown in Fig. 8.30. It should be noted that a small variable capacitor is connected between the upper end of the windings of L_1 and L_2 for the purpose of increasing M. This makes possible the desired coupling beyond the critical value. The response curve of such a coupling system is indicated in Fig. 8.31. The amplifier coupling system must be developed for minimum dip at the center of the curve and for maximum gain per intermediate-frequency stage. Since the input and output capacitances of the two tubes employed, plus stray and circuit capacitance and distributed capacitance of the coils, are effectively in shunt with either L_1 or L_2, as the case may be, it becomes important to keep these lumped values of capacitance low, a preponderance of L being made use of to obtain the desired results. The small value of variable capacitance C_1 is adjusted to produce a value of M proper for the desired separation between f_1 and f_2. The inductors L_1 and L_2 are of the permeability tuned type so that the primary and secondary tuned circuits may be resonated at the center frequency. Slug tuning is commonly resorted to. From a practical standpoint it is not possible to shunt L_1 or L_2 with small variable capacitors to accomplish tuning, since these will be in shunt with tube, circuit, and stray capacitances, thereby increasing the total value of capacitance in shunt with either coil and limiting the amount of inductance that may be used Minimum shunt capacitance must be obtained in the design if maximum gain per stage and minimum center frequency dip are to result. For the same reason tubes with low interelectrode capacitances must be selected.

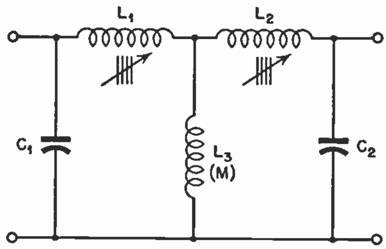


FIG. 8.32

8.12 An Improved Overcoupled Picture Intermediate-Frequency Tuned Circuit. It is considered advantageous to make use of a somewhat different circuit arrangement where overcoupling is to be employed. The improved coupling method is fundamentally described in Fig. 8.32. In this system, L_3 is fixed at the optimum value of L for proper M. The two series inductors L_1 and L_2 are slug-tuned. Since no shunt capacitance is used for tuning purposes, C_1 and C_2 represent the input and output capacitances of the two tubes employed, plus stray and circuit capacitance. This arrangement keeps the shunt capacitance at a minimum, which is very desirable from the standpoint of gain at the higher pass frequencies, as well as ensuring a broad band-pass characteristic. With low shunt capacitance, the values of L_1 and L_2 may be made sufficiently high to ensure maximum voltage gain per stage.

Such an interstage coupling system is applied in some Du Mont Telesets, an example of which is shown in Fig. 8.33. The values of L_1 and L_2 are made equivalent in both tuned circuits. The elements C_1 and C_2 in Fig. 8.32 are replaced by the input and output capacitances of the two type 6AU6 tubes employed, plus stray and circuit capacitances.

The value of L_3 is so fixed as to produce the required M, which will result in the proper separation between f_1 and f_2. A 0.001-μf. coupling capacitor is used to block the d-c plate potential at V_1 from reaching the control grid of V_2. In judicious design, the value of C_c is made large enough to have negligible effect on the secondary circuit tuning as compared with the input interelectrode capacitance of V_2 (plus stray and circuit capacitance). The component R_3 is the plate-load resistance for the 6AU6 (V_1). It both terminates the filter and serves to provide sufficient damping to result in a reasonably flat response charac-

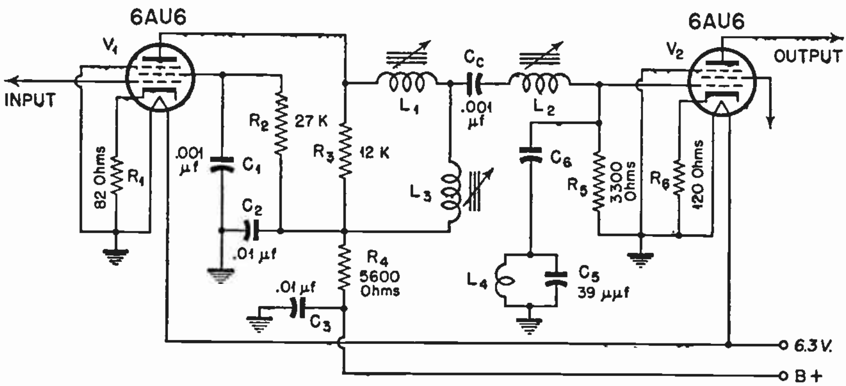


Fig. 8.33

teristic. Both L_1 and L_2 are slug-tuned in order to make possible the adjustment of f_1 and f_2 to the desired frequencies. Resistor R_5 is the grid leak for V_2, and R_1 and R_6 are cathode resistors, providing proper bias for the two tubes. R_2 is the screen voltage dropping resistor, this part of the circuit being by-passed by C_1. The values of C_7, L_4, and C_6 are selected to provide series resonance at the adjacent channel sound carrier, the resonant circuit operating as a rejection network.

8.13 Rejection of Sound Carrier and Adjacent Aural Carrier. The picture intermediate-frequency amplifier must reject the sound carrier frequencies present in the channel under amplification, as well as the adjacent aural carrier. The aural intermediate-frequency signal at 21.25 mc. per sec. will result in clearly defined ripples in the image viewed at the output of the receiver video system, if allowed to pass through the picture intermediate-frequency amplifier. This occurs as a result of modulation of the picture intermediate-frequency voltage by the aural intermediate-frequency carrier. It is common practice to make use of a rejection circuit such as that just described in the article dealing with the Du Mont intermediate-frequency amplifier (see Fig. 8.33). It may be noted that the circuit comprising C_5, C_6, and L_4 is made series-resonant at the interfering sound carrier frequency (the sound intermediate frequency) and offers the minimum impedance at the interfering frequency. Thus, the aural intermediate-frequency carrier component present at the control grid of V_2 is effectively shunted to ground through the rejector circuit and is not amplified by V_2. The susceptance curve of the rejector circuit is shown in Fig. 8.34.

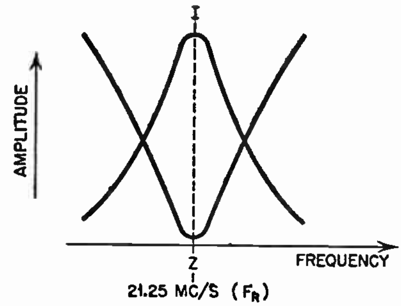


FIG. 8.34

The elements of the series-resonant rejector circuit can be so proportioned that the susceptance curve is very sharp at the sound intermediate carrier frequency. It thus results in maximum current flow at this frequency, since the minimum impedance obtains at resonance. Because

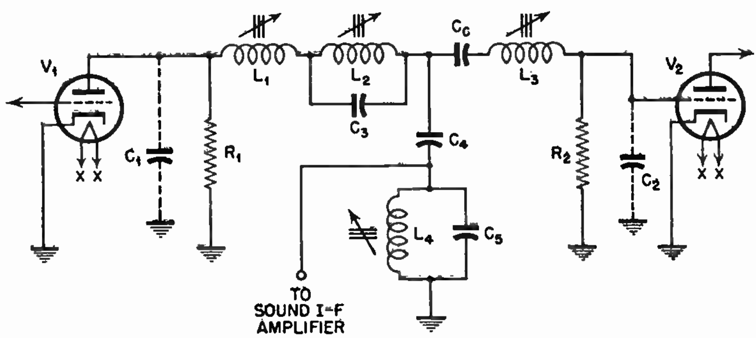


FIG. 8.35

the susceptance curve is made rather steep on either side of resonance, a negligible amount of video intermediate-frequency carrier current is by-passed.

Another rejector circuit employed for the same purpose is shown in Fig. 8.35. The two capacitances C_1 and C_2 represent the input and output capacitances of V_1 and V_2, plus the distributed and stray circuit capacitance in shunt with the input and outputs of the two vacuum tubes. The primary inductance in the circuit is a lumped element comprising the total inductance due to L_1, L_2, and the third inductor L_3, the combination of L_2 and L_3 being reactive and the vector positive at the picture intermediate frequency of 25.75 mc. per sec. The coupling capacitor C_c prevents the d-c potential at the plate of V_1 from reaching the control grid of V_2. This capacitor should result in low d-c leakage current, and for this reason should possess mica dielectric material. The secondary tuned circuit of this coupling network comprises L_3 plus C_2, which includes the input interelectrode capacitance of V_2 plus shunt-circuit and stray capacitance.

The parallel combination of L_2C_3 is designed to have extremely low loss. A preponderance of L and low C is utilized, and the circuit is resonated at the adjacent sound carrier frequency. The susceptance curve of this type of parallel resonant circuit is such that high impedance and minimum current are present at the resonant frequency of the adjacent sound

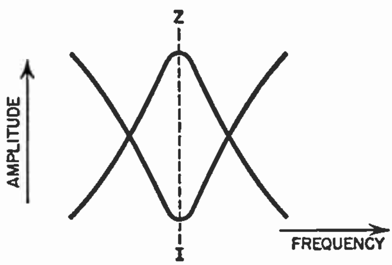


Fig. 8.36

carrier, i.e., the adjacent intermediate sound carrier frequency. With the impedance of the circuit approaching infinity, extreme attenuation is offered at the adjacent sound carrier frequency, while the circuit acts in all respects as an effective component of inductance at the 25.75 mc. per sec. picture intermediate frequency. The susceptance curve for L_2C_3 is shown in Fig. 8.36.

In addition, it will be seen that C_4 and L_4 (shunted by C_5) provide a series resonant circuit at the adjacent sound channel intermediate frequency which is to be rejected. The susceptance curve of such a circuit indicates that minimum impedance is offered at the resonant frequency, and maximum current flows at the adjacent audio intermediate frequency through the circuit to ground. Thus, the adjacent sound intermediate-frequency component is effectively by-passed to ground before it can reach the control grid of V_2.

The elements L_4 and C_5 also operate as a parallel resonant circuit, the resonant frequency of the combination being made 21.25 mc. per sec. Since maximum impedance at the associated sound intermediate carrier frequency for the channel occurs in this part of the circuit, the aural intermediate-frequency voltage at 21.25 mc. per sec. may be taken off above this circuit and conducted to the input of the audio intermediate-frequency channel. At the picture intermediate frequency of 25.75 mc. per sec. the susceptance curve of the resonant circuit L_4C_5 indicates that the circuit is capacitive. It, therefore, takes the form of a capacitance in series with C_4 and provides capacitive coupling between the two resonant circuits of the filter at the picture intermediate frequency. Thus, the circuit provides not only effective coupling at the intermediate picture carrier frequency, but rejection of both the associated and adjacent sound intermediate carrier frequencies. In addition, it provides a means of taking off the aural intermediate-frequency excitation voltage for the sound intermediate-frequency amplifier channel.

8.14 The Sound Intermediate-Frequency Amplifier. The sound intermediate-frequency amplifier requires a band pass of only 50 to 100 kc., which means that standard intermediate-frequency transformer coupling between adjacent stages may be used. Such a coupling system, as employed in some Du Mont Telesets, is shown in Fig. 8.37. The two tuned elements L_1C_4 (comprising the primary tuned circuit) and

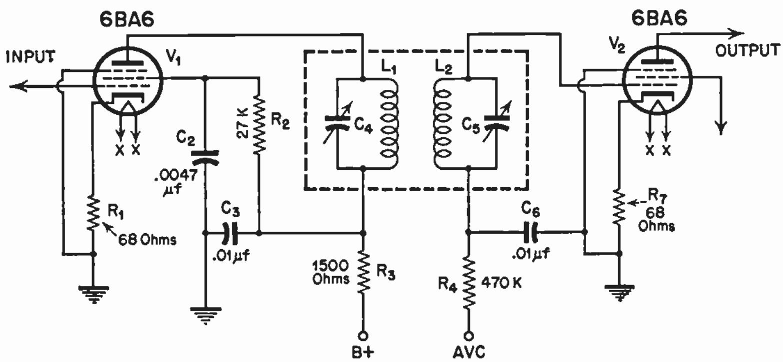


FIG. 8.37

L_2C_5 (comprising the secondary tuned circuit) are tightly coupled beyond the critical point, so that the characteristic two humps with the dip at center frequency occur, thus providing the necessary 50 to 100 kc. band pass. The resistor R_2 is the screen-grid voltage-dropping resistor, the screen circuit being effectively by-passed by C_2. The component R_3 is the plate voltage-dropping resistor for V_1, the plate being by-passed by C_3. Resistor R_4 is the circuit decoupling R for V_2, the grid circuit being by-passed at C_6. The two circuit elements R_1 and R_7 provide bias for V_1 and V_2, respectively. In the Du Mont receivers in which this coupling system is employed, three sound intermediate-frequency stages are used, each incorporating a type 6BA6 vacuum tube, the third stage being followed by a type 6AU6 first Limiter.

8.15 Gain per Stage at the Video Intermediate-Frequency Amplifier. Some of the tubes that have been used successfully in cascaded video intermediate-frequency amplifiers are types 1852, 1853, 6AU6, 1232, and 1649. Such tubes will provide, with the wide band-pass response required of such stages, a gain per stage of about 12 to 20. The low gain requires a number of stages to be employed to achieve the 2 to 6 v. demanded at the second detector input. For this reason, more stages are required in the video intermediate-frequency amplifier than are required in the aural intermediate-frequency amplifier. In some modern television receivers as many as five stages in tandem are required of the picture intermediate-frequency system to provide adequate excitation for the second detector, though fewer stages are found in some of the less expensive models. In any broad-band amplifier system the gain per stage is found to be reduced as the band pass is effectively increased. The reduction is due to the reduced load resistance into which the tube works as circuit Q is reduced. In most cases, the gain per stage may be expressed by the equation $g = G_m Z_L$, where Z_L represents the load resistance and G_m represents the transconductance of the tube selected in design. Since Z_L is always low in broad-band amplifiers, the circuit designer must select tubes with high G_m. Pentodes are, therefore, used exclusively in amplifiers of this type.

It was mentioned earlier in the text that to use a preponderance of L as compared with C in the tuned plate circuit of the video intermediate-frequency amplifier is a matter of paramount importance. The plate load impedance Z_L is broadly equivalent to the ratio L/CR, where L is the inductance present; C, the capacitance; and R, the plate-circuit load resistance. It is seen, therefore, that since the gain $g = G_m Z_L$, and since Z_L is a direct function of L, this latter element must be made as large as possible for maximum gain per stage. As a matter of fact, judicious circuit design involves both the selection of tubes with maximum transconductance G_m and careful circuit design to produce a high L/C ratio.

The magnitude of L that may be used is actually a function of tube interelectrode capacitance. A definite LC product is necessary in the resonant plate circuit for the picture intermediate frequency at which the circuit is to be made resonant. This requirement dictates the use of pentodes that possess low input and output interelectrode capacitance as well as high G_m. It is also important, as it is in video amplifier design, to hold circuit and stray capacitance to the minimum if maximum gain per stage is to be achieved.

An important factor to be taken into account is the figure of merit of a particular tube. The figure of merit is equivalent to the ratio of G_m over the sum of the input and output interelectrode capacitances of the tube. Thus,

$$\text{Figure of merit} = \frac{G_m}{C_i + C_o}$$

where G_m = mutual transconductance
C_i = input interelectrode capacitance
C_o = output interelectrode capacitance

8.16 The Video Second Detector. After the video intermediate-frequency signal has been suitably amplified by passing through the multistage intermediate-frequency amplifier, it must be demodulated so that the video signal may be passed to a succeeding video amplifier. It is also necessary that the synchronizing signal components be removed from this video signal, in order to synchronize properly the vertical and horizontal sweep oscillators of the receiver. Second detectors in the television receiver usually take the form of diode and grid-leak detector systems. The grid-leak type of second detector has been used in a few instances, since it functions as both a signal rectifier and amplifier. The reason is that the grid-cathode elements of the circuit function as a diode rectifier, with the grid leak operating as the load resistance for the diode. At the same time the grid functions in the normal manner to provide amplification of the signal. This double-purpose grid-leak detector results in improved sensitivity over other types, and greater video signal voltage is delivered to the succeeding video amplifier. But, owing to the fact that large values of grid-leak resistance are necessary to obtain optimum operation when weak signals are introduced, overloading takes place when heavy signals are admitted and results in a rather poor amplitude versus frequency characteristic. For this reason it has seen limited use. It must be remembered that the grid-leak detector operates on the bend of the E_gI_p characteristic curve, and heavy distortion is to be expected on input signals of large amplitude. This results in poor picture quality.

Obviously, the simple diode form of second detector is best applicable to television receiver design, the rather low sensitivity of such a demodulation device being compensated for through the provision of adequate gain in both the radio-frequency and intermediate-frequency circuits, and the addition of an efficient a.v.c. system. Since broadband television receivers require a band pass which is many times that required of a high quality broadcast receiver, the diode load resistor is very low in value (about 2,500 to 5,000 ohms). Signal gain in the diode detector, is, therefore, an impossibility at the present time.

The equation used in determining the value of load resistance for a type 6H6 tube, the usual tube employed in the video second detector system, is

$$R_L = \frac{1}{2\pi f_o C_t}$$

where f_o = the upper video frequency at which 70 per cent gain is required, as compared with the gain at the mid-frequency range

C_t = the stray and circuit capacitances in shunt with the load resistance

A simplified diode second detector circuit is shown in Fig. 8.38. It is necessary to introduce high-frequency compensation in the form of the inductance L—to compensate for high frequency signal loss due to shunt, stray, and circuit capacitance and the video amplifier input capacitance. The operation of this inductance in high frequency compensation has already been fully described. The ratio of C_2/C_1 is made such that C_2 is greater by a factor of 2. Circuit and stray capacitance must be kept to the minimum, and an input video amplifier tube must be selected for low grid to cathode interelectrode capacitance. This is because R_L is an

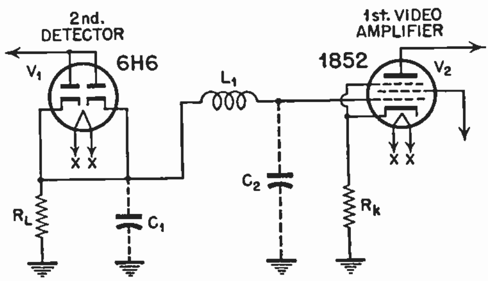


FIG. 8.38

inverse function of C_t, the sum of C_1 and C_2. With this circuit arrangement, it has been shown that R_L may be made 1.5 times greater than shown in the previous equation employed in determining the optimum value of load resistance. Thus,

$$R_L = \frac{1.5}{2\pi f_o(C_1 + C_2)}$$

$$L = \frac{1}{2(2\pi f_o)^2 C}$$

The high-frequency compensation inductance is inserted in series, cathode to control grid of the succeeding 1852 video amplifier. A type 6AU6 tube may be used as the latter amplifier with slightly increased gain.

Another video second-detector system is shown in Fig. 8.39. The second half of the 6H6 diode is employed for picture detection and is followed by a low-pass filter designed to pass a band of frequencies up to 4 mc. wide, cutting off below the picture intermediate frequencies. The first half of the 6H6 diode functions as a sync pulse detector, acting to separate the sync pulses from the intermediate-frequency amplifier output. The video second-detector load is followed by a type 1852 video amplifier operating at grid-leak bias to obtain automatic background control. This method is utilized in lieu of a d-c restorer, the latter being a much more desirable arrangement, although in the circuit just described the zero-bias first video stage has been used in the interests of economy.

The fundamental circuit of another and more efficient type of second detector is shown in Fig. 8.40. Here, a simple low-pass filter is connected between the cathode of the second detector and the control grid of the video amplifier. As in any low-pass filter of this type, the cutoff frequency may be determined through use of the following equation:

$$F_c = \frac{1}{\pi \sqrt{LC}}$$

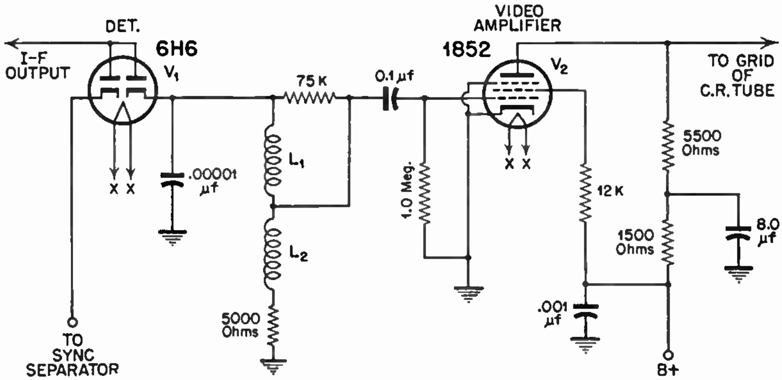


FIG. 8.39

The equation for determining the value of load resistance is

$$R_L = \sqrt{\frac{L}{4C}}$$

In the low-pass filter f_o, or the frequency at which the gain is to equal 70 per cent of the maximum at mid-frequency range, is equivalent to the

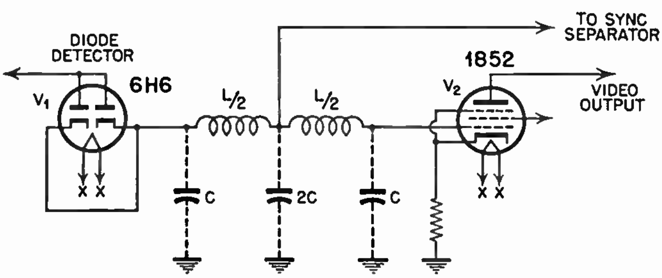


FIG. 8.40

cutoff frequency f_c. This circuit operates to provide demodulation of the intermediate-frequency signal being passed to the video amplifier, the sync components being passed to the sync separator circuit. It is usually necessary to add a small capacitance between the point where the two inductors are interconnected, and ground, for the purpose of obtaining the required $2C$ at this point in the system.

A commercial version of the above circuit is employed in the late Philco television receiver. It is shown in Fig. 8.41. Linear frequency response and minimum distortion are obtained by using a small value of load resistance—3,300 ohms (R_5)—and by using a carefully engineered high-frequency compensation system to reduce loading effects. The two peaking inductances are L_3 and L_4. This peaking circuit comprises a low-pass filter that provides band pass up to 5 mc. per sec. with negligible frequency distortion.

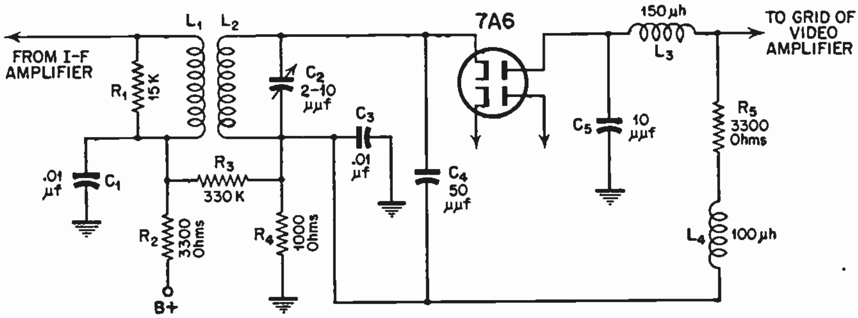


FIG. 8.41

The operation of the circuit is as follows. With the introduction of a positive signal to the detector cathode, which results in a negative signal at the 7A6 plate, no conduction obtains. But when the cathode is driven negative with respect to the plate, conduction occurs, and the video and sync signals are rectified and separated from the intermediate-frequency carrier and sidebands. The intermediate-frequency carrier and harmonics due to detector distortion, since they are much higher in frequency than the cutoff frequency F_c of the detector-peaking-circuit load, are by-passed around the load by C_5. The demodulated video and sync signal is passed to the first video amplifier, a part of the signal being passed to the sync separator system.

8.17 The R.C.A. Picture Detector, Video Amplifier, and D-C Restorer. Figure 8.42 describes the basic circuits incorporated in the R.C.A. model 630–TS television receiver for purposes of picture detection, video amplification, and d-c restoration.

The vacuum tube V_1 is a 6AL5 double diode. The first diode section (6AL5A) operates as the video second detector, while the second diode section (6AL5B) is employed as a d-c restorer. D-C restoration must be utilized in the television receiver to enable the received picture to follow closely the slow variations in background illumination of the scene as transmitted. A number of d-c restorer systems will be later described in the text.

Two video amplifiers V_2 (6AU6) and V_3 (6K6) follow the picture demodulator. The video coupling system that is used is the series-shunt inductively compensated type (already described in the chapter entitled The Video Amplifier and Cathode Follower). One video amplifier stage is arranged to limit or clip the amplitude of noise pulses, and limiting takes place at the peak amplitude of the sync pulses, resulting in practical limiting of the noise passed to the sync system of the receiver.

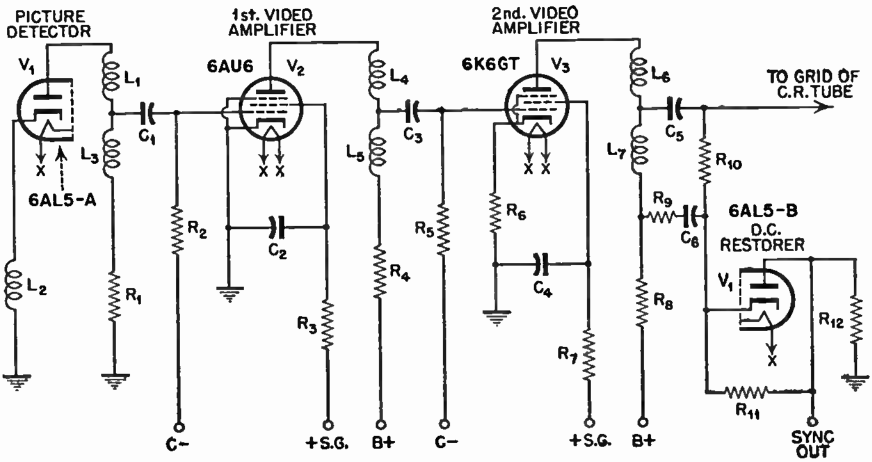


FIG. 8.42

After the signal passes through the final video amplifier, the picture information is passed to the grid or modulating electrode of the picture cathode-ray tube. The d-c restoration is effected at $V_{1(B)}$, and the sync pulses and signal although compressed are removed from the plate of 6AL5B. Inductors L_1, L_4, and L_6 provide series high-frequency compensation in the video amplifier system, while L_3, L_5, and L_7 provide shunt high-frequency compensation.

Capacitors C_1, C_3, and C_5 are employed as coupling capacitors. Grid resistors R_2 and R_5 are made use of at V_2 and V_3, respectively. Capacitors C_2 and C_4 are screen-grid by-pass capacitors, while resistors R_3 and R_7 serve as screen-grid dropping resistors. Resistor R_6 provides cathode bias for the output video stage. Resistors R_4 and R_8 are plate load resistors for V_2 and V_3. Resistor R_{11} is the diode load resistor for the second diode section of the 6AL5 (6AL5B).

Other Video Detector Circuits. An interesting video detector circuit is that shown in Fig. 8.43. This circuit is employed in a Farnsworth television receiver of postwar design. A type 6H6 vacuum tube is incorporated as the video detector, as well as to supply a demodulated signal for the a.g.c. and sync separator circuits. The type 6H6, being a full-wave diode, one half section of the tube is used as the video detector, supplying the demodulated signal output to the succeeding video amplifier. The other half of the full-wave diode supplies video signal for a.g.c. purposes and to the sync separator.

A potentiometer in the cathode circuit of the detector diode section (the diode load) serves as a contrast control, a negatively phased video signal

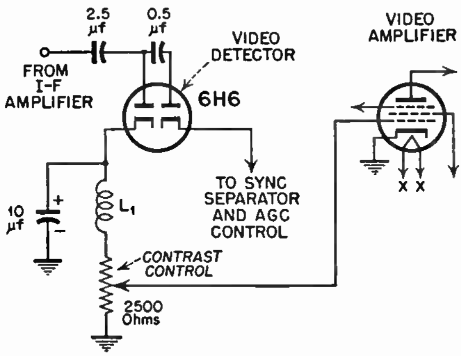


FIG. 8.43

being developed across this circuit element. The signal is coupled directly to the control grid of the video amplifier following the detector.

Figure 8.44 illustrates the use of a type 1N34 germanium crystal as the video second detector. A similar system was used by Du Mont in an

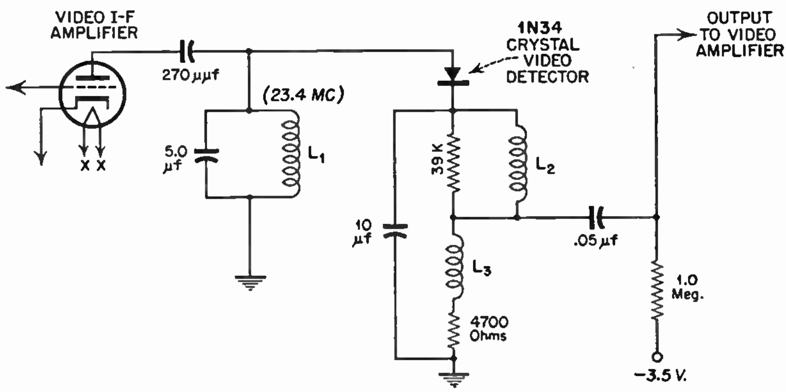


FIG. 8.44

early postwar television receiver. It is seen that the type 1N34 crystal replaces the vacuum tube in this system and operates to provide the demodulated signal, which is subsequently passed to the succeeding video amplifier stage.

8.18 The FM Limiter. The sound intermediate-frequency amplifier was described in Sec. 8.14. Since a discussion of the video channel of the television receiver has been undertaken in connection with the second detector, some consideration should now be given the FM circuits succeeding the aural intermediate-frequency amplifier. The first such circuit to follow the sound intermediate-frequency amplifier is the limiter. Its purpose is to eliminate or minimize the deleterious effects of amplitude variations of the frequency-modulated signal. Great care is exercised at the sound transmitter in the television station so that the FM carrier is not modulated in an amplitude manner. Such a condition is usually achieved when no variation of the plate-current ammeter of the final FM amplifier of the sound transmitter is observed under conditions of complete modulation. However, by the time the signal is received at the output of the aural intermediate-frequency amplifier, there is always some amplitude component even in well-designed circuits. There always appears to be some deviation in the amplitude of the signal as presented at the limiter input, i.e., aural intermediate-frequency amplifier output. Without correction, the result is distortion as viewed at the audio-frequency output of the television receiver.

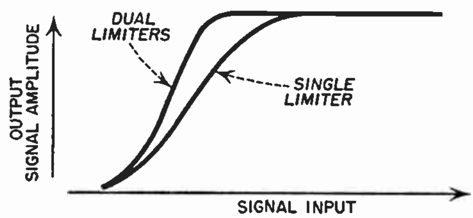


Fig. 8.45

The limiter functions to remove any amplitude component (plus noise) that is present in an interesting manner. It is conventional practice to employ low plate and screen potential in the limiter stage, and grid-leak bias is commonly utilized. The low plate and screen potentials result in the tube reaching plate current cutoff with moderate signals applied to the control grid of the tube. The reason for using grid-leak bias rather than cathode bias in the strict sense is to maintain the output plate current and output signal fairly constant whatever the input signal-voltage amplitude. Thus, regardless of the variation in input signal amplitude, the output signal maintains constant amplitude. Since noise voltages throughout the FM system modulate the signal in an amplitude manner, the noise or interference is eliminated or limited.

In Fig. 8.45, the characteristic curves of a single and double limiter are shown. Inspection of the curve for the single limiter stage will disclose that an increase in limiter output is obtained until a certain amplitude of input signal is reached. Then, the limiter plate current remains approximately constant, in spite of any further increases in input signal amplitude. For the limiter to operate properly, sufficient signal must be received at the radio-frequency amplifier input so that, when amplified, operation takes place beyond the upper bend of the limiter-characteristic curve. Low-level signals of insufficient amplitude to permit the limiter to operate beyond the upper bend of the characteristic curve result in the same noise and distortion present at the aural intermediate-frequency amplifier output appearing at the limiter output. In limiter operation no distortion is introduced with respect to the FM signal, limiting operating only to minimize or eliminate AM noise and distortion. Actually, serious amplitude distortion of unwanted amplitude-modulated signals occurs, owing to the fact that operation takes place beyond the upper

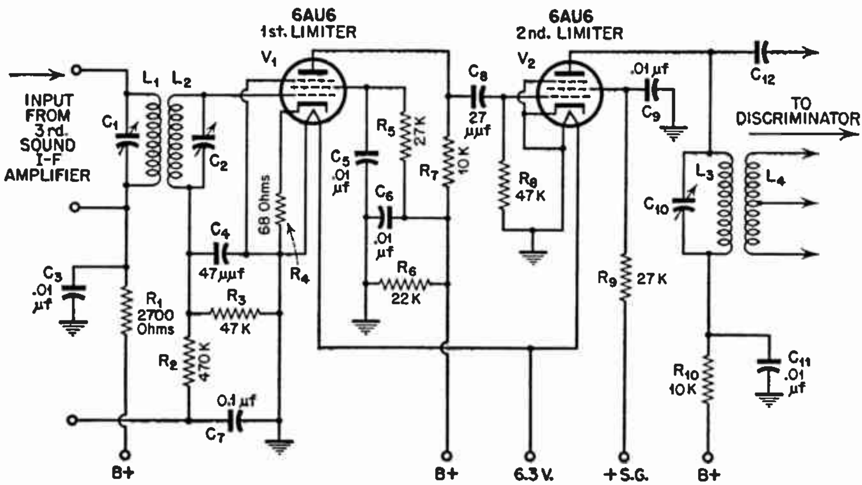


Fig. 8.46

bend of the characteristic curve; and this is the intended function of the system, since such signals are effectively limited insofar as reproduction of the desired FM signal is concerned.

Much better limiting of AM noise and distortion can be achieved if two limiters are operated in tandem in a dual limiting system. The characteristic operation of the dual limiter is indicated in Fig. 8.45, and the circuit arrangement of such a system as employed in late Du Mont Telesets is shown in Fig. 8.46. With two limiters operating in the dual arrangement, the upper bend of the characteristic curve becomes sharper, resulting in more efficient and instantaneous limiting action (see Fig. 8.45). In such a tandem arrangement, pentodes with high G_m as well as sharp plate-current cutoff characteristics are used. The type 6AU6 tube is typical of this family of vacuum tubes and has proved very desirable for this mode of operation.

8.19 The FM Discriminator. In the video second detector discussion it was seen that the video intermediate-frequency carrier was demodulated, its video or picture component being separated and introduced to the succeeding video amplifier and picture tube. It is also necessary in the FM channel of the receiver to obtain the audio variations from the different incoming frequencies by means of a discriminator. In any frequency-modulated system, the greater the frequency deviation, the greater the amplitude of the resulting audio-frequency signal as delivered to the loudspeaker. Hence, the discriminator must develop audio-frequency voltages, the amplitudes of which may vary in proportion to the deviation of the incoming frequencies about the radio-frequency carrier.

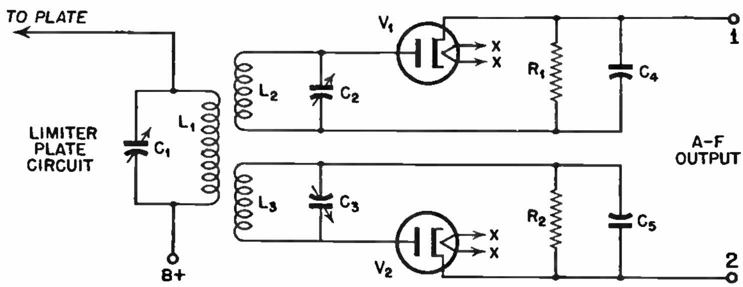


FIG. 8.47

An elementary discriminator circuit is shown in Fig. 8.47. It may be seen that the primary inductance L_1 is inductively related to the two secondary windings L_2 and L_3. These secondary windings are tuned by the variable capacitors C_2 and C_3, and each tuned circuit is across a separate diode. A separate load resistor R_1 or R_2 is associated with each diode. However, the output of the discriminator is proportional to the audio-frequency signal developed across both diode load resistors.

At the modulator of the FM transmitter it so happens that the introduced audio signal varies the frequency either directly or indirectly about the mean carrier frequency. With sine-wave input the maximum amplitude of each alternation would result in the greatest frequency change. As the phase of the sine wave is shifted toward zero or 180 deg., correspondingly lesser excursions about the mean carrier would obtain.

In the elementary discriminator circuit shown, L_2 and L_3 are each peaked by means of C_2 and C_3 so that each tuned circuit is made resonant at the two extremes of the intermediate-frequency band. Thus, if the intermediate-frequency band spread extends from 21.15 to 21.35 mc. per sec., L_2 is peaked at 21.15 mc. per sec., while L_3 is peaked at 21.35 mc. per sec. The sound intermediate carrier frequency is, of course, 21.25 mc. per sec. The resultant characteristic which indicates discriminator operation is shown in Fig. 8.48. The voltage across each load resistor cancels out. The reason is that the voltages oppose one another. At the center frequency (the frequency of the intermediate-frequency sound carrier), the two voltages cancel, the resulting potential being equal to zero.

It will be noted that all frequencies less than 21.25 mc. per sec. result in positive output voltages, whereas all frequencies above 21.25 mc. per sec. result in negative output voltages. Thus, the output voltages of

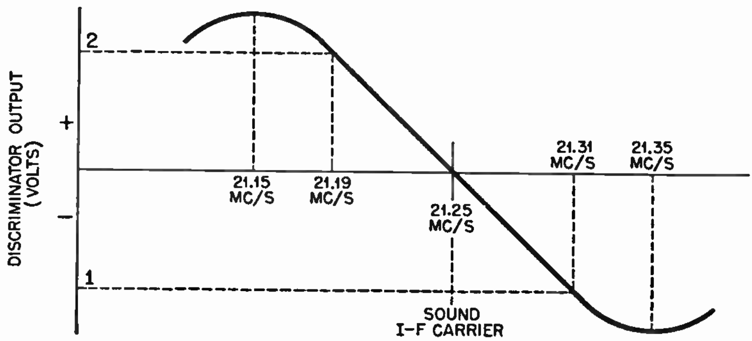


FIG. 8.48

the discriminator will vary as do the frequencies of the discriminator input, and the audio-frequency signals originally impressed upon the modulator of the FM transmitter are again reproduced at the output of the discriminator. The discriminator must operate along the linear or

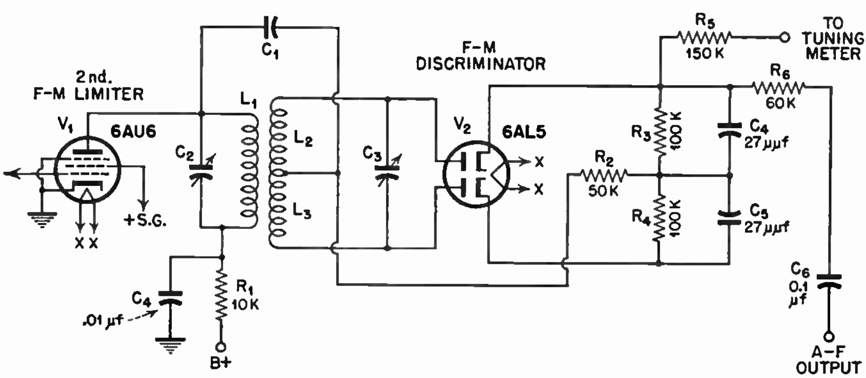


FIG. 8.49

smooth portion of the discriminator curve shown in Fig. 8.48. Otherwise, amplitude distortion will result owing to operation into the upper and lower curvatures of the characteristic curve, i.e., beyond the linear portion of the curve.

The discriminator circuit employed in a modern Du Mont Teleset is shown in Fig. 8.49. As compared with the elementary circuit previously shown, but one tuning capacitor is utilized across the split secondary inductance L_2 and L_3. R_3 and R_4 are the load resistors for the two diode sections. The tap at the center of the secondary essentially splits the one coil into two independent sections L_2 and L_3. The single tuning capacitor C_3 results in both circuit economy and ease of adjustment.

The operation of the circuit is a function of the voltage developed across L_2 and L_3 at the various incoming frequencies. These voltages add vectorially with the voltage in the primary inductance L_1, since they are coupled to the secondary circuit through the fixed capacitor C_1. At resonance the secondary tuned circuit appears purely resistive to the incoming signal. Above resonance the reactance is preponderantly inductive. At incoming frequencies below resonance the secondary circuit becomes essentially capacitive. The phase relations therefore change with frequency, and as the relative phase relationship varies, the audio output voltages across R_3 and R_4 change in proportion.

8.20 The Automatic A.G.C. System. Automatic gain control in a television receiver is applied in much the same way as in a conventional broadcast receiver. The a.g.c. potential varies the gain of the picture intermediate-frequency amplifier in accordance with variations of peak carrier. The result is that the picture does not vary with changes in carrier amplitude—the result of local effects. A number of methods for applying a.g.c. have been effectively used. One method involves the use of one section of a 6H6 diode to generate the a.g.c. voltage from a rectified portion of the picture intermediate-frequency carrier through a suitably selected value of load resistance. Should only one section of a type 6H6 be employed as the video second detector, the other section may be used either as a d-c restorer or as the a.g.c. rectifier. It is very important that some form of a.g.c. control system be employed; for, otherwise, variations in signal amplitude will result, and changes in picture contrast will ensue. Without such a system the receiver contrast control will have to be readjusted each time the receiver is tuned from one station to another. Too, slow variations or fluctuations in d-c potential from the receiver power supply, which result in varying intermediate-frequency gain through the picture intermediate-frequency amplifier, will be effectively compensated for. It is sometimes found that both sections of a type 6H6 diode are utilized for this purpose.

R.C.A. has used the system shown in Fig. 8.50. Such a circuit arrangement provides what is known as "amplified a.g.c." The output of a push-pull second detector supplies not only excitation of the video amplifier following it, but also excitation to the control grid of the first triode section of a type 6F8G vacuum tube. The plate of the first triode section is connected directly to ground. The cathode connects through load resistor R_1 and isolating resistor R_2 to the power-supply voltage divider at a point to obtain -33 v. potential. This arrangement results in the plate of the tube being at +33 v. potential with respect to the cathode. Changes in detector output cause corresponding potential changes across R_1. All except very slow variations across R_1 are effectively shorted to ground by the 0.1-μf. capacitor connected between cathode and ground.

The second triode section control grid connects above R_1, with the result that slow voltage variations, which a.g.c. tends to reduce, are amplified by the second triode section of the 6F8G. The cathode of the

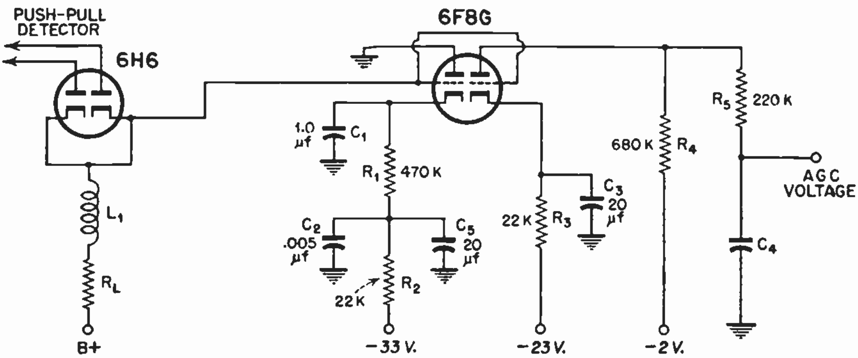


FIG. 8.50

second triode section is held at −23 v. potential through isolating resistor R_3. The plate is supplied with −2 v. potential through load resistor R_4. The second triode section thus operates with plate potential of +21 v. The control grid of the second triode section of the 6F8G connects through R_1R_2 to −33 v., which results in the grid operating at −10 v. with respect to the cathode. With the applied plate potential of +21 v., the second triode section is biased beyond plate-current cutoff, providing delayed a.g.c. until the signal reaches an amplitude for plate-current cutoff. Bias potential for the controlled tubes of the picture intermediate-frequency amplifier is −2 v., as obtained from the power supply, plus the a.g.c. voltage potential developed across R_4, in addition to bias provided at individual intermediate-frequency tubes by cathode resistors. The bias of −2 v. plus a.g.c. is applied to the grids of intermediate-frequency tubes through a filter (R_5 and the 0.5-μf. capacitor, as well as isolating resistors in the grid circuits of each intermediate-frequency stage). It is not required that all intermediate-frequency amplifier stages are under a.g.c. control. Enough stages are provided with a.g.c. potential to obtain the proper compensating effect with variations in signal amplitude.

8.21 The Video Amplifier and D-C Restoration. Not only is the signal at video frequencies transmitted, its amplitude being responsible for the degree of contrast observed in the reproduced picture, but a second d-c voltage, termed the "brightness" component, is transmitted. The brightness level is established in the studio control room as the engineer adjusts for optimum setting, i.e., the pedestal or brightness level. The judgment of the control room engineer in setting his control determines, to a greater extent than any other contributing factor, whether the scene as transmitted and received bears the proper relation to average brightness present before the cameras in the studio. It is possible to obtain the desired brightness level for a particular scene by judicious adjustment of the brightness or pedestal level. For instance, it is entirely possible to simulate the effect of dusk by "dropping" the brightness level. Actually, this control permits adjustment for average brightness of the transmitted picture.

It is necessary that the receiver deliver the same degree of average-scene brightness as is viewed on a properly adjusted monitoring cathode-ray tube at the video transmitter modulator input. Quite a problem presents itself when an attempt is made to modulate the video radio-frequency carrier with the d-c or brightness component of modulating signal. The problem is due to the fact that the average brightness of a scene may vary slowly over a time interval of several seconds. This rate of change is so slow that at the frequency produced (by the change against time) the coupling capacitors in the video amplifiers present practically infinite reactance. In other words, the coupling capacitors do not pass the d-c variations at such a slow rate, and consequently it is not possible to pass along these rather slow changes in average brightness.

The result is that it has been found necessary to amplify the video and d-c brightness components of the signal separately. After being separately amplified, the d-c component is introduced directly into the radio-frequency modulated amplifier grid bias without having passed through any of the coupling capacitors of the video amplifier system. It is seen, therefore, that the carrier is not only amplitude-modulated by the video and sync components of signal, but the transmitted picture carrier level is made to vary slowly as changes in average picture brightness take place. It follows that a d-c amplifier is required to provide the average d-c brightness component before picture carrier modulation takes place.

The d-c component of signal is present throughout the video transmitter and receiver circuits—in fact, right up to the output of the second video detector of the receiver system. It must be recalled, however, that a coupling capacitor is connected between the plate output circuit of the last video amplifier and the grid or modulating electrode of the cathode-ray picture tube. Here, again, the same problem appears as was encountered at the transmitter-modulator input.

A practical solution to the problem is that shown in Fig. 8.51. Here, one section of a type 6H6 diode is used to apply the d-c component in series with the picture-tube grid bias. Thus, the rectified output of the 6H6 rectifier comprises the d-c component of signal and supplies restoration of the original d-c component of signal as presented at the video transmitter modulator input. It is seen that combination high-frequency compensation is applied in the video amplifier plate circuit, both series and shunt peaking being made use of. After compensation, the video component of signal is applied through C_1 to the modulating electrode of the cathode-ray picture tube. In this respect, the circuit is entirely conventional.

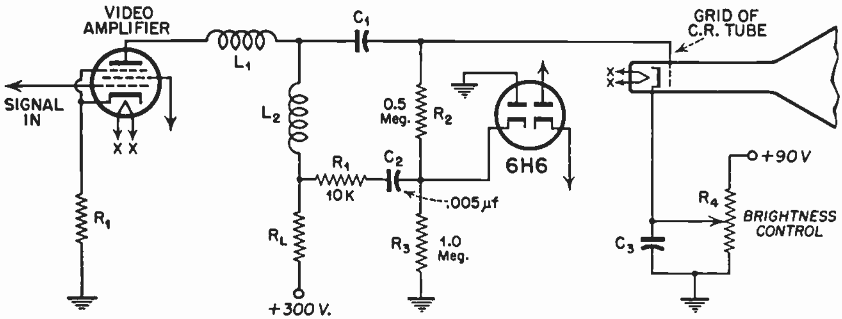


FIG. 8.51

The driving voltage for the d-c restorer tube is taken off at the point of interconnection between the shunt-peaking coil and the video amplifier load resistance. The signal is taken through the two series circuit elements R_1 and C_2 to the restorer cathode. The cathode of the restorer connects to the grid of the cathode-ray tube through R_2 (0.5 megohm) and to ground through R_3 (1 megohm).

When the amplitude of the d-c component of signal increases, the rectified current through R_3 to ground increases in amplitude. Thus, the cathode end of R_3 becomes more positive with respect to ground. Normally, about —30 v. of bias is supplied to the cathode-ray tube cathode through the voltage divider R_4. The cathode is made positive with respect to ground, resulting in the grid (which connects to ground) becoming negative with respect to the cathode. Should the pedestal-level amplitude decrease, the operation is just the opposite. The average negative bias increases, while the average picture brightness, as viewed at the fluorescent screen of the picture tube, decreases.

Thus, slow variations of average brightness, as seen at the output of the studio camera chain (or at the transmitter input), are simulated through d-c restoration. The brightness control R_4 need be set for only average brightness when the test pattern of a particular transmitting station is viewed at the beginning of a period of program transmission. Thereafter, brightness changes are automatically taken care of by the d-c restoration system. Often the term "d-c reinsertion" is employed to describe the operation just discussed. The two terms may be used interchangeably, since both mean exactly the same thing.

The use of type 1N34 germanium diodes in television-receiver design has come into some prominence. Such practice is the inevitable result of attempts to reduce the number of vacuum tubes employed in the typical television-receiver chassis. A circuit using three type 1N34

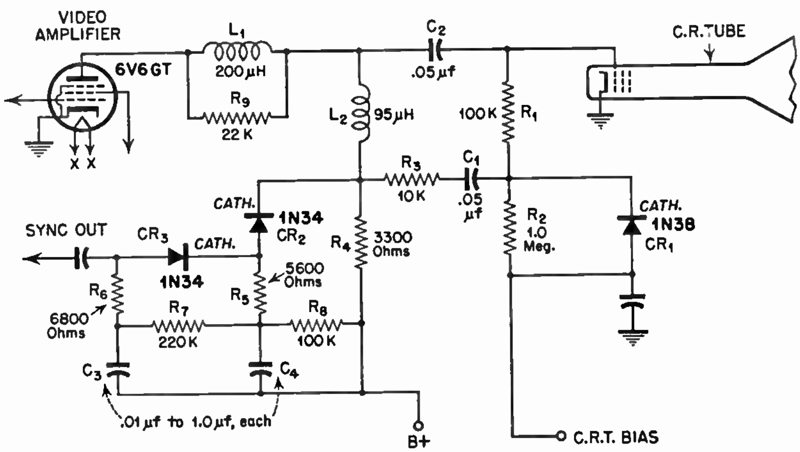


FIG. 8.52

germanium diodes to effect d-c restoration and sync separation is shown in Fig. 8.52 and was reported in the *Proceedings of the Radio Club of America* (Vol. 2, No. 2, 1949), by Dr. Stuart T. Martin and Harold Heins of Sylvania Electric Products, Inc.

The use of the germanium diode as a d-c restorer (CR1) improves operation by providing a more positive clamp at blanking level owing to the greater conductance of the diode. This serves to reduce the tendency for a shift in the black level to occur when the picture content is dark. The life of the germanium diode in this service is very satisfactory. On life tests at 100 v. on a 15 per cent duty cycle, no deterioration or failure was noted to occur after more than 3,600 hr. test.

Since the use of germanium diodes reduces the space usually required for vacuum tubes, there is a reduction in the required size of a television-receiver chassis, the diodes being wired into the circuit in the same manner as any other small component would be connected. These diodes may find their place in receiver design, along with printed circuit techniques, both leading to the eventual reduction in physical size of the television-receiver chassis.

An interesting video amplifier and d-c restorer system is that found in Du Mont receivers which incorporate the RA–103 television-receiver chassis (see Fig. 8.53). Two tubes are utilized, a type 6AC7 vacuum tube as a video amplifier and one triode section of a type 6AL5 tube as

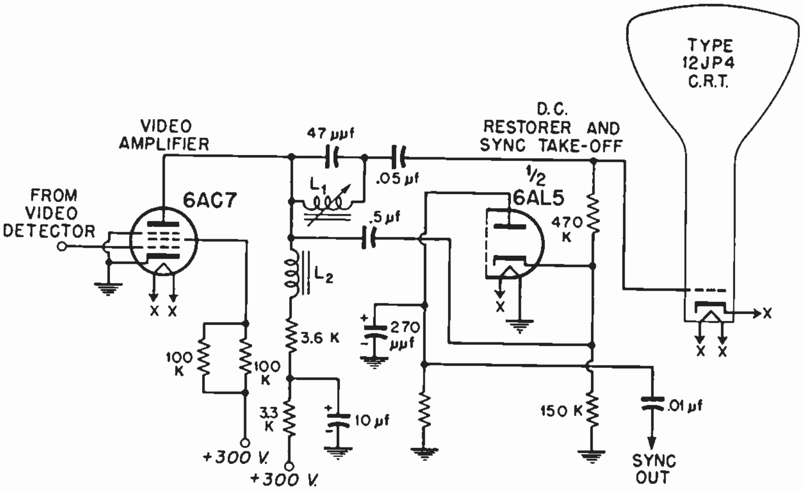


FIG. 8.53

the d-c restorer. The synchronizing circuit signal is taken from the plate circuit of the ½ 6AL5. Combination or series-shunt high-frequency compensation is used in the output circuit of the 6AC7 video amplifier, L_1 and L_2 comprising the two peaking inductances. Inductance L_1 is made adjustable, while the inductance of L_2 is fixed. A 3,600-ohm resistor is employed as the plate load for the 6AC7. The output of the amplifier is coupled through a 0.05-μf. coupling capacitor directly to the modulating grid of a type 12JP4 12-in. picture tube. Because the d-c component of signal is lost owing to the presence of this coupling capacitance, d-c restoration must be accomplished through use of the ½ 6AL5 restorer. This circuit is employed in the Du Mont Savoy and Chatham receivers, among others in the line.

The two-stage video amplifier used in Belmont television receivers 22A21, 22AX21, and 22AX22 is shown in the accompanying diagram (see Fig. 8.54). Two tubes are used to achieve the desired video amplification, the output of the video detector being applied directly to the first video amplifier stage, which employs a type 6AU6 vacuum tube. This input stage is followed by the second stage which makes use of a type 6K6GT/G tube. A voltage-dividing potentiometer is used at the signal grid input of the first stage to function as a contrast control. The first stage is biased by the picture signal flowing through the contrast control, the cathode of the first tube being connected directly to ground. The video detector potential is such as to bias the first video amplifier at the proper contrast level, thus effectively clipping off any noise peaks which might accompany the synchronizing impulses. It is seen that combination high-frequency compensation is used in this amplifier output circuit, L_1 and L_2 making up the series-shunt compensation network. Low-frequency compensation is strictly conventional, and R_1 and C_1 make up the compensation network here. A 3,000-ohm resistor provides

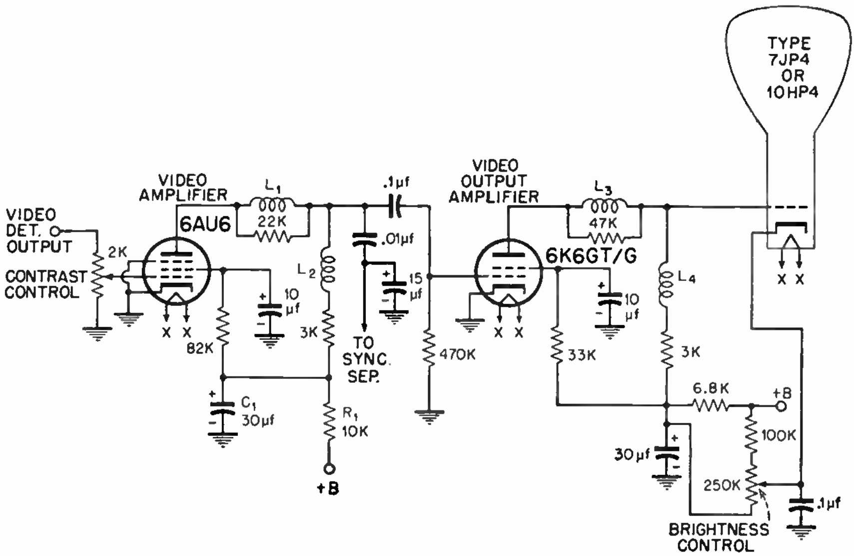


FIG. 8.54

the plate load for the input stage. The 22,000-ohm resistor in shunt with the series high-frequency compensating inductance in the plate circuit is employed to prevent overpeaking of the higher frequencies within the pass band.

The signal output of the 6AU6 is applied to the signal grid of the 6K6GT/G output amplifier through a 0.1-μf. coupling capacitor. The output video amplifier makes use of conventional grid-leak biasing to restore the d-c signal lost by virtue of the signal passing through the interstage coupling capacitor. D.C. coupling is applied to the modulating grid of either a type 7JP4 7-in. cathode-ray tube or a 10-in. type 10HP4 picture tube. It will be noted that combination high-frequency compensation is employed in the plate circuit of the output stage, which is identical with that used in the first stage. The cathode of the output amplifier is connected directly to ground, since grid-leak bias is employed. This circuit provides ample video signal to the picture tube, for the video voltage developed at the output of the second stage is well within the requirements for optimum operation of the picture tubes.

The two-stage video amplifier in some late-model R.C.A. receivers is also shown (see Fig. 8.55). This well-designed circuit uses a type 6AU6 vacuum tube in the first amplifying stage and a type 6K6GT tube in the output amplifier. Combination high-frequency peaking is again

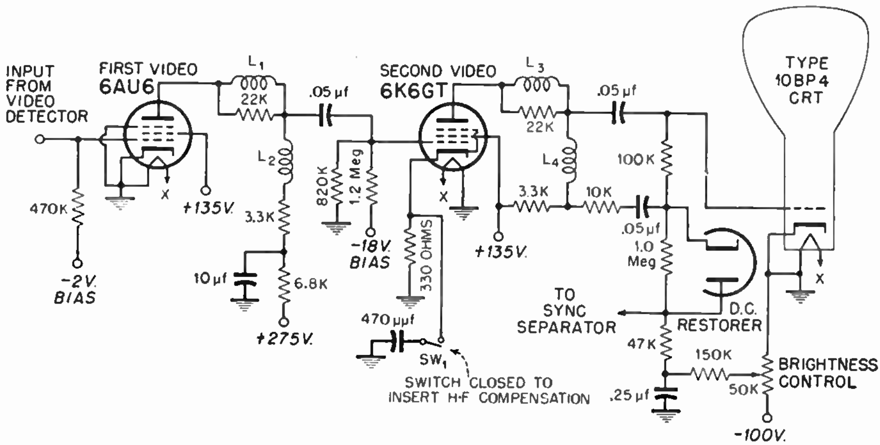


FIG. 8.55

applied here in both the first and second stages of this amplifier. A 3,300-ohm plate-load resistor is employed in each of the stages. It will be seen that a 22,000-ohm resistor is connected in shunt with the series high-frequency peaking coil of each stage, this component being employed to eliminate the possible occurrence of excessive high-frequency peaking. The low-frequency compensation network in the output circuit of the first stage is conventional, comprising a 6,800-ohm resistor in series with the plate-load resistor and the plate-voltage supply. The 6,800-ohm resistor is by-passed with a 10-μf. capacitor.

The type 6AU6 vacuum tube in the first stage is so biased that the peak of the synchronizing impulses just drives this tube to plate-current cutoff. Thus, noise voltages that have greater peak amplitude than that of the synchronizing impulses fail to develop at the output of the tube. This, of course, results in a greater signal-to-noise ratio, and the first stage operates both as a video amplifier and as noise limiter.

It should be noted that the output of this first stage is coupled to the signal grid of the 6K6GT output stage by means of a 0.05-μf. interstage coupling capacitor. The second video stage is followed by a d-c restorer, which employs a half-wave diode. The signal at this point in the system is coupled out to the synchronizing circuits of the receiver.

It will be noted that the cathodes of both the first and second video amplifier tubes are connected at ground potential, and that fixed bias is supplied to the grid of each tube. This type of connection eliminates grid resistors and by-pass capacitors that would normally be used in these circuits. Since these components usually produce an appreciable low-frequency attenuation of the video signal in the conventional amplifier, an advantage is achieved. Likewise, with the screen voltage being applied directly to the screens of the tubes, and without the use of conventional

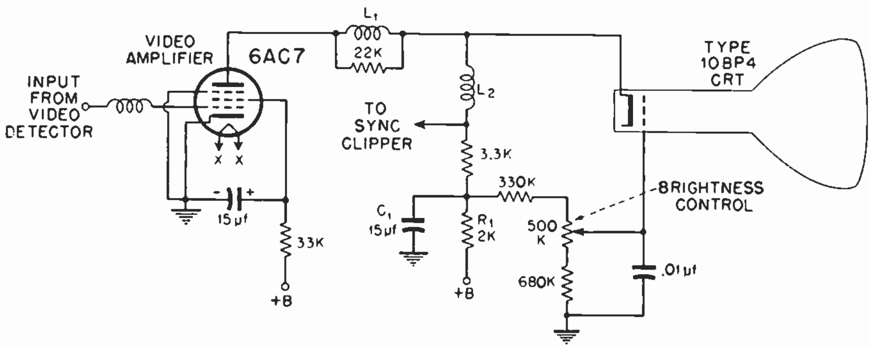


FIG. 8.56

screen grid resistors and by-pass capacitors, an improvement in over-all response results. A 470-$\mu\mu$f. capacitor may be connected between the cathode of the output stage and ground to provide additional high-frequency compensation if desired. If found unnecessary, this capacitor is disconnected at SW_1. The video output of the second stage is coupled through a 0.05-μf. capacitor to the modulating grid of a type 10BP4 10-in. picture tube. A 50,000-ohm potentiometer in the cathode circuit of the viewing tube serves as a brightness control.

Of much interest is a rather simple yet effective circuit utilized in some late model General Electric receivers (see Fig. 8.56). Direct coupling is used between a single video amplifier and a type 10BP4 picture tube. This circuit arrangement eliminates the need of a d-c restorer circuit, since the elimination of a coupling capacitor between the output of the video amplifier and the picture tube obviates the need for any d-c restoration. It will be remembered that in the usual circuit the coupling capacitor blocks the d-c component of signal thereby requiring some form of d-c restoration. It may be seen that the video signal is coupled to the cathode of the picture tube rather than to the modulating grid. This coupling dictates that the picture signal be of negative polarity as applied to the viewing tube. In the ordinary circuit arrangement, where the video signal is applied to the modulating grid of the tube, the signal is applied in the positive polarity.

The video amplifier in this unique circuit arrangement makes use of a type 6AC7 vacuum tube, combination or series-shunt high-frequency compensation being incorporated in the output circuit. Peaking inductances L_1 and L_2 provide the necessary compensation, and L_1 is shunted with a 22,000-ohm resistor to preclude the possibility of overcompensation, as has already been described. Resistor R_1 (2,000 ohms) and capacitor C_1 (15 μf.) provide necessary low-frequency compensation. A 3,300-ohm resistor constitutes the plate load for the tube. The cathode of the 6AC7 is connected directly to ground. The signal for the synchronizing circuits is coupled out of the video amplifier output circuit. The brightness control system is conventional.

8.22 Sync Separation. In the preceding articles in this chapter, the signal has been followed through the television receiver from the receiving dipole to the modulating grid of the cathode-ray tube. Little attention, however, has been devoted to the composite synchronizing signal that is a part of the complete television signal. Actually, the synchronizing signal has passed through the video intermediate-frequency amplifier along with the picture signal and is present at the intermediate-frequency amplifier output and at the second detector output. The sync separation circuits of the television receiver are utilized to remove the synchronizing impulses from the composite television signal after intermediate-frequency amplification and demodulation. After they are separated, it is necessary to segregate the horizontal from the vertical synchronizing impulses, since they are later employed to drive and synchronize the horizontal and vertical saw-toothed deflection amplifiers of the television receiver.

Although there are many methods practically applied for the purposes of sync separation, most circuits fall into two major classifications. In one the sync impulses are separated from the composite television signal by means of rectification, the rectifier being actuated by a part of the intermediate-frequency signal. In the other a circuit is used whereby the demodulated television signal is admitted to a clipper, where the sync signal is clipped off through limiting, or the intermediate-frequency signal is admitted to a full-wave diode, one half of the diode producing the rectified video signal and the other section producing the sync signal. The latter circuit falls in the rectifier classification. Thus, we may conclude that the sync signal is removed either by limiting or by rectification.

Three commonly used sync separation circuits are described in Fig. 8.57. In the circuit (1) a simple diode is used to remove the synchronizing impulses from the composite signal. In this arrangement the combined values of C_1R_1 maintain a relatively high average bias between plate and cathode of the diode. The result is that conduction occurs only during the sync pulse intervals. These impulses extend above pedestal level and are of greater amplitude than the remainder of the signal. The diode current that flows through R_1, which is selected to be of a large value, results in a high average bias being applied to the diode, the bias being sustained through the relatively large value of cathode capacitor C_1 and R_1. This value of bias must be exceeded before the signal appears across R_2, the latter being of much lower value than R_1. By judicious selection of R_1 and C_1, diode current can be made to flow only during the interval when the sync signal exceeds the blanking level.

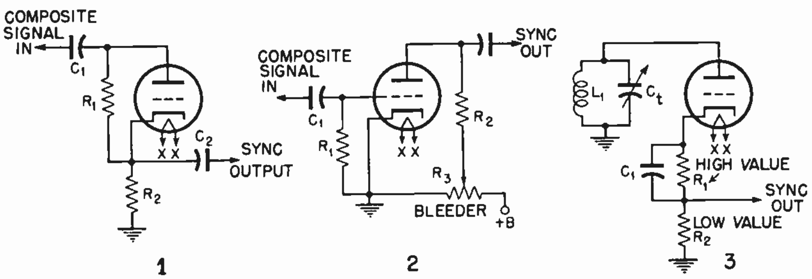


FIG. 8.57

Of course, this is actually the case, since the sync impulses are of greater amplitude, extending beyond the blanking level. The resistor R_2 is not by-passed, and the sync pulses are removed from this section of the circuit described.

In circuit (2), the composite video signal, including both the picture information and the synchronizing impulses, is made to drive a triode, the sync pulses being removed by limiting, or clipper, action. The circuit arrangement is such that the cathode is grounded, the applied plate voltage being maintained at a relatively low value and the grid bias being made to approach zero with no signal admitted to the control grid. When a composite signal of positive polarity is applied, the tips of the sync impulses result in grid current flowing in the input circuit of the tube. The grid current flows through R_1 developing an average grid bias for the tube. The value of the grid resistor R_1, and of the plate voltage, are so selected that an average grid bias develops which is beyond plate-current cutoff. Thus, plate current flows only during the sync-impulse interval, this being the most positive portion of the composite signal, i.e., the portion of the signal developing greatest positive amplitude. Plate current cutoff occurs at blanking level, or at the base of the sync impulse, with the result that plate current actually flows only during the sync-impulse intervals. Separation of the sync by limiting action is indicated in Fig. 8.58. One desirable feature of the system just described is that it is entirely automatic over a wide range of signal amplitudes. As the amplitude of the composite television signal varies, the average bias on the triode follows the signal variation. The result is that cutoff remains constant at blanking level regardless of the signal input variations.

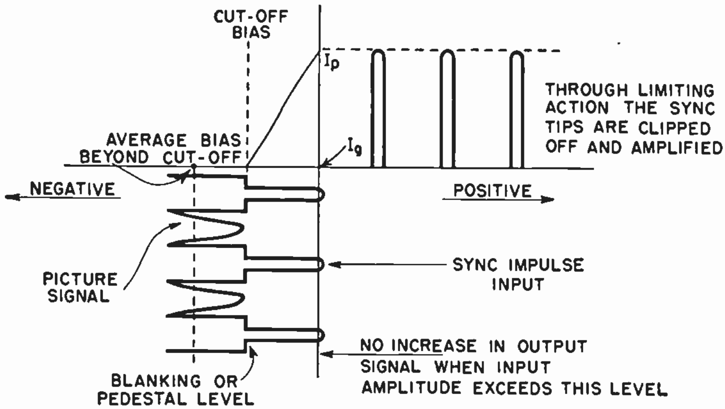


Fig. 8.58

Circuit (3) operates through rectification of the intermediate-frequency signal before this signal is applied to the video second detector. The average diode current passing through R_1 develops an opposing diode bias which must be overcome before diode current can flow. R_1 is made a high value as compared with R_2. Thus, there is no signal across R_2 except during sync intervals. The sync signal developed across R_2 is coupled out to the succeeding synchronizing and deflection system of the receiver.

8.23 Segregation of the Horizontal and Vertical Synchronizing Impulses. The purpose of the sync separation circuits is to separate the sync from the composite television signal. This step is necessary in order to provide properly timed control of the horizontal and vertical sweep oscillators of the receiver deflection system. Once the synchronizing impulses have been removed from the composite television signal, the next requirement is to segregate the horizontal and vertical impulses. *Sync separation and sync segregation must not be confused.*

Differentiating and integrating networks, such as have already been described, may be used in accomplishing sync segregation. These two networks are shown again in Fig. 8.59. A fundamental requirement of the differentiating network is that the time constant RC be made small as compared with the repetition rate or fundamental frequency of the applied impulses. The ratio C/R in the network is also important. The reactance across the capacitance is a function of frequency, being, in fact, inversely proportional to the frequency of the applied impulse. Hence, the higher the value of applied frequency, the more reduced becomes the value of X_C at C and the greater the voltage developed across the shunt resistance R. In this case we speak of R as being in shunt with the input of the tube following the network. It may also be considered in series with R of the network.

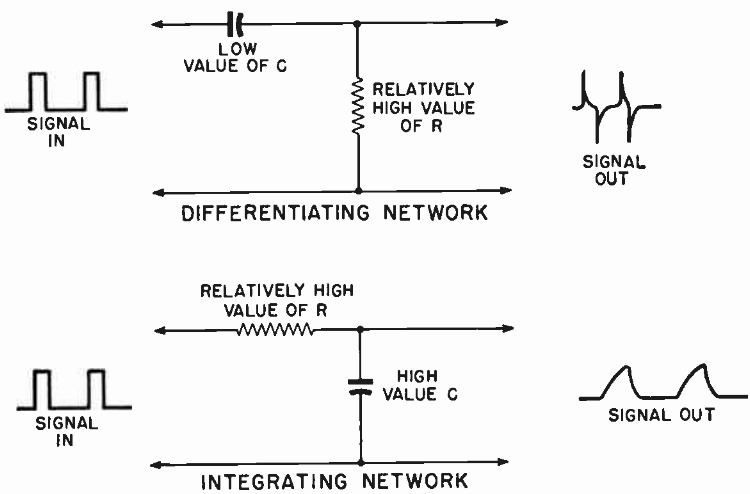


FIG. 8.59

Should a sine-wave voltage be applied to the differentiation network, no distortion will occur. There will result only a gradual reduction in amplitude as the frequency of the sine-wave recurrence is reduced. This is not the case when a nonsinusoidal wave, such as the rectangular sync pulse, is introduced. Such a signal contains components over a very wide frequency range. The change in reactance of C that takes place with the change in frequency upon application of the rectangular wave results in unequal amplification of the impulse, which tends to distort the shape of the pulse. It is this characteristic of the differentiator which is used to segregate the low- and high-frequency components of the rectangular sync pulse.

From the preceding discussion it should be obvious that if a low value of series C is employed in the network, and if the value of R is low to result in a short time constant, the low value of reactance at C at high-pass frequencies will end in voltage at these higher frequencies appearing across R. Since the capacity reactance of C is inversely proportional to F, energy at the lower frequencies cannot reach the network output, because the increasing reactance of C at the lower frequencies effectively retards the flow of current at these frequencies.

The leading and trailing edges of the rectangular sync pulse represent the high-frequency components of signal. Hence, the vertical aspect of the signal appears at the output, while the flat top has disappeared. The shape of the output pulse is shown in Fig. 8.59. Actually, the rectangular wave suffers a change in appearance that is due to the unequal transfer of its many component frequencies in passing through the network.

The time constant employed in the differentiator is a function of its impedance as related to that of the other circuit elements with which it is associated. A small value of C and a relatively large value of R produce a much higher impedance than would obtain with a small value of R and a preponderance of C in the network. This condition holds even though the time constant RC might be the same in either case. In a strict interpretation of the circuit from the standpoint of impedance, it must be remembered that the source of the applied pulse is a vacuum tube, and that the component elements C and R of the differentiating network not only make up the differentiator but serve as a coupling network as well. The load for the network—a second vacuum tube—comprises a lumped impedance, which includes the input capacitance C_{in} of this following vacuum tube.

If the input tube of the network is a pentode, as is the case in a number of circuit applications, it has very high plate resistance R_p. The high value of $R_p = \dfrac{\Delta E_p}{\Delta I_p}$ requires a large value of load resistance R_L. It has been shown that the apparent source impedance is R_p and R_L in parallel, producing a high value of impedance.

From the above, it follows that combined C and R in the differentiator must usually be of relatively high impedance. This condition, in turn, means that a small value of C and a large value of R must be employed. The total resistance of the differentiator R must not be considered as R alone. Rather, it must be considered as $R + \dfrac{R_p R_L}{R_p + R_L}$, which means that R must be large compared with $\dfrac{R_p R_L}{R_p + R_L}$, or low output voltage will result. In considering the value for C, the value of C_{in} of the following tube must ordinarily be considered as in shunt with C of the network. In practice, C is made at least four or five times the value of C_{in} of the tube following the network.

An integration network may be attained by simply reversing the positions of C and R in the circuit; that is, a relatively high value of R is series-inserted in one input arm of the network, while C is connected in shunt across the input to the following vacuum tube. The function of the integrator is exactly the opposite of the function just described. In the integrator only the low-frequency components of the wave appear across the output. It should be recalled that the high-frequency components of the signal appeared across the output in the case of the differentiator. The long time constant in the case of the integrator RC network is such that the rapid change in voltage due to the leading edge of the rectangular pulse cannot charge the shunt C. The voltage, instead, slowly increases, reaching maximum some time after the low-frequency flat portion of the pulse has been reached. Also, the same elapsed time is required for the capacitor to discharge after the steep trailing edge of the rectangular pulse has passed. With judicious selection of the RC components which affect time constant, the shunt C has only partly discharged before the next serrated pulse arrives to reinforce the original charge due to the preceding rectangular pulse. Thus, each successive impulse adds a small additional charge on C, and the cumulative potential across shunt C is used to synchronize the vertical oscillator of the receiver.

Two conventional sync segregation circuits are illustrated in Fig. 8.60. In system (1), the composite sync signal is applied to the control grid of the triode V_1. Two output signals are taken from the tube: one from the plate and the other from the cathode. A differentiating network (shown within the dotted lines) is connected across the cathode resistor. The low value of C_1 and the short time constant of the combination of R_1C_1 results in the sharp leading and trailing edges of the sync pulse appearing across R_1. The sharp positive leading edges of the sync pulse are therefore used to synchronize the horizontal saw-toothed oscillator of the television receiver.

Since each of the component pulses making up the composite sync signal develops a sharp positive pulse in passing through the differentiating network R_1C_1, these sharp positive pulses, whether due to horizontal, vertical, or equalizing components, result in continuous synchronization of the horizontal saw-toothed oscillator. Thus, the horizontal saw-toothed oscillator maintains perfect synchronization even during the vertical and equalizing impulse intervals of the transmission of the Standard Television Signal. It now becomes apparent why the long vertical pulse is serrated, or broken up into shorter intervals. The purpose is to maintain horizontal synchronization during the time interval when the vertical pulses are being transmitted. If this synchronization were not maintained, the horizontal saw-toothed oscillator would lose synchronization during the transmission of the necessary vertical impulse.

It has been shown how horizontal synchronizing impulses are taken off the cathode of the differentiator R_1C_1. But, it must be recalled that a second signal is present at the plate of V_1, namely, the composite sync signal, which in all respects except amplitude is identical with the signal introduced at the control grid. This signal is admitted to the control grid of V_2 through C_3. It will be noted that a large value of capacitance C_2 shunted with resistor R_2 is placed in the input circuit of V_2. The combination results in a large time constant at the input of the tube. With the application of each component pulse of the com-

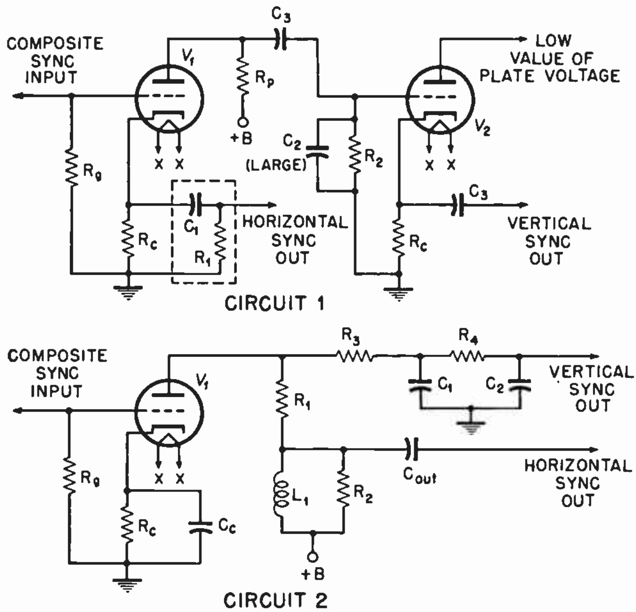


FIG. 8.60

posite sync signal introduced, capacitor C_2 slowly charges and then as slowly discharges through R_2 (see Fig. 8.61). With judicious selection of R_2C_2 and consequently of the time constant of the network, complete discharge of the capacitor is obtained between horizontal pulses. Complete discharge prevents the accumulation of a charge on C_2 during the interval of the horizontal pulse, which, otherwise, would result in the firing of the vertical saw-toothed oscillator during the period of transmission of the horizontal pulses. The same condition applies during the transmission of the equalizing impulses, since they have no effect upon vertical synchronization for the same reason. The capacitor, however, develops a cumulative charge during the time interval when the serrated vertical synchronizing impulses are being transmitted.

As mentioned in Chap. 5 (dealing with the synchronizing generator), the vertical pulse is serrated or broken up into a train of six successive vertical synchronizing impulses, each of relatively long time duration. It will be noted that the time interval between successive vertical impulses is shorter than that between the horizontal impulses. This shorter interval not only gives the capacitor more time to charge but allows the charge to attain a greater amplitude. With a shorter time interval between successive vertical pulses, the capacitor is allowed to discharge only through a relatively short time interval. These facts are important, since there is a gradual accumulative charge across C_2 during the interval of transmission of the six vertical synchronizing impulses, and it is sufficient to synchronize perfectly the vertical saw-toothed oscillator of the receiver. The vertical synchronizing signal is

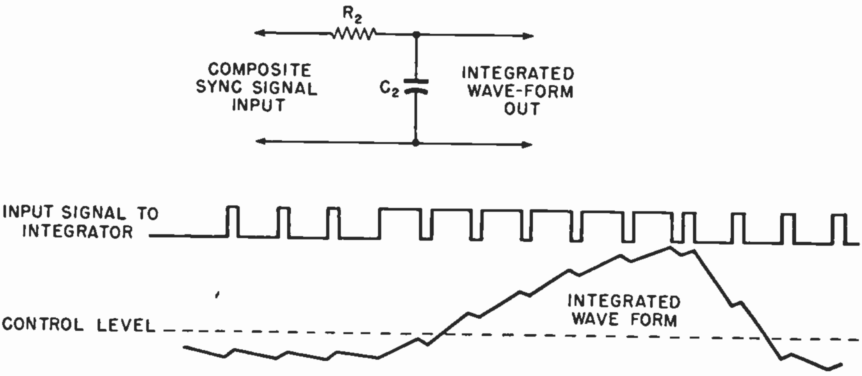


FIG. 8.61

conducted out of the cathode of V_2. The operation of V_1 and V_2, and the associated circuits illustrate how sync segregation is accomplished. Sync segregation must not be confused with sync separation. In the latter case, as described in the preceding section, the composite sync signal is separated from the standard television signal. Sync segregation involves making use of the high- and low-frequency components of the composite sync signal through integrators and differentiators to synchronize the receiver saw-toothed oscillators.

At (2) in Fig. 8.60 a second sync segregation circuit is shown. In this case, after separation the composite sync signal is applied to the control grid of a triode. This tube has two plate loads. The horizontal signal plate load circuit comprises an inductance L_1 shunted by a damping resistance R_2. A differentiated horizontal output signal appears across this network. The reactance of L_1 is a direct function of frequency. Thus, as frequency increases, the reactance of L_1 increases as does the voltage drop across it. The leading and trailing edges of the rectangular wave represent its high-frequency components. The voltage due to these high frequencies then appears across L_1, while the voltage due to the low-frequency component, i.e., due to the flat-topped portion of the sync pulse, does not appear. Hence, differentiation occurs. Any resonant effects arising from the presence of L_1 and its distributed capacitance are effectively damped out by R_2.

The vertical sync appears at the output of the dual section differentiating network R_3C_1 and R_4C_2. Two sections are employed to obtain a cleaner pulse after differentiation as well as greater signal amplitude.

The circuits just described are used with certain modifications in many current television receivers. Fortunately, the basic principles in each system remain essentially as described and illustrated. For that reason they should be closely studied by the engineer or technician.

8.24 The Receiver Deflection System. A synchronized blocking-tube oscillator of the same fundamental type as described in Chap. 5 is sometimes made use of in the television receiver deflection system. Two such generators are required, one to produce the horizontal sweep and the other to produce the vertical saw-toothed waveform. The two oscillators or sweep generators are engineered to develop linear saw-toothed waveforms at line and field frequencies, which, after suitable amplification, are passed to the deflection yoke at the viewing cathode-ray tube. In the case of an electrostatic type of cathode-ray tube, the saw-toothed voltage is resistance-capacity coupled directly to the deflection plates of the tube. One generator produces a saw-toothed waveform at the frequency of 60 c.p.s., while the other produces the horizontal-deflection saw tooth at the required line frequency of 15,750 c.p.s. Both deflection generators are synchronized by the impulses that have been separated from the composite television signal and then segregated. The two synchronizing signals are applied to the oscillators for the purpose of locking them in step at the standard field and line frequencies.

Oscillator circuits and systems other than the blocking-tube oscillator, which is about to be described, have been used in the television-receiver deflection system, but have not proved popular until quite recently. The advantage of the blocking-tube oscillator lies in the fact that it can be made to operate properly with a very weak synchronizing signal. In addition, the circuit is simple and straightforward and is not materially affected by stray voltages and other interference. A simple synchronized blocking-tube oscillator followed by a discharge tube is shown in Fig. 8.62. This system is capable of developing a saw-toothed waveform such as is required for deflection of the cathode-ray tube beam.

An in-phase potential is fed back to the control grid of V_1 through the transformer T_1. The operation of the oscillator is quite simple. Assume that the grid of the oscillator has been driven slightly positive. The result is an increase in plate current and a decrease in plate potential. Negative potential across the primary of transformer T_1 is induced into the secondary winding in such polarity as to effectively reinforce the original positive grid swing. This feedback condition drives the grid sharply positive, and the grid continues in the positive direction until any greater increase in grid potential results in no further increase in plate current. When this condition arises, saturation has taken place. When no further change in plate current occurs, no plate current variation obtains at the primary of transformer T_1. With no feedback, the grid becomes positive, plate current suffers a decrease, and there is an increase in plate voltage. Since a change in plate current has occurred,

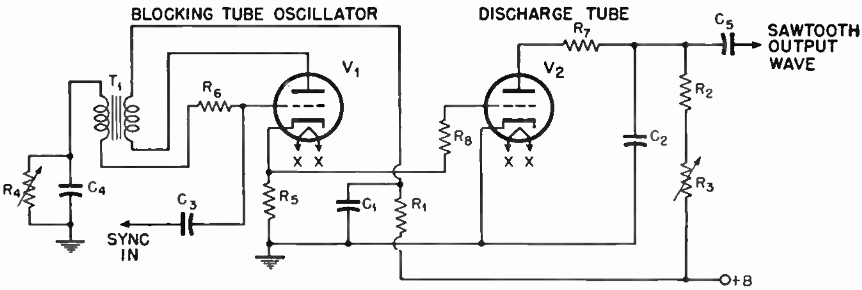


FIG. 8.62

the change is induced into the secondary of the blocking-tube oscillator transformer and results in an even greater decrease in grid potential, the grid being quickly driven negative by feedback of the opposite polarity.

The large swing in plate voltage as the grid is driven beyond cutoff, with a considerable negative charge being left at C_4, tends to maintain the grid beyond cutoff until the charge on C_4 leaks off to ground through grid resistor R_4. The time constant of R_4C_4 (determined by their product) determines the frequency of the saw-toothed wave developed by the oscillator. Thus, R_4 is made variable and through proper adjustment results in the oscillator working at the proper saw-toothed frequency. R_5 is the cathode resistor, determining the proper bias voltage for V_1. C_1 in the plate circuit of V_1 assumes a charge when the tube is at cutoff, discharging during the time interval when the tube is conducting. The discharge tube V_2 is employed in developing a more linear saw-toothed waveform. The control grid of V_1 is directly coupled to V_2. The plate-circuit network of V_2 is so proportioned as to result in a long time constant, with C_2 charging over the linear portion of the saw-toothed waveform and the grid of V_2 being biased to cutoff by the grid voltage of V_1 during the greater portion of the operating cycle.

When the grid of V_2 goes positive, the tube conducts and C_2 discharges.

The circuit elements R_2 and R_3 result in C_2 charging very slowly. The time constant in this part of the circuit is greater than that of R_4C_4. Thus, R_4 and C_4 control the frequency of the saw-toothed wave that is produced, while C_2R_2 and R_3 control linearity of waveform as well as the amplitude of the wave. The blocking-tube oscillator is synchronized by the application of a positive pulse at the desired frequency to the control grid of V_1. The oscillator could also be synchronized by the application of a negative pulse to the cathode of V_1.

The frequency of the sync pulse must be slightly greater than the free-running frequency of the blocking-tube oscillator. This relationship is taken care of by so adjusting R_1 at V_1 that the frequency of the oscillator when free running is slightly less than that of the applied sync pulse. Perfect synchronization then occurs. It is important, of course, that the frequency of the recurrent sync pulse be accurately maintained, since it is a function of the accuracy with which the synchronizing generator at the transmitting station is maintained.

In the practical design of such an oscillator it is important to employ components that have a low-temperature coefficient. Otherwise, ambient gradient is likely to cause the oscillator to slip sync. In order to produce a saw-toothed wave of constant amplitude and linearity, it is important that the capacitor at which the exponential charge is developed to produce the saw-toothed wave should be of the negative temperature coefficient type. A change in capacitance at this point in the circuit, which can be brought about by a temperature change, will most likely result in a nonlinear saw-toothed wave. The saw-toothed waveform must have the same time constant throughout the linear portion of its forward slope. Failure to employ a linear saw-toothed wave at the deflection yoke will result in nonlinear reproduction of the picture along the axis so affected.

Figure 8.63 illustrates the waveform of the free-running oscillator at (1), the waveform of the synchronizing impulse at (2), and the waveform of the oscillator when synchronized.

Though the composite synchronizing signal is first separated and then segregated in order to provide both horizontal and vertical synchronization of the two respective deflection generators or oscillators, it must be understood that the sync pulses also reach the modulating electrode, or grid, of the viewing cathode-ray tube. The sync-signal component of the composite picture signal present at the output of the video second detector has no deleterious effect upon reaching the cathode-ray tube grid. The explanation is that the synchronizing signal is more negative than the pedestal, which is employed to drive the grid of the tube into the blacker-than-black region, thereby rendering invisible the return trace of the electron beam between lines and frames. As has been explained, neither the video nor pedestal signals are used in the deflection system.

After the vertical and horizontal saw-toothed deflection voltages are developed by the two generators, it is necessary to increase their amplitudes in order to provide the proper sweep at the screen of the picture tube. The increase is achieved by means of deflection amplifiers, one succeeding each deflection generator. The deflection amplifiers are

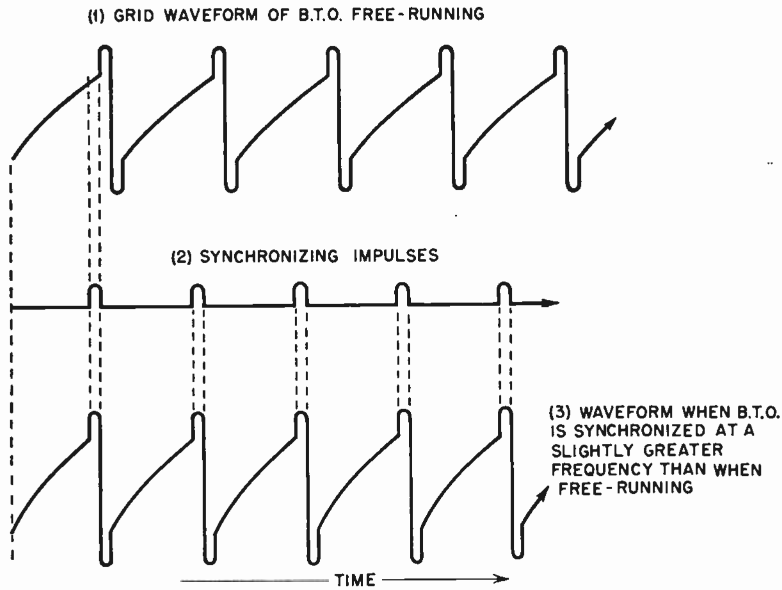


FIG. 8.63

designed to produce complete deflection of the electron beam of the cathode-ray tube, which traces out the reproduced image across the fluorescent screen. Ordinarily, cathode-ray tubes utilizing electrostatic deflection require greater deflection voltages, i.e., saw-toothed voltages of greater amplitude, than are required by tubes utilizing magnetostatic deflection. Another principal difference between amplifiers employed for magnetic and electrostatic deflection is the manner in which the outputs of the deflection amplifiers are coupled to the tube's deflection system. In the case of a viewing tube incorporating electrostatic deflection, resistance-capacitance coupling is used. The deflection potentials at the outputs of the two deflection amplifiers required for magnetic-type tubes are transformer-coupled to the horizontal and vertical windings of the deflection yoke. The position of a magnetic-deflection yoke about the neck of a 12-in. Teletron is shown in Fig. 8.64. The output transformer for the horizontal amplifier should be capable of passing the upper harmonics of the saw-toothed wave at line frequency as well as the fundamental. In the case of the horizontal amplifier, a high current output is essential because high-frequency components of the voltage are present at the horizontal output and the horizontal winding of the deflection yoke includes only a few turns and a small value of inherent in-

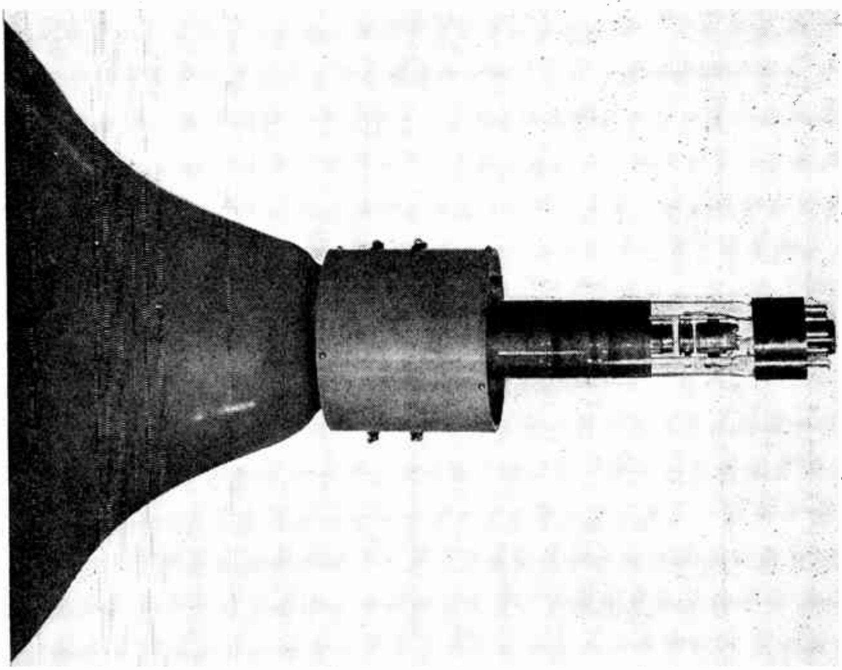


FIG. 8.64 Magnetic deflection yoke about the neck of a cathode-ray tube. (Courtesy of Allen B. Du Mont Labs., Inc.)

ductance. Since the horizontal dimension of the raster exceeds the vertical dimension, more ampere-turns in the horizontal winding are necessary.

The model RTY5 cathode-ray picture tube yoke is manufactured by United States Television Mfg. Corporation to the following specifications:

Horizontal Coils	Vertical Coils
$L = 5$ mh.	$L = 20$ mh.
$R = 20$ ohms	$R = 30$ ohms
$Q = 15$	

This yoke is manufactured for use with 50- and 55-deg. deflection-angle direct-viewing cathode-ray tubes, and production of the yoke is so controlled that deviation from true rectangularity of the scanning raster is less than 0.3 per cent of any edge dimension.

The over-all length of the yoke is 3 in. maximum, and the outside diameter is 3¼ in. plus or minus ⅓₂ in. plus terminal lugs. The inside diameter is 1½ in. Connections are made at terminal lugs to the rear of the outside shell.

A step-down horizontal-deflection output transformer is normally used to couple the horizontal deflection amplifier to the H windings of the yoke. When an R.C.A. type 9857 deflection yoke is involved, a single 6L6 may be incorporated in the horizontal deflection amplifier, the output transformer having a step-down ratio of 5.78 : 1. The R.C.A. yoke referred to has a horizontal winding inductance of 1.5 mh. and a resistance of 5 ohms.

For vertical deflection, a step-down transformer with a ratio of 15.95 : 1 may be used, a type 6J5 tube being incorporated in the vertical-deflection amplifier. Lower current output of this amplifier is required owing to the greater value of inductance and relatively greater number of turns made use of in the vertical winding of the deflection yoke. The inductance of the vertical winding of the R.C.A. type 9857 deflection yoke is 45 mh. with 45 ohms resistance. Lower current from the deflection amplifier may then develop the required ampere-turns for maximum deflection of the beam at the screen of the tube.

Since the electrical requirements of the deflection yoke have been discussed, the next step is a discussion of the two deflection amplifiers needed to provide proper saw-toothed current output. Several such amplifiers are described in the next sections.

8.25 Vertical-Deflection System. The vertical-deflection system of a General Electric Model 90 television receiver is shown in Fig. 8.65. A 6F8G twin triode functions as a blocking-tube oscillator and vertical-sweep or vertical-deflection amplifier. Vertical sync, after separation and segregation, is applied through C_1 to the oscillator control grid (first triode section of the type 6F8G vacuum tube). The vertical synchronizing impulses of positive polarity charge capacitor C_2, which is series-connected between the primary of the oscillation transformer and the control grid of the first triode section, thereby providing synchronization of the multivibrator. Potentiometer R_2 is the vertical-frequency, or hold, control. It is sometimes referred to as a "vertical-speed control," its purpose being to adjust the oscillator frequency so that complete synchronization at the field frequency occurs. Potentiometer R_3 permits adjustment of the bias for the second triode section of the 6F8G tube, thereby providing control of saw-toothed linearity. The amplitude of the vertical saw-toothed wave is adjusted by means of potentiometer

R_6. This potentiometer is commonly referred to as the "vertical-size control."

The output saw-toothed wave is coupled to the vertical coils of the deflection yoke through transformer T_2. The primary of this transformer is shunted by a 100,000-ohm resistor R_7, which damps out any oscillation that might develop in the primary circuit of the transformer. The exponential charge and discharge of capacitor C_3 is responsible for

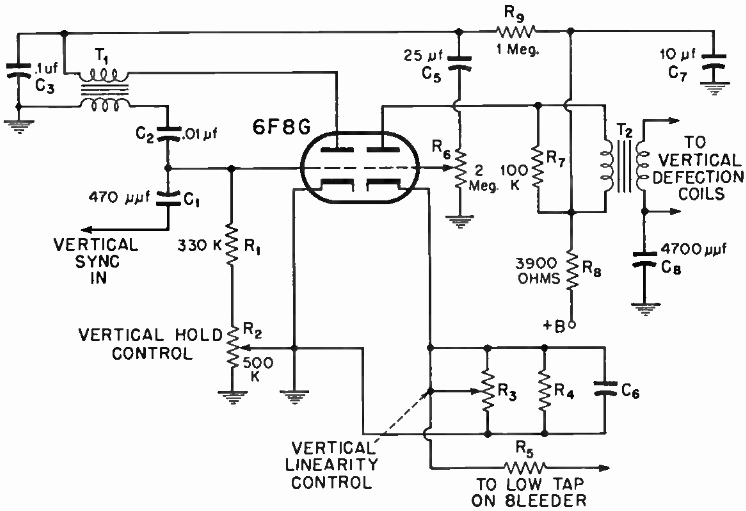


FIG. 8.65

the development of the saw-toothed wave, which is amplified by the second triode section of the type 6F8G vacuum tube before application to the primary of the output transformer.

8.26 The Horizontal-Deflection Amplifier Output Transformer in Modern Systems. Considerable information has appeared in the literature describing the design factors involved in the production of the horizontal-deflection (or H-deflection) amplifier output transformer.*

* Friend, A. W., "Molded Iron Dust Cores for Use in Horizontal Deflection Circuits," *R.C.A. Review*, Vol. VIII, No. 1 (March, 1947), pp. 98–138.

Schade, O. H., "Magnetic-Deflection Circuits for Cathode-Ray Tubes," *R.C.A. Review*, Vol. VIII, No. 3 (September, 1947), pp. 506–538.

Torsch, C. E., "A Universal Application Cathode-Ray Sweep Transformer with Ceramic Iron Core," National Electronics Conference Paper, Chicago, Ill., Sept. 26–28, 1949.

Schlesinger, Kurt, "Anastigmatic Yoke for Picture Tubes," *Electronics*, October, 1949.

Hutter, R. G. E., "Electron Beam Deflection," *Journal of Applied Physics*, Vol. 18 (August, 1947), p. 70; Vol. 18 (September, 1947), p. 797.

The fundamental design criteria relating to the development of television systems, as well as the relation of the horizontal-deflection amplifier to the rest of the sweep system, have been well covered. Noteworthy has been the work of C. E. Torsch of the General Electric Company.

Certain essential requirements are fundamental in modern design. It is an axiom that high magnetic efficiency in the deflection yoke should be accompanied by high Q at the effective retrace frequency, so as to ensure rapid retrace as well as maximum energy recovery in power feedback systems. It has been known for some time that tighter primary-secondary coupling in the H-deflection output transformer, together with high-Q core material of high permeability, would yield considerable improvement over earlier types of combination high-voltage and H-deflection transformer design. In this regard, we refer to the conventional horizontal-deflection amplifier transformer, which also possesses a tertiary winding (at the secondary) for the purpose of supplying high voltage (through a rectifier) for application to the second anode or intensifier terminal of the picture tube.

It is now accepted practice to operate the H-output amplifier as a class B power amplifier. The result is reduced plate-power consumption as well as less cathode emission for a given power output. Reference to the characteristic curves for a particular vacuum tube intended for use as a horizontal-deflection system power amplifier will establish the criteria for proper class B operation for the purpose intended.

It is well that the power feedback of yoke energy be fully used to the rated inverse limit of high-perveance triode damping tubes (such as the type 6AS7G), or high-perveance diodes (such as the types 6W4–GT or 25W4–GT). In current receiver design, new power tubes are being used which may be operated at lower d-c plate-voltage swing to achieve complete deflection of modern picture tubes, even those possessing 19- and 20-in. diameter viewing screens. Two new tubes employed in modern H-deflection output power-amplifier design are the types 6BQ6–GT and 25BQ6–GT. The application of these tubes results in reduced d-c plate-voltage requirements as well as the elimination of expensive transmitting tube insulation requirements in tubes intended for H-deflection amplifier service.

In the use of H output transformers that possess tertiary windings for

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Cocking, W. T., "Deflector Coil Efficiency," *Wireless World*, December, 1947.

Dressel, R. W., *Deflection Coils*, Vol. 22, M.I.T. Radiation Laboratory Series, McGraw-Hill Book Company, Inc., New York, 1948, Chap. 8.

Knoll, M., "Elliptical Deflection Coil," *Telefunken Hausmitteilungen*, Vol. 20, No. 81 (July, 1939), p. 72 (Berlin).

Torsch, C. E., U.S. Pat. 2, 428, 947; Torsch, C. E., and E. B. Cain, U.S. Pat. 2, 428, 948; Schade, O. H., U.S. Pat. 2, 439, 223; Farnsworth, P. T., U.S. Pat. 2, 051, 372, and 2, 059, 683; Torsch, C. E., U.S. Pat. 2, 451, 641, and patents pending.

the purpose of producing high potential for the anode requirements of picture tubes, it has been determined that low distributed capacitance is required in the tertiary winding, resulting in higher efficiency. It has also been established that high distributed capacitance in the primary and secondary windings of the H-output transformer is not desired in view of the required tight magnetic coupling that is considered essential.

Although direct drive of the H-deflection coils (without the presence of an output transformer) has been used in some receiver designs, it has not proved to be good engineering practice for several reasons. In the first instance, power feedback is obtained through the use of an output transformer with a very substantial reduction in d-c plate voltage to the power-amplifier tube through inversion of the secondary voltage-reference polarity. Series heater voltage or grounded power supplies for the damper tube may be utilized where voltage-surge inversion is present. An advanced type of damper tube that is being used is the 6W4GT, the cathode of which is easily insulated for 450 v. to heater. Thus, the heater winding need not be especially insulated, and a special heater transformer for the tube is not required. Production costs are thus reduced and economies in receiver design effected.

The connection of the damper tube on the secondary side of the H-output transformer serves to bring about a reduction in the inverse-voltage surge on the plate-cathode insulation of the tube (with reference to the driver tube surge), and when the optimum step-down ratio is obtained for power feedback.

When "H"-deflection coils of the yoke are driven directly by the power tube in the deflection-power amplifier, high-voltage high-inductance yoke windings are required to match the power-output tube impedance. With the use of an output transformer, less inductance is required in the secondary to drive a low-impedance deflection coil at the yoke. This affords a further economy.

Sweep-surge high-voltage systems are considered to be more efficient in obtaining high anode potential for the picture tube. Separate high-voltage rectifiers for this purpose necessitate more space on the receiver chassis and impose an increased input power demand, both resulting in more expensive design. Although radio-frequency power supplies or auxiliary pulse-type d-c power supplies have been used in furnishing high anode potential for modern picture tubes, increased rectifier-output filtering is needed, as well as radiation shielding in the case of radio-frequency power supplies. This is due to the presence of nonsynchronous ripple voltage as well as the presence of ripple during the picture-tube trace time. The radiation from a radio-frequency power supply is a well-understood problem. Hence, sweep-surge high-voltage systems are rapidly replacing the radio-frequency power supply.

The important factors to be considered in the development of a suitable H-output transformer for the modern television receiver have been stated as follows:

1. The picture size
2. The picture-tube sweep angle (the deflection angle required for a particular picture tube)
3. The required anode potential for the picture tube
4. The plate-voltage supply requirement for the driver tube
5. The choice of deflection-yoke impedance
6. The desired efficiency and Q of the transformer windings during retrace time
7. The existing driver and damper-tube current and surge-voltage ratings
8. The available transformer space allowed on the chassis
9. The interchangeability with existing transformers
10. The available core materials
11. The allowable cost of the transformer in relation to the cost of the complete television receiver

It may be readily seen that horizontal driver-output transformer design and production are no small undertaking. C. E. Torsch of General Electric Company has very ably described these problems.*

The development of horizontal-deflection transformers with ceramic iron-core construction has brought about greatly increased efficiency and transformers of smaller physical size at lower cost and permits the improvement of other components in the associated sweep system. A transformer of this type, developed by General Electric Company, is shown in Fig. 8.66.

It is universal in application, being equally useful in application to sweep circuits for directly viewed picture tubes such as the 8AP4 (8 in.), 10FP4 (10 in.), 12KP4 (12 in.), 16BP4 (16 in.), or the 19AP4 (19 in.), tube. It may be operated as an output transformer for horizontal deflection amplifiers operating at d-c plate-voltage supply levels of 125 to 325 v. and with modern efficient power tubes, such as the 6BQ6–GT, 6BG6–G, 19BG6–G, or the type 25BQ6–GT. These power tubes have come into widespread use as drivers because they may be operated in high-efficiency class B circuits at reduced plate-voltage requirements.

The ceramic iron-core transformers are usually operated in sweep circuits employing high-perveance triode damper tubes, such as the type 6AS7–G, or high perveance diode dampers, such as the types 6W4–GT or 25W4–GT. A single tube, such as the 1B3–GT, may be employed as a high-voltage rectifier to produce 8 kv. d-c for the type 8AP4 (8 in.) picture tube (54-deg. sweep) or 14 kv. d-c for the type 19AP4 (19 in.)

* *Ibid.*

direct-viewing picture tube (66-deg. sweep). A tertiary winding is provided in the transformer, which, in series with the primary, supplies adequate high a-c potential for rectification by a single 1B3–GT diode in providing ample high-potential anode voltage for all commercially available picture tubes, including the 19-in. types.

One important advantage of the ceramic iron-core transformer of universal design is the fact that it may be used to satisfy a wide variety of yoke and tube matching conditions. It may be adapted for use with a great many different deflection yokes and driver and damper tubes.

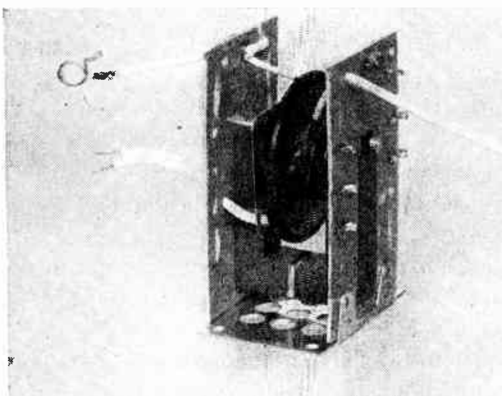


FIG. 8.66 Horizontal sweep transformer for TV receivers. (Courtesy of General Electric Company, Electronics Dept.)

Taps on the extended secondary winding will permit adaptation to practically all present-day sweep systems employed in modern television receivers, and the transformer will no doubt find application to future horizontal sweep systems. Its universal application is indicated in Fig. 8.67, where four circuits are shown in which it finds use, each of them relating to the use of one of the most popular types of direct-view picture tubes in current use.

The universal horizontal amplifier output transformer shown is designed to work into horizontal-deflection yoke windings having an inductance of 8 mh. When this value of inductance is used in the deflection yoke, a satisfactory load impedance is provided for matching practically all commercial types of damping tubes at their most effective ratings for sweeps of 50 to 67 deg. at picture tubes operating with anode potentials of 6 to 30 kv. Horizontal-deflection yoke windings that possess an inductance of 8 mh. have been found to require peak values of 15,750-c.p.s. saw-toothed current of approximately 0.5 to 1 amp. for anode voltages in the range of 6 to 30 kv. While the saw-toothed current demand may seem high, it is readily obtained through the use of several commercially available power tubes, and with voltage step-down

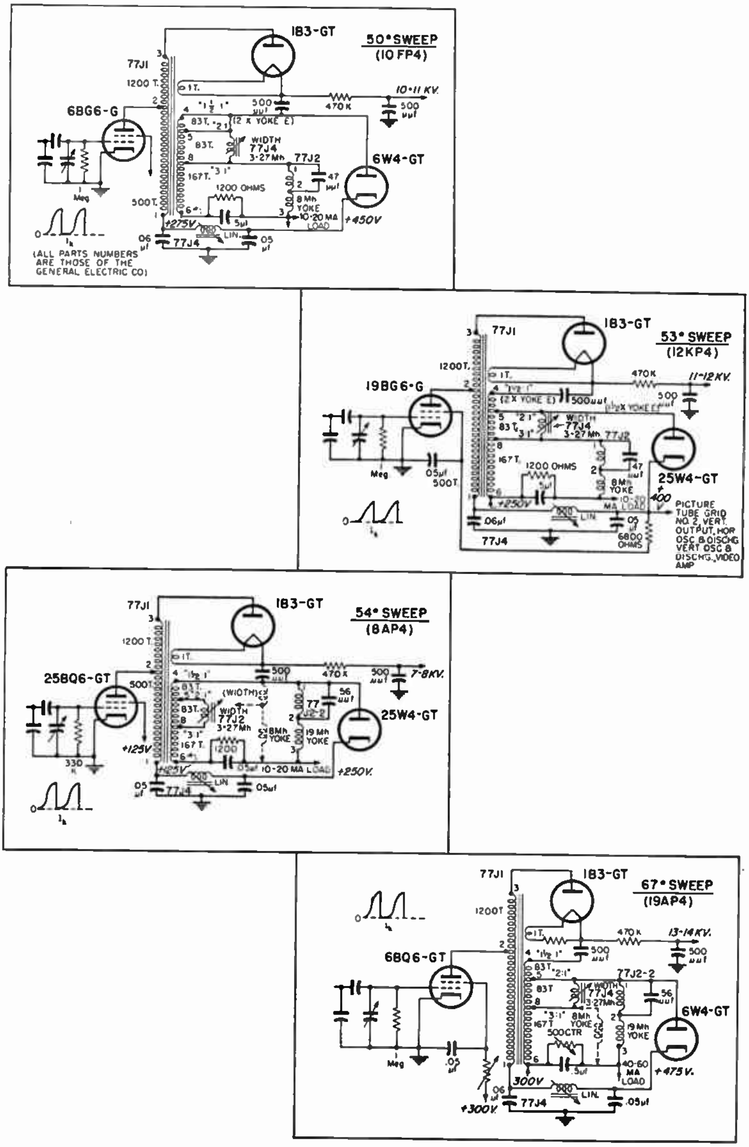


Fig. 8.67

ratios of 2 : 1 to 3 : 1 in the matching output transformer. One such tube is the type 6BG6–G, which has proved a well-adapted driver tube for the purpose. Such a tube may be used with direct-viewing picture tubes, two being employed in parallel where projection-type picture tubes are used.

When the horizontal-deflection coils have an inductance of 8 mh., it is possible to limit the peak surge voltages in the yoke owing to the rapid peak-current reversal during the 10-μsec. blanking interval of television-line transmission. These surge voltages may be limited to 2,000 peak volts, which is easily insulated for by the use of a Formex coating on the coil conductor, together with series operation of the winding halves of the deflection-yoke coils. The use of a yoke having low impedance permits high-speed winding techniques to be used in manufacture, since the wire size is large as compared with that used in the production of high-impedance yokes. With the use of fewer turns, plus an economy in labor due to high-speed winding, production costs are considerably reduced.

With the improvement of damper-tube insulation, there has been a tendency to employ higher yoke-winding impedances, these impedances being connected directly across the damper tube. This permits remaining within the current ratings of economical diode dampers, such as the 6W4–GT, yet providing the yoke energy required with the higher anode potentials demanded by modern direct-view picture tubes. The use of the universal horizontal output transformer with ceramic iron core permits the 8-mh. inductance at the H-yoke winding to be retained. This condition is made possible by operating the damper tube at one of two high-impedance taps at the transformer secondary, i.e., at 1.5 or 2 times the yoke voltage. These extensions on the transformer secondary provide tight coupling to the yoke section so that leakage-reactance decoupling does not bring about appreciable "ringing" in the yoke current wave during the damping cycle. The design of the new transformer is such that as higher yoke impedances come into use, the secondary taps of the transformer may be adjusted to match approximately double or quadruple the present standard yoke impedance.

Torsch has pointed out that high effective shunt-resistance losses serve to limit the speed of the horizontal saw-toothed retrace, as well as the efficient recovery of reactive energy stored in the deflection yoke and transformer during the last half of the trace period. It has been shown that the retrace yoke-current wave is approximately a cosine function, bringing about a reversal of the peak yoke current in one half cycle of an 80- to 100-kc. oscillation of energy stored in the yoke and transformer during trace time. This reactive energy passes from positive peak coil current at the conclusion of the sweep into the charge of all distributed winding capacitances to a zero peak. This occurs when the yoke current passes through zero toward a negative peak at the beginning of a subsequent trace. The voltage peak so brought about is utilized for the picture-tube high anode supply, current control being taken over by the damper tube after the negative peak has passed.

The yoke-current switching transient surge of voltage imposes an insulation burden on the damper tube during its nonconducting interval, particularly if the tubes are operated at the secondary extension taps of the transformer being discussed. Under this circuit condition, up to twice the yoke-voltage swing occurs. This swing necessitates the use of adequate insulation at all critical points in the circuit. Also, retracing should be conducted as slowly as possible within the available blanking interval. Such procedure will reduce to the minimum voltage stresses on driver and damper tubes through the reduction of the retrace yoke-current wave slope. There is an improvement in high-voltage rectifier regulation in a high-efficiency sweep system possessing slower retrace time. The improvement is due to the somewhat broader high-voltage pulse produced for anode-supply rectification. Simple rectifier theory shows that the more the wave shape can be broadened, the more improved the regulation of the rectifier will become, because the rectifier is operating through a greater portion of the current cycle.

Many modern television receivers are applying the type 6W4–GT damper tube in the horizontal-deflection output system because improved insulation has been employed in this small diode. Button stems, such as have been utilized in the type 1B3–GT high-voltage diode rectifier tube base, have been included in the tube design, together with slotted-mica tube element supports. This feature increases the inverse peak-voltage safety factor. The cathode coating of this tube has been made exceptionally rugged so as to complement the high electrical perveance demanded. The type 6W4–GT has an inverse voltage rating of 2,000 v., permitting it to be used at the ceramic iron-core transformer secondary extensions. This brings about a reduction in the losses of stored yoke energy through feedback loops as described by Schade and Torsch.

The damper-tube heater-to-cathode insulation is not subjected to high peak voltages and surges when connected in the manner shown in the sweep-system diagrams in Fig. 8.67. The 450-v. rating of the tube is met by connection of the secondary of the ceramic iron-core output transformer in such a way that negative voltage surges appear on the damper plate during the retrace time, only small ripple voltages being superimposed on the direct current between heater and cathode.

The driver systems shown in the sweep-system diagrams have been developed for optimum operation of the driver tube employed. The type 6BG6–G has been chosen for its high perveance and its adequate plate insulation. Some output systems, through the selection of various output-transformer ratios, have resulted in operation of this tube at positive voltage surges approaching the 6,000-v. peak rating of the

6BG6–G tube, negative pulse surges occurring at nearly 1,900 v. Such a negative plate surge is likely to result in undesired internal oscillations (Barkhausen-Kurz) of the driver tube. This, in turn, brings about radio-frequency radiation of the driver back into the receiver front end. These oscillations are visible as a bar or series of vertical dark bars across the screen at intervals. The ceramic iron-core transformer, when used in the indicated circuits, reduces to the absolute minimum both positive and negative primary surge voltages induced from the yoke-current switching. The reduction is accomplished through the use of extremely tight windings and relatively high distributed capacitances in some transformers in the primary-secondary system as compared with the tertiary winding and rectifier load.

The tight-winding coupling between primary and secondary provides more effective reaction of the damping tube upon the primary-circuit induced transient, according to Torsch, thereby decreasing the negative plate surge on the driver. With proper driver grid-voltage wave shape, the tendency toward Barkhausen oscillation is reduced to the minimum.

By using the type 6BQ6–GT driver tube with plate current of 75 ma., an 8-mh. yoke winding, and the 3 : 1 voltage tap on the secondary of the General Electric type TTJ–1 sweep transformer, it is altogether possible to sweep the 14-kv. beam of a 19AP4 picture tube through the full 67-deg. deflection angle and with but 325 v. d-c at the plate of the driver tube.

To illustrate the efficient use of the ceramic iron-core transformer of universal design, it has been demonstrated that the same power tube will sweep a 53-deg. angle at 12 kv. to provide efficiently a full deflection at a type 12KP4 picture tube. In this application, a 250-v. d-c plate supply is provided for the driver tube (type 19BG6–G), as well as d-c potential for the vertical driver tube, plus screen voltage.

The horizontal output-amplifier and deflection circuits shown indicate that this new transformer is truly universal in operation and may be used in virtually every application where it is desired to supply an efficient means for adequate sweep voltage, anode potential, and damper operation.

8.27 Du Mont Horizontal-Deflection Amplifier. The horizontal-deflection amplifier that follows the saw-toothed generator in late model Du Mont Telesets is illustrated in Fig. 8.68. Here, two type 807 vacuum tubes are parallel-connected to provide the sweep amplitude necessary for large-screen cathode-ray tubes. Some Du Mont receivers employ direct viewing with picture tubes having front faces 20 in. in diameter, which dictates the use of much greater sweep amplitudes than are employed in other modern telesets. Such cathode-ray tubes make possible a useful picture size of 10½ by 14 in., without distortion obtaining as a result of the curvature of the screen at the outer edges of the tube face. A larger image can be had if slight distortion at the extreme edges of the image can be tolerated, although Du Mont Teletrons of this type have relatively flat front faces, much more so than would have been thought possible only a few years ago. The new 19AP4 metal-cone tube with a 19 in. diameter screen is a later large-screen tube design.

It is seen that the output of the saw-toothed generator is capacitively coupled to the two grids of the horizontal-deflection amplifiers, 27-ohm antiparasitic resistors being employed in series with the grids to eliminate

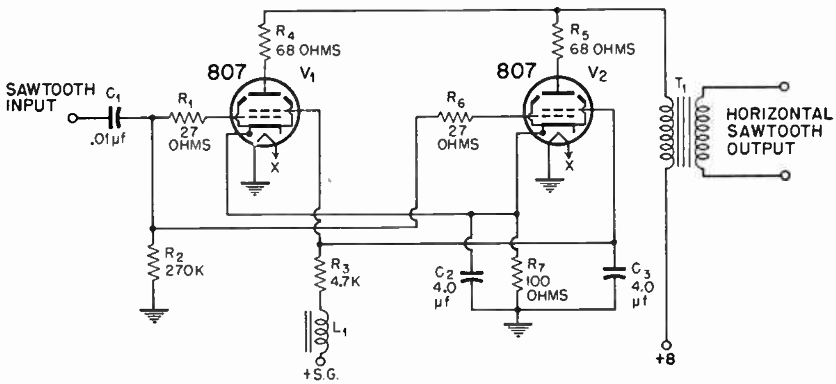


Fig. 8.68

the possibility of transient oscillations. A 100-ohm 10-w. resistor provides cathode bias for both tubes, being by-passed with a 4-μf. capacitor. The grid resistor is common to both tubes and has a value of 270,000 ohms. The screen-grid dropping resistor has a value of 4,700 ohms and is also common to both screen grids. This resistor is effectively by-passed with a 4-μf. capacitor. The two plates of the type 807 tubes are parallel-connected, the primary of the horizontal output transformer being in series with these plates and the d-c plate supply. A retard is employed in series with the screen-grid dropping resistor to prevent oscillation developing because both the screen and plate circuits are supplied by the same d-c power supply, the output impedance of this supply otherwise being common to both the screen and plate networks of the circuit. This amplifier supplies a current saw tooth of sufficient amplitude to result in the required horizontal sweep at the yoke of the viewing cathode-ray tube.

8.28 Horizontal Transients. High-voltage transients occurring at the horizontal-deflection amplifier result in distortion of the saw-toothed waveform. The horizontal-deflection amplifier must pass not only the saw-toothed wave at the fundamental line frequency of 15,750 c.p.s. but frequency components up to at least the tenth harmonic as well. The voltage across the transformer and deflection coil windings is equivalent to IX_L, and X_L is a direct function of frequency. Hence, the reactive voltage drop across these components can become very high, particularly at the harmonic frequencies to be passed. At the beginning of the horizontal retrace, after the forward slope of the horizontal saw-toothed wave has been completed, there is a rapid change in current. At this instant high-transient potentials are produced across the inductive reactances of the output transformer windings as well as across the inductive reactance of the horizontal-deflection coils of the yoke. These recurrent transient voltages result in shock excitation of the windings, an oscillation occurs, and this oscillation modulates the sweeps.

The end result is a series of bright vertical lines through the left portion of the raster at the viewing tube. Not only is the linearity of the sweeps distorted, but the horizontal scanning lines are distorted in that area of the picture where the effect is seen. Instead of each scanning line appearing perfectly straight horizontally from left to right through the raster, they appear wavelike. This condition can be greatly annoying and produces eye fatigue in viewing.

Several methods have been employed to eliminate these horizontal transients. Perhaps the most simple arrangement is to shunt the secondary of the horizontal output transformer, as well as the horizontal coils of the yoke, with low values of resistance. This results in the rapid retrace currents being shunted off through the resistors, obviating the possibility of high-voltage transients developing across the circuit reactances.

A more satisfactory method of eliminating horizontal transients is to employ a horizontal damping tube across the horizontal-sweep amplifier output circuit. This damping tube is usually some form of diode and is connected in such polarity as to conduct during the retrace intervals. Under conduction the diode places a partial short across the circuit reactances when the current change is most rapid. Thus, the transients are effectively damped out. It is important that the diode rectifier be capable of handling heavy current, and it must have suitable internal insulation to prevent high-voltage breakdown, the reactive voltages being quite high.

Such a circuit is shown in Fig. 8.69. It is the damping circuit employed in some Du Mont Telesets and makes use of a type 6AS7G vacuum tube. It will be noted that the tube is connected across the secondary of the output transformer, and the provision is made for control of the damping through adjustment of a 500-ohm potentiometer in series with one of the cathodes. The circuit is also arranged to make possible control of horizontal saw-tooth peaking, horizontal saw-tooth linearity, as well as horizontal positioning. Thus, it provides the requisite adjustments for delivery of a clean and linear saw-toothed current wave to the horizontal coils of the deflection yoke.

The various control potentiometers are usually adjusted while the viewing tube has imaged upon its screen one of the test patterns being transmitted by a local television station, although an oscillograph is more desirable in obtaining an accurate check of the waveform. The use of an oscillograph, which permits the insertion of timing marker pulses along the zero axis of the saw tooth wave will enable the engineer to determine

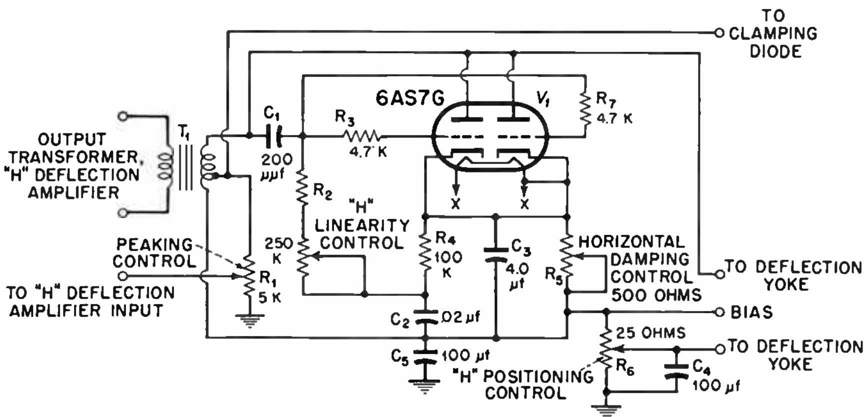


Fig. 8.69

whether the wave is linear with respect to shape throughout its forward slope. Nonlinearity of the wave with respect to shape will result in the reproduced image packing or pulling along its horizontal axis.

Nonlinearity of scanning is produced by inconstant speed of the scanning spot in tracing out each line. The scanning spots at the transmitter and receiver must move simultaneously in traversing the image, line by line, so that their relative positions always correspond. They must, therefore, move at constant velocity. Should the transmitter scanning spot move faster than that of the receiver, the picture elements in the reproduced image will be "packed." If the receiver scanning spot moves with greater speed, the picture elements will be spread, or "pulled." The effects are termed "packing" and "pulling." Constant velocity of movement of both spots is essential in assuring linearity of scanning, and this dictates the use of linear saw-toothed scanning waveforms.

At the television station much time is spent to ensure that both the vertical and horizontal saw-toothed waveforms employed throughout the transmitting system are precisely linear and distortionless. Packing or pulling, as observed in the image viewed at the television receiver, will most likely be a fault of the receiver deflection system rather than of the transmitting system. Observation of the test pattern as transmitted by the television station just prior to the beginning of program transmission will enable the receiver owner to ascertain whether the saw-toothed waveforms of the receiver deflection system are nonlinear. Any nonlinearity is readily discernible through careful observation of the geometry of the pattern. It is the problem of the engineer to determine where any such distortion originates in the receiver. As has already been pointed out, this is best accomplished with an oscillograph. Distortion of the saw-toothed waveforms of the receiver deflection system can be due to transients or to improper time constant. There are other causes and other types of distortion, some of which are treated elsewhere in the text.

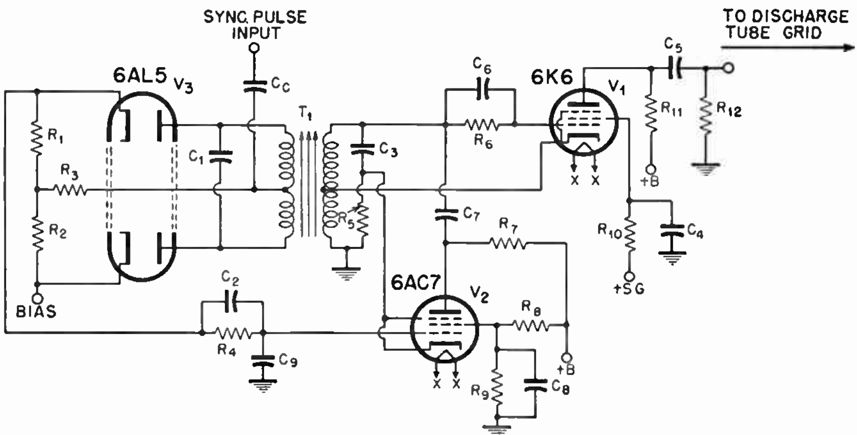


FIG. 8.70

8.29 The R.C.A. A.F.C. Sync Circuit. Some R.C.A. television receivers have used an a.f.c. sync circuit. The system provides "fly-wheel" stabilization of the horizontal-deflection oscillator. It also prevents bursts of noise from displacing horizontal scanning lines in the reproduced image. An elementary diagram of the system is shown in Fig. 8.70. The 15,750-c.p.s. horizontal line frequency is produced by V_1, a type 6K6 vacuum tube connected as a Hartley electron-coupled oscillator. The sine-wave output of the oscillator is introduced through transformer T_1 to a circuit that is similar to that of a conventional a.f.c. discriminator. It should be noted that a 6AL5 twin triode V_3 is employed in this circuit, the center-tapped secondary of the transformer being connected to the plates of the diode sections.

The external horizontal sync pulse is capacitively coupled through C_c to the center tap of the transformer secondary. This results in the sync pulse being effectively superimposed upon the sine-wave output of the horizontal (type 6K6 vacuum tube) deflection oscillator. This is indicated in Fig. 8.71. When the sine-wave output of the horizontal oscillator and the superimposed synchronizing impulse are in phase, and the frequencies of both are the same, the condition indicated at (1) of Fig. 8.71 obtains. Under these circumstances the average value of current developed by the two diode sections of V_3 are equal, the result being that zero bias is developed at the output.

An out-of-phase condition between the introduced sync pulse and the output of the deflection oscillator is indicated at (2) in Fig. 8.71. The sync pulse is seen to ride up on one sine wave and to ride down on the other. When this condition obtains, the upper diode section passes more current, resulting in the development of a positive d-c bias. The lower diode passes

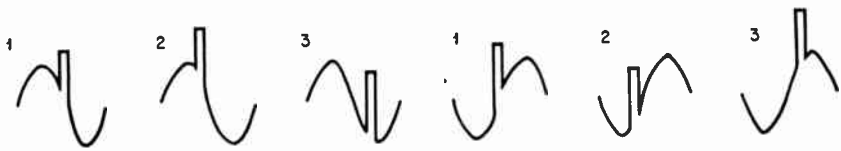


FIG. 8.71

more current, and a d-c bias of opposite polarity is developed when the sine-wave phase departs from the sync-pulse phase in opposite sign. This is indicated at (3). The bias resulting at the output of V_3 is effectively in series with the fixed bias applied through R_1 and R_2. The total bias is passed to the control grid of reactance tube V_2. The output of the type 6AC7 reactance tube is connected across the tank circuit of the Hartley electron-coupled oscillator V_1. The reactance reflected into the horizontal-oscillator tank circuit is of such sign as to shift the oscillator frequency in the proper direction to produce an in-phase relationship of the sync pulses. The design of the circuit is such that correction obtains in the time duration of several horizontal scanning lines, and the result is that any noise introduced into V_3, along with the sync pulses, are averaged and have negligible effect on oscillator frequency. The plate of V_1 is connected to the H-deflection generator. The system operates to make the following deflection generator adhere to the stabilized frequency of the horizontal oscillator, correction being automatic. The system is very similar to that employed in some television synchronizing generators for the purpose of affording stabilization and control of the master oscillator.

8.30 Power Supplies for Television Receivers. With the advent of large-screen television receivers, either employing direct viewing through the use of cathode-ray picture tubes having large-diameter fluorescent screens or projection systems of one type or another, there has developed the need for compact high-voltage supplies for providing the necessary second anode potential. In order to achieve sufficient screen brilliance in projection tubes, the second anode potential must be made very high. This results in increased velocity of the electrons which bombard the screen material. The end result is the development of sufficient light per unit area of the screen surface to permit projection of the image.

A pulse type of high voltage supply has already been described. Another solution to the problem has been the development of the high-frequency type of high-voltage power supply. The radio-frequency supply produces a high-frequency voltage of 10 to 50 kv. by means of a high-frequency oscillator, the output of this oscillator being multiplied by means of a step-up high-frequency transformer—after which rectification is brought about through use of a special type of rectifier tube. Such a supply, the product of United States Television Corporation,* is illustrated in Fig. 8.72. An under-chassis view of the same power supply is shown in Fig. 8.73. Such a system becomes practical since the second anode, or intensifier electrode, current demand of a cathode-ray tube employed in large screen receivers is relatively low, the current requirements of such tubes averaging 250 μa. to 1 ma. The fundamental circuit of a 10-kv. high-frequency power supply is illustrated in Fig. 8.73.

In this power supply, an R.C.A. type 8016 half-wave rectifier tube is made use of. This tube is unique in that its filament is heated to the point of copious emission by means of induction from the type 6Y6–G radio-frequency oscillator tank circuit. The use of the type 8016 rectifier tube eliminates the necessity for a separate-filament transformer, thereby considerably reducing manufacturing costs. In the case of the conventional 60-c.p.s. high-voltage power supply, a filament transformer must be supplied that is suitably insulated, primary to secondary, for the full peak-voltage rating of the power supply.

It should be noted that only a single filter capacitor is used to attenuate the ripple component at the rectifier output. This filter capacitor is rated 500 $\mu\mu$f. (in one design) at the peak-voltage output rating of the rectifier. The use of the high-frequency supply offers this further economy of design as compared with the 60-c.p.s. type of high-voltage supply. The latter supply would require fairly heavy capacity in the low-pass filter at the rectifier output, and such high voltage capacitors are expensive and dangerous.

In the design of high-frequency high-voltage power supplies, the oscillator section has ordinarily been designed to operate in the range from 50 to 300 kc. per sec. When potentials up to 50 kv. are required of the power supply, it has been customary to design the oscillator for operation in the lower portion of the above frequency range, i.e., closer to the lower

* Baumann, H. C., "R.F. Power Supplies," *Communications,* March, 1946.

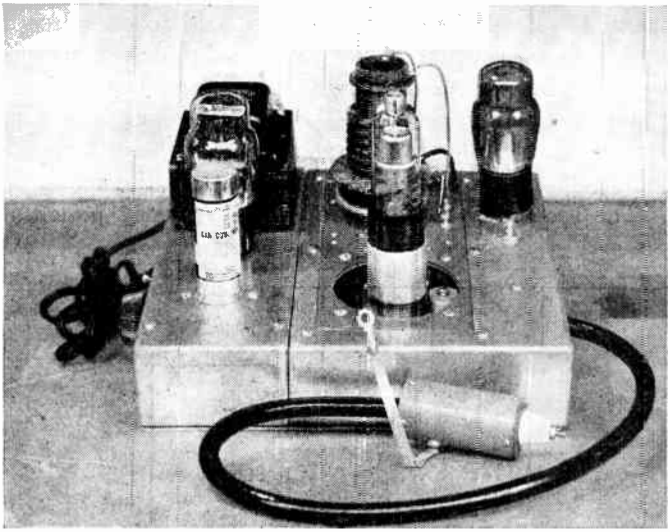


FIG. 8.72 High-voltage radio-frequency power supply, model 10HFP-2. (Courtesy of U.S. Television Corp.)

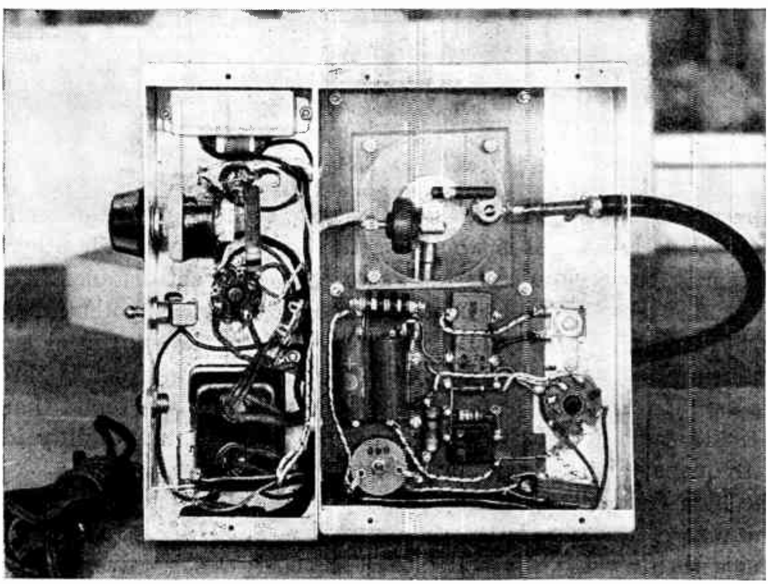


FIG. 8.73 High-voltage radio-frequency power supply, bottom view of chassis, model 10HFP-2. (Courtesy of U.S. Television Corp.)

limit of 50 kc. per sec. This is because increased spacing in the coils is required, and the lower frequency coils are said to offer less danger of arc-over. In the design of high-frequency coils for the greater second-anode potentials, losses must be made proportionately lower.

In the fundamental circuit (Fig. 8.74), L_1 is the primary inductance of the high-frequency step-up transformer, L_2 being the principal secondary and providing the high-frequency stepped-up potential for the type 8016 rectifier. The secondary L_4 provides high-frequency potential for the

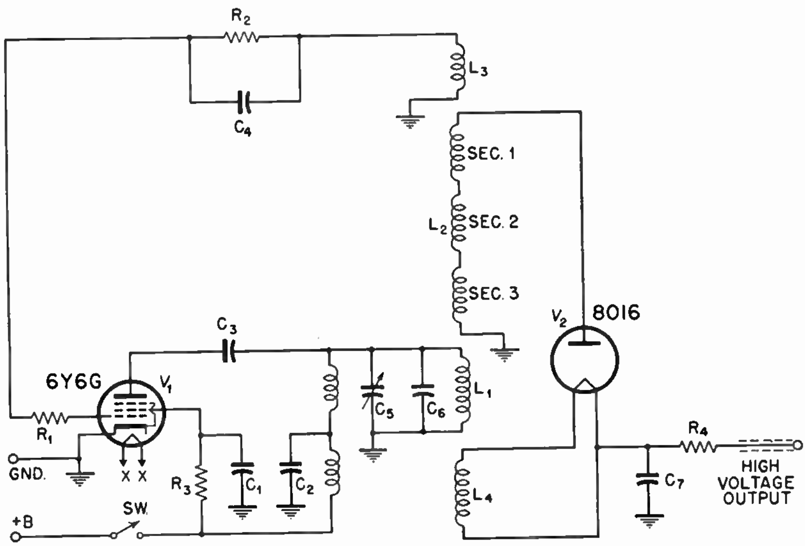


Fig. 8.74

rectifier filament, while inductance L_3 is the tickler coil of the oscillator circuit. This latter coil is wound on the same form with the other two inductances, but is physically separated by a sufficient distance from L_2 to prevent arc-over. The secondary supplying filament potential to the type 8016 rectifier is physically related with the low-potential end of secondary L_2. Feedback in the oscillator circuit occurs from L_1 through L_2 to L_3. In the design of such oscillators, it has been found that the grid-tickler type of circuit arrangement provides greater stability in the high-frequency high-voltage power supply.

The high-frequency potential step-up transformer may be found just to the rear of the type 8016 rectifier in Fig. 8.72. This transformer is wound with litz wire to provide space economy, and a universal type of winding on low-loss tubing effects a further reduction in the mounting space required. The physical dimensions of the transformer are largely a function of the voltage and current requirements; these requirements, in turn, dictate the length of the principal secondary winding. A typical radio-frequency transformer designed to supply 10 kv. to the second anode of a television cathode-ray tube has an over-all length of 4 in. and a maximum over-all diameter of 2.5 in. (across the primary). This transformer occupies little space on the receiver power-supply chassis as compared with that which would be required to mount a bulky 60-c.p.s. high-voltage transformer of equivalent voltage rating. In the design of a 30-kv. radio-frequency transformer for the high-frequency type of power supply, a separate form is made use of for the primary coil. The tickler coil and primary are wound on the same form, this form being of such diameter that it may be slipped over the universal-wound high-voltage secondaries, since these coils are wound on forms of smaller diameter. An air gap must be allowed between the inner surface of the primary coil and the outer surfaces of the secondary coils. Leads are brought out to suitable high-voltage insulation, such bushings and terminals being ordinarily of ceramic material. The secondary of the high-voltage transformer is of high impedance at resonance, and the inductance of the principal secondary is resonant at the operating frequency with the combined distributed capacitance of the winding and the capacitance due to the diode load.

The stability of the secondary under load is improved by overcoupling, resulting in a maximum developed potential appreciably less than that which would be obtained at critical coupling. The improved stability that is due to such overcoupling is felt to be advantageous, even though a slight reduction in output potential results.

H. C. Baumann has described the following design requirements with respect to the radio-frequency transformer design:

$$\text{Coupling factor } K \gg K_c \text{ (critical coupling)}$$

where

$$K_c = \frac{1}{Q_1 Q_{11}}$$

and

$$K = \frac{M}{\sqrt{L_1 L_2}}$$

The measured values of $(\omega L/R)$ of the primary and secondary K for a 10- and 30-kv. coil have been given by Baumann as follows:

10-*Kv. Coil*

Primary (with 2,000-$\mu\mu$f. tuning capacitor):

$$Q = 130$$

Secondary (with 30-$\mu\mu$f. tuning capacity):

$$Q = 100 \qquad K = 0.26$$

30-Kv. Coil

Primary (with 0.01-$\mu\mu$f. tuning capacity):

$$Q = 90$$

Secondary (with 30-$\mu\mu$f. tuning capacity):

$$Q = 95 \qquad K = 0.28$$

These values were measured with the coil unloaded, and obtained by means of a Q meter.

A simplified schematic of the oscillator and radio-frequency section of a typical 30-kv. supply is shown in Fig. 8.75.

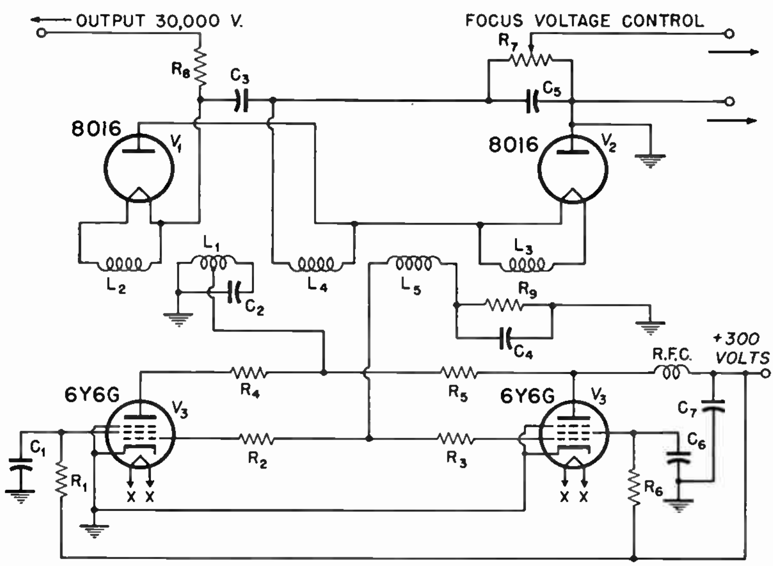


FIG. 8.75

A factor of considerable importance in the design of such supplies is that of corona. The transformer winding form must possess high dielectric strength. Sharp corners and jagged points on the transformer form must be avoided, as well as sharp curvature of the winding itself. The universal, or pie-section, construction of the principal secondary winding not only reduces physical size but limits the distributed capacitance of the coil, as well as the electrical field between various parts of the winding. Impregnation of the high-voltage coil is desirable where high humidity is present, silicon impregnation having been used successfully for the purpose.

8.31 Typical Television-Receiver Power Supply. In most instances, the television receiver will require at least two d-c power supplies. One is a low-voltage supply, used to provide all d-c potentials to the receiver exclusive of that required for the anodes of the picture tube. The low-voltage supply is ordinarily operated from the 110-volt 60-c.p.s. a-c power source in the home. Full-wave rectification is used, and the maximum d-c potential supplied is in the order of 300 to 500 v.

The high-voltage supply will normally furnish second-anode potential to the picture cathode-ray tube, and this may vary from 6,000 v. d-c for a 10- or 12-in. viewing tube to 20 to 30 kv. if a projection tube is used. Ordinarily, half-wave rectification is involved, since ripple content or hum is not the problem at the viewing-tube anodes that it is in the circuits associated with the low-voltage supply.

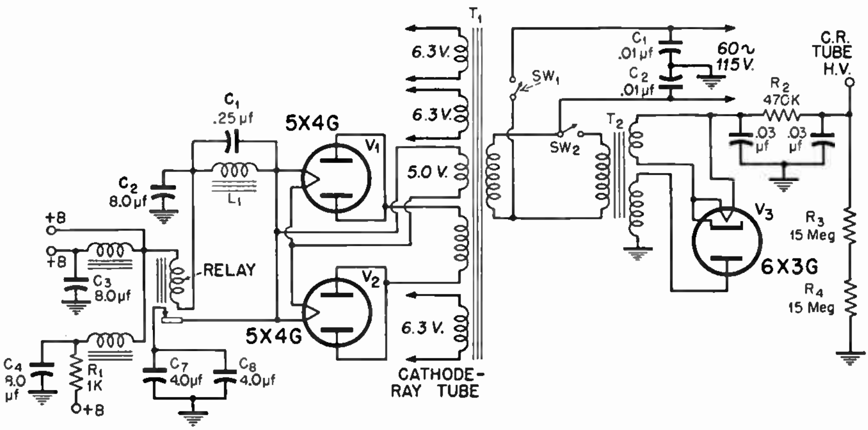


FIG. 8.76

A typical and well-engineered receiver power-supply system (Philco) is shown in Fig. 8.76. It is seen that two type 5X4G tubes V_1 and V_2 are used in the low-voltage supply, and one type 6X3G tube is employed in the high-voltage supply. The input a-c supply from the power line is admitted to the primaries of the two power transformers T_1 and T_2 through the power switch Sw_1. An interference filter comprising C_1 and C_2, the two capacitors being center-tapped to ground, prevents line interference from entering the receiver circuits through the power supply. An interlock, or protective, switch Sw_2 opens the a-c supply to the high-voltage primary whenever the protective cover of the rectifier is removed.

A pie-section filter composed of two capacitors and resistor R_2 provides the essential filtering at the high-voltage power supply. Two 15-megohm resistors R_3 and R_4 are provided as a protective bleeder to discharge the high-voltage capacitors, as well as to provide a protective load for the rectifier.

The power transformer T_2 supplies filament potential to the 6X3G tube and also high potential to the rectifier. The circuit is simple and straightforward in every respect. It is important to bear in mind that a high-voltage power supply of this type is a very dangerous device if the proper safety precautions are not observed. The high potential that is supplied can prove fatal should the engineer or service technician come in contact with it. A wise policy is to discharge the capacitors, even though the safety switch is believed to have operated when the safety cover was removed from the supply. The discharge may be made by means of an insulated stick, to the end of which is attached a copper tip which may be connected by means of a heavy copper cable to some point on the chassis known to be at ground potential.

There are five secondaries associated with transformer T_1. One 6.3-v. winding supplies heater potential to the picture tube. An additional 6.3-v. winding and a 2.5-v. winding provide heater potential to all the tubes of the television receiver exclusive of the cathode-ray picture tube. A multiple pie-section filter provides sufficient filter action to ensure essentially ripple-free d-c power to the receiver circuits. Two type 5X4G rectifier tubes are employed to pass the heavy current demand of the receiver circuits (250 ma. at 350 v. in this case) safely. The plates of each rectifier are parallel-connected, the two tubes providing full-wave rectification in the conventional manner. A 5-v. secondary winding provides heater current to the two rectifier tubes.

The first filter choke L_1 is made use of as part of a low-pass filter as well as to provide additional filtering because of capacitor C_1 being connected in shunt. The components L_1 and C_1 provide a parallel resonant circuit which filters out second-harmonic ripple. The load side of L_1 is by-passed by C_2. A relay winding is connected in series with the load side of the filter, and the relay is included, since the cathodes of the 5X4G tubes are directly heated. Hence, the power supply provides d-c voltage before the cathodes of tubes in the receiver circuits permit current flow. The d-c voltage is prevented from reaching an excessive value while the current demand is at minimum. It disconnects capacitors C_7 and C_8, thereby providing a choke-input type of circuit. In other words, the input capacitors are disconnected until sufficient current flows through the relay winding to cause it to operate, in which case C_7 and C_8 are connected across the input to the filter system, thereby increasing the d-c output potential to the required maximum. Three output d-c lines supply the receiver, two of which include pie-section filters to provide greater ripple attenuation to certain circuits of the system.

8.32 Projection Television. One of the limitations imposed by television receivers that provide direct viewing from the face of a cathode-ray tube has been that of image size. Except for the tubes that possess large-diameter screens, observation of the reproduced images for an appreciable length of time results in some eyestrain and fatigue. At the present time a screen diameter of 20 in. represents the practical limit for direct-viewing tubes. Eyestrain is not severe in viewing images on screens 12, 15, or 16 in. in diameter; but the fact remains that as the image area can be made greater, eyestrain and fatigue are reduced to proportion. The larger-diameter tubes provide bright, well-defined images, although as the size of the cathode-ray tube is increased, manufacturing problems are greater, production costs are higher, and the tubes are more difficult to produce and sell economically. Lately, mass production of tubes of large-screen diameter has resulted in economical production. An example is the Du Mont type 19AP4 tube.

Although most manufacturers have concentrated their efforts toward large-scale production of receivers for direct viewing, some progress has been made in the development of projection-type receivers. Projection systems include two general methods for increasing image size. *The first method for increasing image size*, which is the oldest, involves the placement of a special lens before the face of the cathode-ray tube, thereby projecting the image onto a larger screen at some distance from the receiver.

This method of projection has several serious limitations. First, light cannot be transmitted through any lens system without appreciable attenuation, and the illumination available at the fluorescent screen of a cathode-ray tube is low at best. It has been shown that the space distribution of light emitted by the fluorescent screen of a cathode-ray tube follows approximately the cosine or Lambert's law of perfectly diffusing surfaces. When a motion-picture projection lens is used to project an image originating at the face of a cathode-ray tube, the over-all efficiency is low. No cathode-ray tube has yet been developed that provides illumination at the fluorescent screen of an intensity comparable with the light available from a slide or motion-picture projector lamp house. When projecting light from a perfectly diffusing surface onto a viewing screen by means of a projection lens, a great amount of light is lost. Treated projection lenses of good quality, with an aperture of f/2 and a transmission coefficient of 100 per cent, collect from a cathode-ray tube and transmit to the viewing screen a magnified image of only 6.25 per cent of the light produced at the tube's screen.

A second limitation is imposed by the fact that much of the image illumination is reflected from the lens surface, only a small part of the original light ever reaching the screen.

A third disadvantage, which is true of any currently developed projection system, lies in the fact that considerable second-anode potential at the cathode-ray tube is necessary to provide workable screen illumination, and this condition results in short tube life. There is rapid degradation of the screen phosphor due to accelerated bombardment of the material, a high anode potential being necessary for adequate screen illumination. In projection cathode-ray tubes screen diameters are made small in order to concentrate the available light over a small area, thereby increasing the intensity of illumination. The light output is usually made 10 to 20 times that of a conventional tube employed for direct viewing. Second-

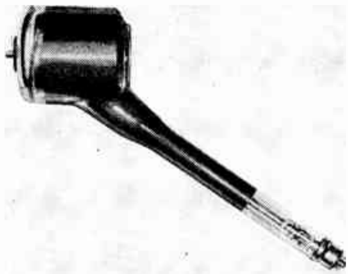


FIG. 8.77 (Courtesy of The Rauland Corp., Chicago, Ill.)

anode potentials in the order of 20,000 to 30,000 v. are necessary, and the construction of the gun is modified so that a smaller diameter and more intense beam is made available for scanning.

A projection tube of advanced design is shown in Fig. 8.77. It may be seen that the shape of the bulb or envelope is considerably different from that found in other cathode-ray tubes. The screen of the tube is so placed that the light to be provided is obtained from the same surface upon which the electrons arriving from the gun impinge. The advantage obtained is that light is reflected from the same surface under electron bombardment and does not have to pass through the phosphor material of the screen as in the conventional tube. Although the light must still pass through the glass envelope before reaching the optical lens system of the projection-type receiver, some light is conserved and a greater light level is available for projection.

The tube is dipper-shaped and resembles the physical shape of another member of the cathode-ray tube family, namely, the Iconoscope. The gun structure is brought out at an angle to the axis normal to the screen. This arrangement is necessary to keep the presence of the gun from interfering with transmission of light from the screen to the lens system and screen. The screen area of the tube is circular, with a diameter of 4 in. An image of fairly high illumination is provided through use of 30,000 v. accelerating potential at the second anode. Projected images up to 18 by

24 in. in size have been obtained with this tube, a product of the Rauland Corporation.

A larger projection tube of the same general type is shown in Fig. 8.78. It is specifically designed for theater projection systems, and the projec-

FIG. 8.78 (Courtesy of The Rauland Corp., Chicago, Ill.)

tion receiver in which it is used is illustrated in Fig. 8.79. The screen of this tube is 7.5 in. in diameter. It has projected images upon a screen measuring 15 by 20 ft.

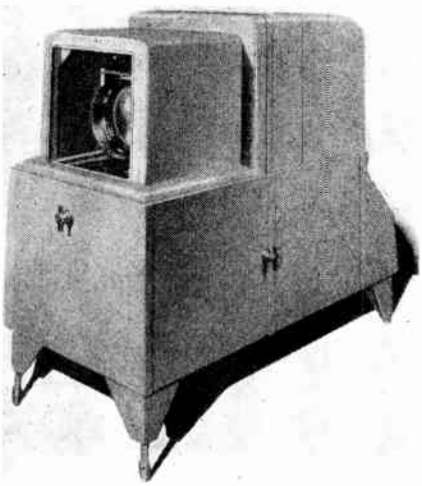


FIG. 8.79 (Courtesy of The Rauland Corp., Chicago, Ill.)

8.33 Reflective Optics in Projection Television. *The second method at present employed to produce large-screen images* by projection involves the Schmidt optical system, originally used in the construction of astronomical telescopes. The high efficiency of the Schmidt system is due to the fact that there are fewer reflecting surfaces present in the arrangement.

As applied in astronomical telescopes, the system comprised a spherical reflecting surface, a photographic plate, and an aspherical correction lens. The optical arrangement resulted in maximum light being concentrated upon the photographic plate. Owing to a form of optical distortion in the

FIG. 8.80 An early R.C.A. projection receiver employing the Schmidt optical system. Only the translucent projection screen is shown here. (Courtesy of Radio Corporation of America.)

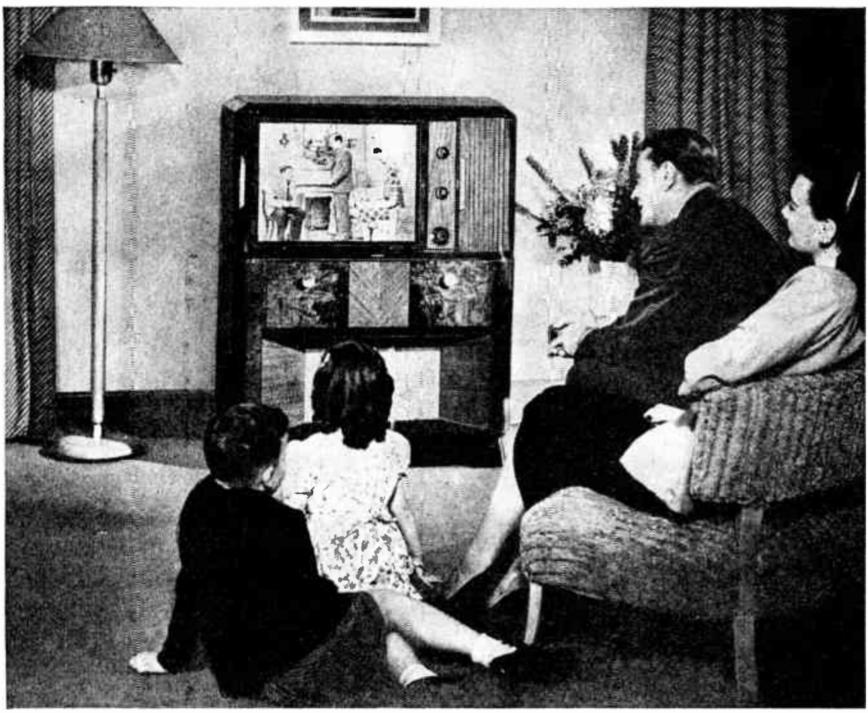


FIG. 8.81 An R.C.A. projection receiver incorporating the Schmidt optical system. (Courtesy of Radio Corporation of America.)

system (known as "spherical aberration"), it was necessary to employ a correcting lens. Spherical aberration is brought about when all the light rays impinging upon a spherical surface fail to come to sharp focus on the central axis. The aspherical correction lens eliminates this form of distortion.

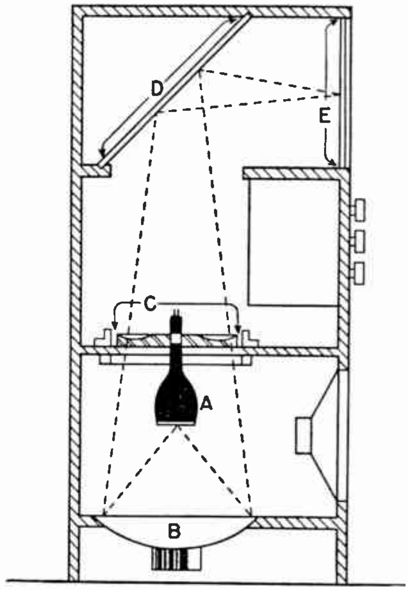


FIG. 8.82 In the Schmidt optical system employed in the R.C.A. projection-type receiver, the light at the face of the projection tube *A* falls upon the spherical front surface mirror *B*. The light is then reflected through the aspherical correction lens *C* and strikes the face of the inclined mirror *D*. It is then reflected to the translucent projection screen *E*, upon which the final and enlarged image is viewed.

Two R.C.A. projection receivers using the Schmidt optical system are illustrated in Figs. 8.80 and 8.81, and the general arrangement of the projection system is shown in Fig. 8.82. The R.C.A. system makes use of a spherical front surface mirror and an aspherical lens that is positive in the central portion and gradually changes into negative near its periphery. A gain in screen illumination of about 6 : 1 or 7 : 1 is obtained as compared with a conventional f/2 lens.

The aspherical lens is molded of a plastic material called "lucite," a Du Pont product. The molded lens possesses excellent light-transmission qualities with low scattering of light properties and can be mass-produced at low cost. In molding the lens, very great pressure is applied to the heated plastic material while it is confined in a heated mold. It is then cooled under pressure until room temperature is reached. The mold is then opened and the lens taken out. Next, a hole is bored through the center to accommodate the neck of the cathode-ray tube. A glass lens of comparable quality would require days of skilled grinding and polishing, while this plastic lens of Lucite methyl methacrylate resin is produced in a matter of minutes. A molded lens of this type is illustrated in Fig.

8.83. These plastic lenses possess better light-transmission properties than do equivalent lenses of optical glass, and there is less scattering of light than is present with a glass lens. They do not demonstrate the surface hardness and scratch resistance of glass, but are enclosed in the receiver cabinet, and, therefore, do not have to withstand extreme abuse.

The R.C.A. system illustrated is designed for a fixed image distance and requires a cathode-ray tube that possesses a face curvature fixed in relation to the curvature of mirrors in the system. Essentially, operation of the system is as follows. The light due to the image upon the face of the cathode-ray tube is projected downward upon the surface of the spherical glass mirror; it is then reflected up through the aspherical cor-

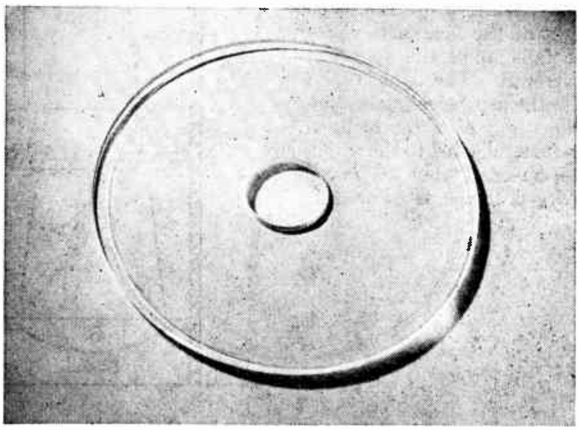


FIG. 8.83 An aspherical correction lens molded of Lucite (methyl methacrylate resin). (Courtesy of E. I. du Pont de Nemours & Co., Inc., Plastics Dept., Arlington, N.J.)

recting lens and upon a flat inclined mirror. The mirror projects the reflected image onto a translucent viewing screen. The translucent screen of the receiver illustrated in Fig. 8.81 permits an image 21⅓ by 16 in. This image is adequate for effortless viewing in a living room of normal proportions.

In a number of projection receivers of this type that have been developed, optical efficiencies of 18 to 35 per cent have been achieved. The smallest projection system used a cathode-ray tube 3 in. in diameter with spherical mirror 9 in. in diameter and an aspherical correcting lens with a diameter of 6 in. Another receiver employs a cathode-ray tube 5 in. in diameter with a spherical mirror 14 in. in diameter and a correcting lens 9.5 in. in diameter. The distance between the correcting lens and the viewing screen has varied between 36 and 54 in.

With the public demand for images of large-screen area, considerable progress may be expected in the field of projection television. Because of the need for large-screen theater systems, a number of research and development groups are attacking the problem, and other methods for throwing large images upon the screens of theaters are undergoing tests and refinement.

8.34 The Television Receiving Antenna. Television signals are propagated in a portion of the frequency spectrum where the properties of the waves are similar to those of light, and the waves may therefore be described as quasi optical. They may be reflected much as are light waves and follow paths through space that are in line of sight between the transmitter and receiver, provided that no obstacle intervenes. The waves are horizontally polarized in direct opposition to those vertically polarized waves that are propagated in the more familiar AM band extending from 550 to 1,600 kc. per sec.

The use of horizontal polarization of the very high frequency waves emitted by a television station definitely limits the transmission along line-of-sight paths that do not extend beyond the theoretical horizon. This fact permits the duplication of stations in many cities, with all these stations occupying a common channel and having no serious interference among the stations. The very high frequencies that are used permit the efficient utilization of the already overcrowded total radio-frequency spectrum and enable the licensing authority to grant licenses to a great many more stations than would be possible at lower frequencies. Actually, no space exists at the lower frequencies where the broad-band television signals, each channel occupying 6 mc. of the spectrum, might possibly be transmitted.

The use of very high frequencies and horizontal polarization dictates special types of receiving antennas. The most popular of these types is the *horizontal half-wave dipole antenna* shown in Fig. 8.84. In this instance, a reflector has been added. Such an antenna combines the polar characteristics of a half-wave antenna with the impedance-transforming properties of a quarter-wave line, and its characteristic impedance at the terminals is approximately 72 ohms in free space. The antenna is said to be "horizontally polarized" because its principal plane is parallel with the earth's surface, and because the antenna receives horizontally polarized waves. It is termed a "half-wave antenna" because the horizontal stubs of the antenna are, together, approximately ½ wavelength long, i.e., at the operating frequency for which it is designed. The common half-wave dipole is made up of two quarter-wave stubs. These stubs are cut from aluminum and dural tubing and are insulated one from the other, the two stubs being separated at the center. Its polar characteristic is such that it will receive signals from opposite directions, the signals arriving at right angles to the principal horizontal axis of the antenna. Because of this characteristic, it is termed a "bidirectional antenna." This characteristic dictates that the antenna must be oriented so that signals enter at right angles to its principal horizontal axis. Maximum energy is delivered when it is so adjusted. There is very little pickup off the ends of the stubs.

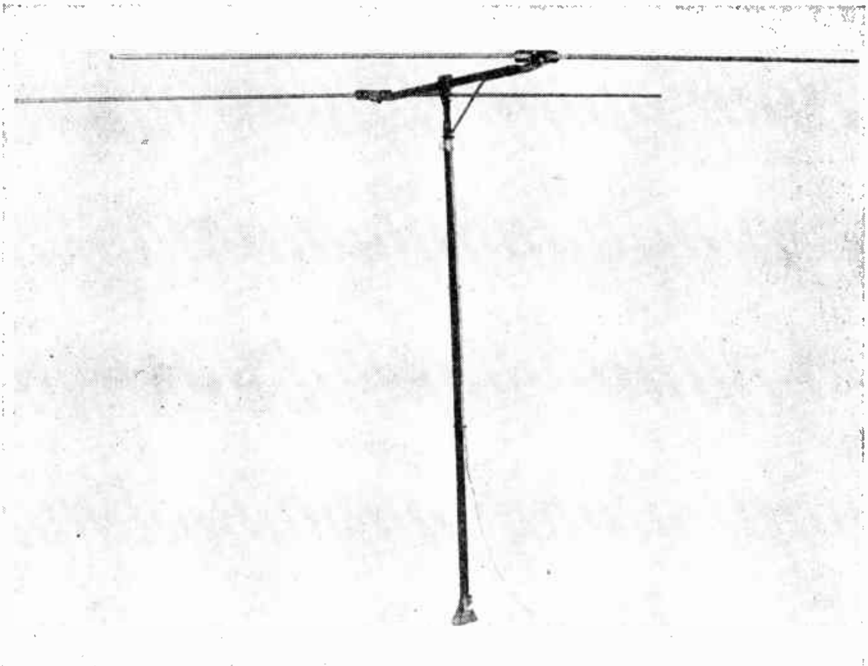


FIG. 8.84 Half-wave dipole antenna with reflector. (Courtesy of Ward Products Co., Cleveland, Ohio.)

Increased signal strength will be delivered to the television receiver if a reflecting element is placed ¼ wavelength back of the antenna and parallel with the principal element. This reflector is normally made about 5 per cent longer than the dipole element, and its use will also improve the directivity characteristic of the dipole. The physical length of the principal dipole element may be determined through use of the following equation:

$$\text{Length (in feet)} = \frac{468}{\text{frequency (in mc. per sec.)}}$$

Each stub of the dipole is made one half the length so determined. The larger the diameter of the material of which the elements are cut, the lower will be the impedance of the antenna at the transmission line terminals and the broader the band pass. In making use of large-diameter metal tubing, the input impedance of the antenna is increased and the Q decreased, tending to broaden the resonance characteristic.

Another low-impedance television receiving antenna is known as the *folded dipole*. One type is illustrated in Fig. 8.85. It comprises a half-

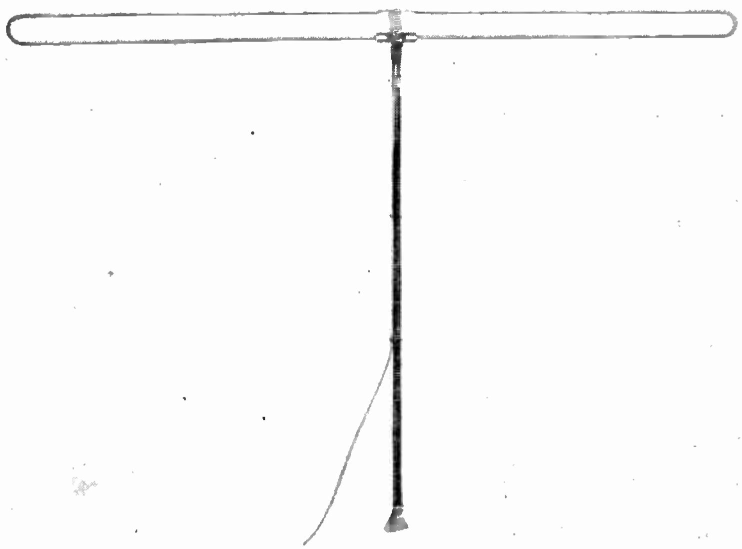


FIG. 8.85 A half-wave folded dipole antenna. (Courtesy of Ward Products Co., Cleveland, Ohio.)

wave dipole with another half-wave element connected between its ends. It is called a "folded dipole," since one half-wave element is folded back across the principal half-wave element. The spacing of the two sections is made a few per cent of the wavelength, a separation of about 3 in. being proper for operation in the television band. The total length of the antenna may be made equivalent to 1 wavelength at the desired operating frequency, and to a close approximation it may be calculated by means of the following equation:

$$\text{Length (in feet)} = \frac{492(N - 0.05)}{\text{frequency (in mc. per sec.)}}$$

where N = the number of half waves standing on the antenna

The terminating impedance of such an antenna is approximately four times that of a simple half-wave dipole, or about 300 ohms. This suggests the use of the new 300-ohm twin-conductor transmission line such as is illustrated in a later section. An impedance discontinuity would result if coaxial cables of the 72-ohm type were used for the antenna transmission line, and this might result in an inefficient transfer of voltage with degradation of the image as viewed at the viewing tube of the receiver. The folded dipole with reflector is illustrated in Fig. 8.86.

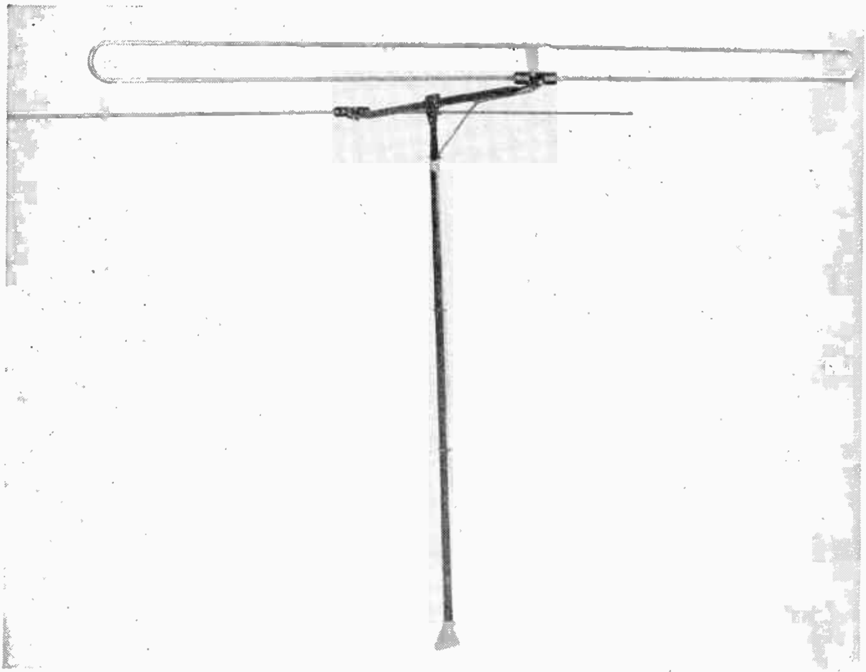


Fig. 8.86 A half-wave dipole antenna with reflector. (Courtesy of Ward Products Co., Cleveland, Ohio.)

Another type of antenna sometimes used in television reception is the *stacked dipole*. It is made up of two or more half-wave dipoles, each with reflector, and with the dipoles and reflectors mounted vertically, one above the other. Such an array provides increased directivity, lower angle reception, broader band pass, and greater energy at the output terminals. Because of the physical size of such an array, it is exceedingly bulky and difficult to mount. Nevertheless, it has found widespread use in fringe areas where the field intensity of the TV station is low.

The use of a horizontally polarized antenna of any of the types described provides a greater signal-to-noise ratio than would equivalent antennas making use of vertical polarization. The reason is that most of the noise that would interfere with picture quality is vertically polarized. Though it is well known that the wave intercepted by a television antenna contains both horizontal and vertical components of energy, most of the energy is in the horizontal plane, since the transmitting antenna is so polarized. The Standards of Good Engineering Practice of the F.C.C. dictate that horizontally polarized antennas be employed at the transmitting station. Practice has shown that horizontally polarized antennas in television provide more distant transmission and reception.

Since television receiving antennas must accept signals that are in line of sight with the transmitting antenna, it follows that the more elevated both antennas can be made, the more energy will be transferred from one to the other. (See the antenna installation in Fig. 8.87.) Sometimes an

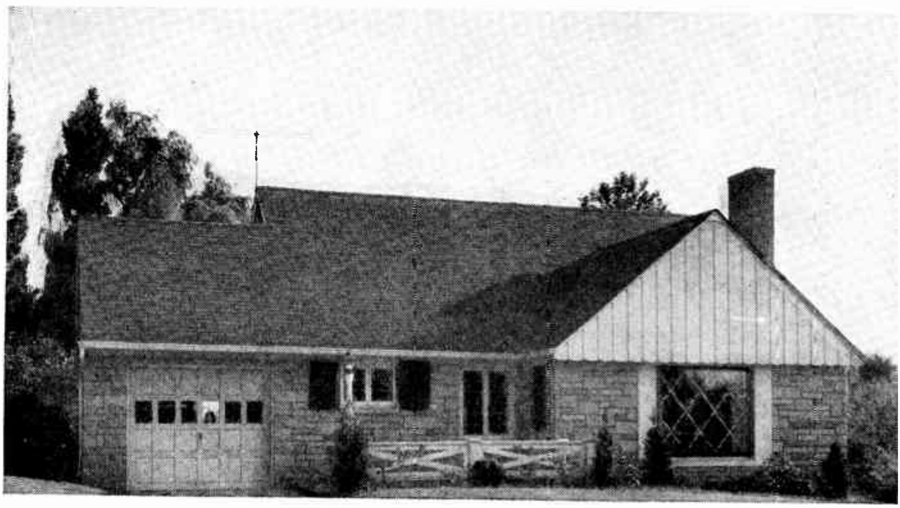


FIG. 8.87 A half-wave dipole antenna suitably mounted on the roof of a dwelling. (Courtesy of Ward Products Co., Cleveland, Ohio.)

intervening building, hill, or other object will prevent reception along a signal path that is in line of sight. Television signals may be reflected by such objects, particularly if the intervening object presents appreciable mass. In many cases the signal will arrive at the receiving antenna by more than one path, resulting in a particularly disagreeable form of phase distortion. The reason for the phase distortion lies in the fact that the reflected signal or signals will arrive somewhat later than the signal by direct line of sight. The result is that a *ghost* appears on the screen of the viewing tube. This ghost has the appearance and takes the form of the principal image, though it is displaced slightly to the right of the predominating image. The signal arriving by means of a separate path, owing to reflection, may be either white or black, depending upon its polarization. The intensity of the ghost image may vary during reception of a program, depending upon the attenuation of the reflected signal along the path to the receiver. At the present state of the art, elimination of ghost images is a difficult and often impossible task. Orientation of the antenna for the minimum ghost image and selection of the optimum antenna location at a particular site are about all that may be accomplished toward reducing or eliminating such phase distortion.

8.35 The Cosgrove Antenna. A special type of receiving antenna, known as the "Cosgrove antenna," has been widely used. This antenna is designed to cover both the high- and the low-frequency television chan-

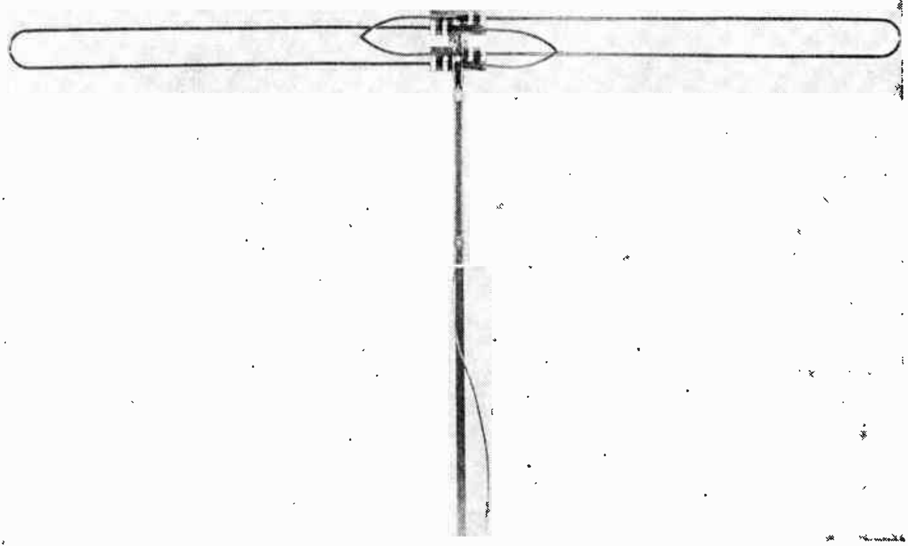


FIG. 8.88 The dual band Cosgrove antenna. (Courtesy of Dielectric Products Co., Jersey City, N.J.)

nels with approximately equal sensitivity, and in addition it covers the FM band around 100 mc. per sec. quite well. Although the antenna has slightly less gain than a standard dipole throughout the lower channels, its broad-band characteristic has made it particularly useful as a pickup device for the combination type of receiver that is designed for both FM and television reception on all 12 channels.

A typical Cosgrove antenna is shown in Fig. 8.88. This antenna was designed for use with receivers having 72-ohm balanced or unbalanced inputs and may be used with RG59/U coaxial cable or with 72-ohm open two-wire polyethylene-bonded line. A broad-band balancing transformer is used when RG59/U cable is employed. This arrangement is being found useful where interference from noise pickup is encountered. Stable and predictable broad-band performance is assured when this antenna is installed with RG59/U coaxial line at a receiver with a nominal input impedance of 72 ohms.

By removing the transformer, the antenna may be used with the two-wire bonded 72-ohm line. Receivers having an input impedance of 300 ohms and making use of the new 300-ohm twin conductor line must be equipped with a balancing transformer and matching pad at the receiver terminus of the line. The Cosgrove antenna has a gain that is slightly less

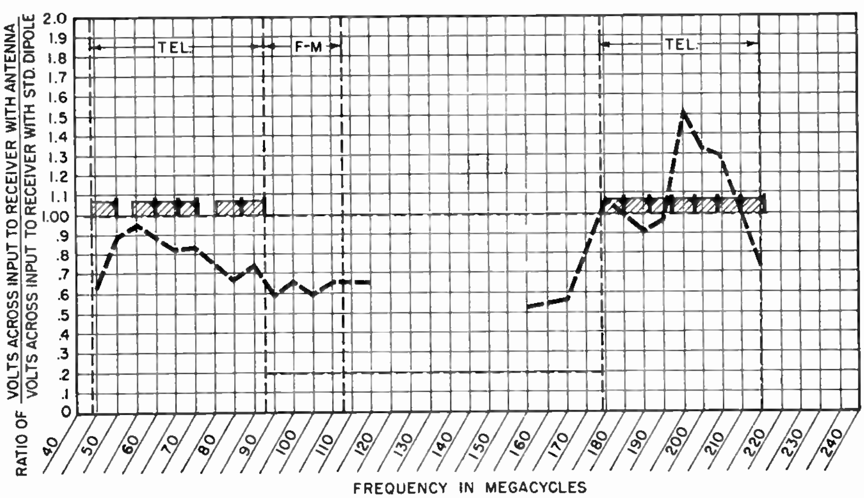


FIG. 8.89

than that of a standard dipole cut to frequency at some center frequency in the region 54 to 88 mc. per sec., but its gain is slightly greater than that of a standard dipole cut to frequency in the higher band that extends from 174 to 216 mc. per sec. The antenna has a fair amount of acceptance in the FM band extending from 88 to 108 mc. per sec.

The field patterns of the antenna are similar to that of a standard dipole in the 54 to 88 mc. per sec. band and unidirective with the main lobe in front of the antenna at the 174 to 216 mc. per sec. band. A reflector attachment may be used to give a good degree of unidirectivity in channels 2, 4, and 5 in the 54 to 88 mc. per sec. region. This permits minimizing difficulties due to multipath signals arriving at the antenna, and more gain is realized. A comparison of the antenna's operation, insofar as delivered signal intensity is concerned, with that of a standard dipole, is indicated in Fig. 8.89. The standing-wave ratio throughout the two television bands is indicated in Fig. 8.90. It may be seen that the standing-wave ratio is acceptable throughout either band. The polar pattern of the antenna at 80 mc. per sec. is shown in Fig. 8.91, while the

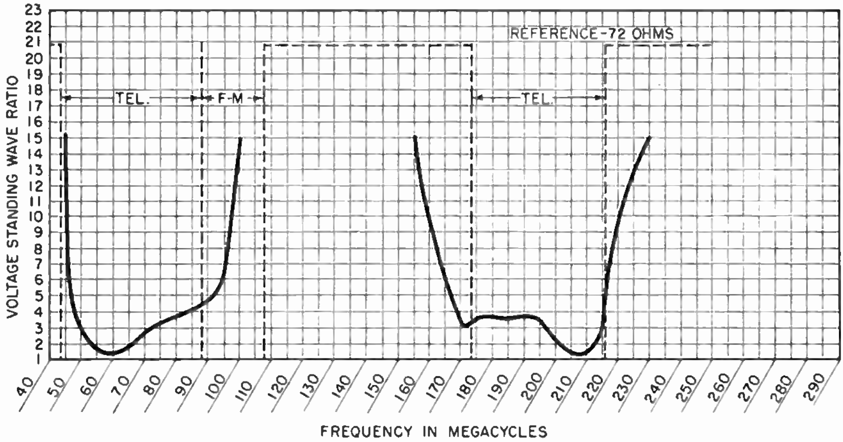


Fig. 8.90

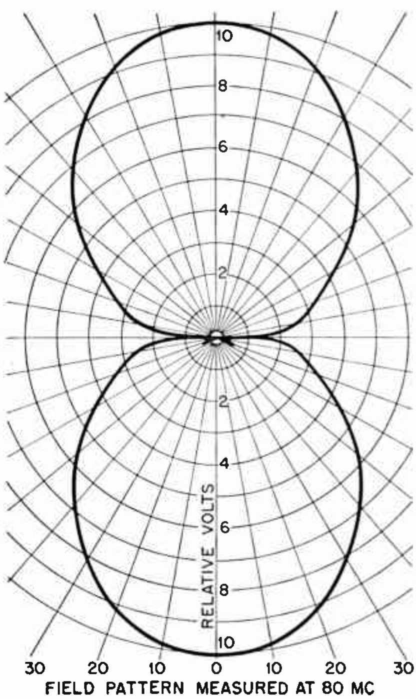


Fig. 8.91

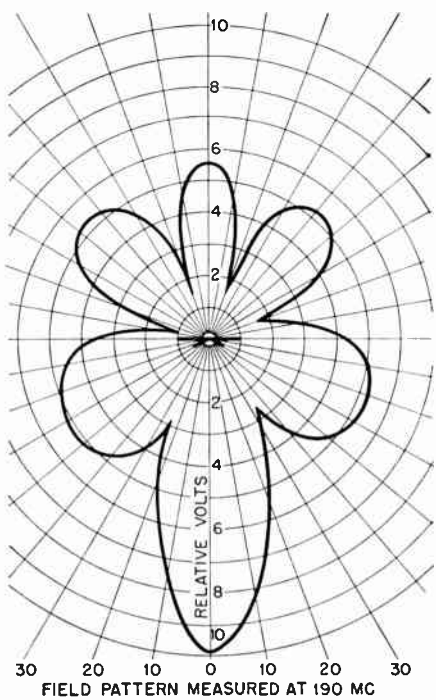


Fig. 8.92

characteristic pattern of the Cosgrove antenna when operating at 190 mc. per sec. in the upper television band is shown in Fig. 8.92.

The antenna is a form of folded dipole array, two sections being used. The "horns" are zero reactive throughout the higher television band, while the longer and more familiar folded dipole section is zero reactive, or nearly so, throughout the lower television band. It is more highly directional at the higher television frequencies than it is when operating throughout the region that includes channels 2 through 6.

Many new and improved types of television receiving antennas have come into prominence recently. Among these is the Channel Master conical antenna, which is of unique design. The "Hideaway" antenna of the same manufacturer is designed for indoor use, and is said to be effective in practically all cases where such antennas are desired.

FIG. 8.93 A short length of coaxial or concentric cable. (Courtesy of American Phenolic Corporation.)

8.36 Coaxial Lines and Cables. Since the pass band in television apparatus extends to well above 4 mc. per sec., it is essential that cables carrying the video signal from one unit of equipment to another be of the concentric or coaxial type. Concentric cable possesses very low distributed capacitance per unit length, and there results, therefore, negligible shunting effect at the higher pass frequencies. Since the outer conductor of the cable effectively shields the inner conductor, stray electrical fields are not likely to be induced. This advantage is very important in instances where low-level video signals must be conducted from one point to another through surrounding electrical fields. A typical length of coaxial or concentric cable is shown in Fig. 8.93. The general construction and appearance of the cable is indicated. It is seen that the inner conductor is surrounded by an outer conductor, with a suitable dielectric or insulating material used to separate one conductor from the other. It is common practice to ground the outer metallic conductor, which results in an unbalanced line.

Most types of coaxial cables used in television employ a dielectric material known as "polyethylene." This synthetic plastic material was originally prepared in Great Britain, but the manufacturing processes adapted to large-scale production were achieved by American engineers during the late war. Fundamentally, polyethylene is a pure hydrocarbon resin, the end result of high-pressure polymerization of ethylene gas.

The resulting dielectric material is highly flexible, practically odorless, and waxy and may be produced in a great variety of colors, although the common form is almost translucent. This synthetic dielectric material is deposited about the inner metallic conductor of a coaxial cable by the familiar extrusion process, which is common in the plastics industry. Polyethylene possesses great toughness and is highly resistant to oils, alkalies, acids, and most chemicals at normal temperatures. It may be used at temperatures below 0°F. or under operating temperatures as great as 180°F. Care must be exercised, however, in applying a soldering iron to make up cable splices, since the material may melt and run. It is nonhygroscopic and may be used under water, in open air, or buried underground. It presents very high resistance to moisture and has an extremely low absorption characteristic. For this reason, it may be used out of doors in television field pickup operations without fear of a short circuit caused by water getting into the cable. It is extensively used to interconnect the television receiving antenna and receiver.

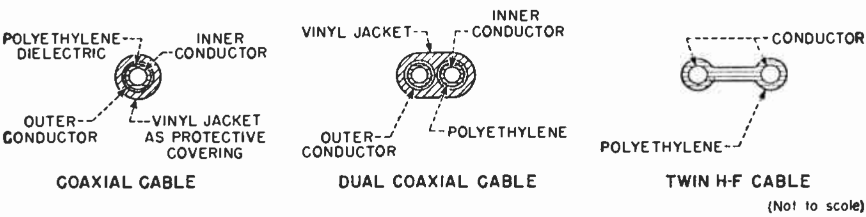


Fig. 8.94

Ordinarily, the inner conductor of a coaxial cable is first entirely surrounded with the polyethylene material; then it is enclosed by either a tight-fitting metallic covering of flexible wire braid, or a vinyl jacket over a serving of wire braid. The latter type of outer covering is most generally encountered in television applications. A drawing indicating the cross-sectional areas of various commercial cables is shown in Fig. 8.94. Of these general types of coaxial cable, the single coaxial type of construction is most generally employed, although the twin-type cable is sometimes used for special purposes, since a balanced wire line results, the impedance being roughly twice that of a single coaxial cable. When operated in this fashion (series-connected as in the common two-wire line), the nominal impedance for commercial types varies from 140 to 300 ohms, depending upon the manufacturer and the type of cable. Since the voltage at the far end of the cable is equivalent to IZ, then, with the current remaining the same, greater amplitude of voltage is developed at the far end as compared with single coaxial cables.

While the single coaxial cable is preferred at the present time for general use about the television station, a balanced two-wire line that comprises two copper conductors embedded in an over-all flat covering of plastic material is employed extensively in receiver installations. Such a cable is not of the coaxial or concentric type, but it is sometimes more desirable from the standpoint of radio-frequency amplifier input design at the receiver. The nominal surge impedance of such a cable is about 300 ohms (illustrated in Fig. 8.95). Its use is certainly practical from the installation standpoint, the twin-conductor cable being secured to walls or other supporting structures by introducing a screw

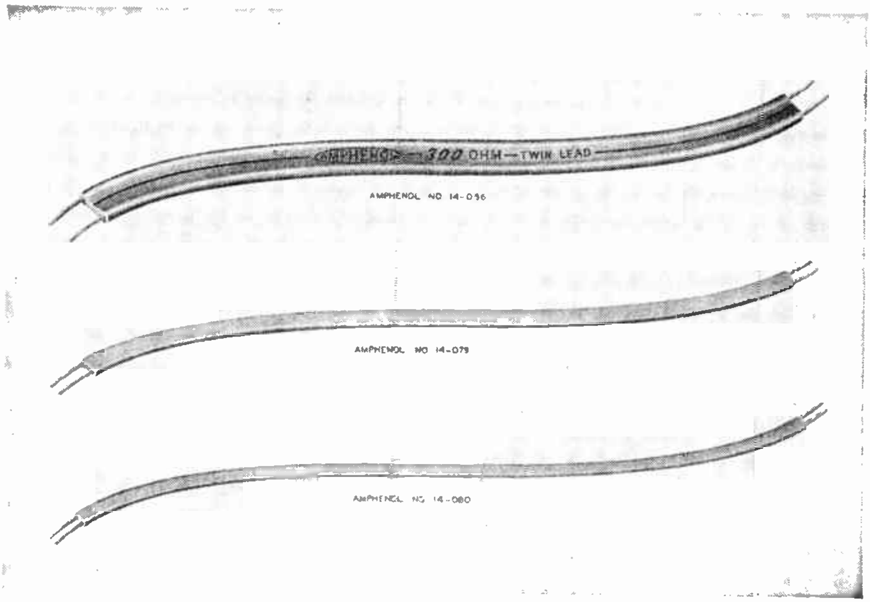


FIG. 8.95 Balanced two-wire TV transmission lines. (Courtesy of American Phenolic Corporation.)

or nail through the polyethylene or other plastic material separating the two metallic conductors. The coaxial type of transmission line is preferred for receiver installations where local interference noise is of such magnitude as to indicate the use of a shielded line. The flat twin-conductor 300-ohm line has less attenuation per unit length, however, as compared with present coaxial types.

A chart indicating a comparison of the general characteristics of some of the coaxial cables encountered in television is shown in Fig. 8.96, and a comparison of the characteristics of polyethylene, low-loss rubber, and steatite is also indicated. In some of the heavier coaxial cables employed in transmitting installations, it becomes necessary to use air as the dielectric material because of the peak voltages encountered, the inner conductor being made of copper tubing and the outer conductor

Characteristics of Typical Television Cables

Army Navy Type no.	Nominal impedance (ohms)	Inner conductor	Diameter over dielectric (inches)	Outer conductor used	Outer protective covering	Over-all diameter (inches)	Weight (pounds per foot)	Maximum operating voltage
RG-8/U	52.0	7/21 AWG (copper)	0.285	Single copper	Vinyl jacket	0.405	0.106	4,000
RG-11/U	75.0	7/26 AWG (tinned)	0.285	Single copper	Vinyl jacket	0.405	0.096	4,000
RG-13/U	74.0	7/26 AWG (tinned)	0.280	Double copper	Vinyl jacket	0.420	0.126	4,000
RG-17/U	52.0	0.188 solid copper	0.680	Single copper	Vinyl jacket	0.870	0.460	11,000
RG-58/U	53.5	20 AWG copper	0.116	Single tinned copper	Vinyl jacket	0.195	0.025	1,900
RG-59/U	73.0	22 copper weld	0.146	Single copper	Vinyl jacket	0.242	0.032	2,300

(Comparison of polyethylene dielectric with other insulators)		Polyethylene	Low loss rubber	Steatite
Dielectric constant	10 mc./sec.	2.3	2.8	6.0
	100 "	2.2	2.7	5.9
	1000 "	2.2	2.6	5.8
Power factor	10 "	0.0002	0.01	0.003
	100 "	0.0002	0.03	0.004
	1000 "	0.0003	0.01	0.005
Dielectric strength (volts per mil.)		850.0	425.0	250.0

(Transmission loss in decibels per 100 ft. of popular types of high frequency lines)	Loss in db. per 100 ft. at 100 mc./sec.
Rubber insulated pair	10.0
RG-59/U and RG-58/U	4.0
RG-8/U	2.25
RG-11/U and RG-13/U	2.0
3/8" Air Dielectric Coaxial	1.25
RG-17/U	0.85

FIG. 8.96

of large-diameter copper pipe. The nominal impedance of such coaxial line usually varies from 51.5 to 75 ohms.

Generally, it is well to avoid splices in coaxial cables of the flexible type most used about the television studio. Splices can very likely result in impedance discontinuities if not made up properly. However, with the use of standard fittings, such as those illustrated in Fig. 8.97, these discontinuities can be kept to the minimum or eliminated entirely. If fittings are not readily available, a manual splice may be attempted. For a cable of the RG11/U type, the manual splice involves removing all the coverings and shields for a distance of about 4 in. from the ends of the two cables to be spliced. Next the polyethylene is cut back for a

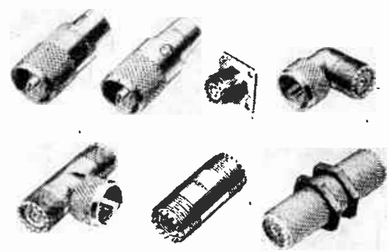


FIG. 8.97 Typical coaxial transmission line connectors and fittings. (Courtesy of American Phenolic Corporation.)

distance of 3 in., and the two inner conductors are spliced in the conventional manner. The splice is then served with narrow varnished cambric tape until the diameter over the splice is built up to the original diameter of dielectric material. A tie wire is then soldered across the enclosed splice to connect the two outer conductors or sheaths, after which a protective covering of varnished cambric and friction tape is applied. The entire splice may then be coated with General Electric glyptol insulating varnish. Too much varnish should not be applied—just enough to ensure a weatherproof coating is all that is necessary.

All coaxial cables used in the television system—in installations at the television studio, control room, transmitter, or to remote points in the system—must be properly terminated with a resistance equivalent to the characteristic impedance of the particular type of cable employed. Therefore, each interconnecting cable, whatever its purpose in the system, must be terminated at its far end when the installation is made. Since the termination, when it is proper, takes the form of a fixed and definite value of resistance, it is not good practice to terminate with a potentiometer for the purpose of controlling signal amplitude at some point in the system. Such practice results in the termination impedance changing as video or other signal levels are varied. The line must first be properly terminated, any level or gain controls being placed in the circuit following the termination and decoupled.

Coaxial cables operating point to point in a television system may be properly terminated through use of a video sweeper or wobbulator, a reliable oscillograph capable of passing through its input amplifier the wide band of frequencies expected to be passed through the line, and a number of precision nonreactive resistors. These resistors should have values approximately equivalent to the expected or assumed impedance of the line. If one variable nonreactive resistor of proper range may be had, this will serve to facilitate the adjustment of the termination.

The video sweeper or wobbulator is connected to the input of the coaxial line, the sweep it produces being observed on the screen of the cathode-ray oscillograph, the Y signal input being connected across the input to the line. The deflection amplifiers of the oscillograph are connected for suitable and convenient deflection of the trace as observed on the screen.

If the coaxial line is not terminated at the far end or is improperly terminated, reflections will be observed along the trace when viewed on the screen of the cathode-ray tube. The nonreactive resistors are now tried, one by one, across the far end of the line, until one is found that results in no reflections back down the line. The reflections will be entirely absent when the terminating resistance is equivalent to the surge impedance of the line. Any reflections due to improper termination will appear as wavelike undulations moving horizontally across the observed trace. It is not good practice to assume that the characteristic impedance as stated by the manufacturer indicates the proper value of terminating resistance to use in every case. Distributed capacitance and inductance in the circuit at the point of termination and reflected impedance or reactance from the circuit to which the cable is connected may result in the expected value varying somewhat. The proper value will in some instances be found quite critical.

BIBLIOGRAPHY

1. Holmes, R. S., W. L. Carlson, and W. H. Tolson, "Experimental Television System, Part III, The Receiver," *Proc. I.R.E.*, November, 1934.
2. Engstrom, E. W., "A Study of Television Image Characteristics," Part II, *Proc. I.R.E.*, April, 1935, p. 295.
3. Keall, O. E., "Correction Circuits for Amplifiers," *Marconi Review*, May–June, 1935, p. 15; September–October, 1935, p. 9.
4. Ardenne, M. von, and D. S. Puckle, *Television Reception*, D. Van Nostrand Company, Inc., New York, 1937.
5. Schroter, F. (ed.), *Fersenhen*, Verlag Julius Springer, Berlin, 1937.
6. Terman, F. E., "Radio Engineering," McGraw-Hill Book Company, Inc., New York, 1937.
7. Beal, R. R., "Equipment Used in Current R.C.A. Field Sets," *R.C.A. Review*, Jan., 1937.

8. Cocking, W. T., "The Television Receiver," *Wireless World*, May 14, 1937, p. 475.
9. Dent, H. B., "Television Aerials," *Wireless World*, May 28, 1937, p. 506.
10. Cocking, W. T., "The Wireless World Television Receiver," *Wireless World*, July 2, 1937, p. 2, to July 30, 1937, p. 98.
11. Tyers, P. D., "Television Scanning and Synchronizing," *Wireless World*, Aug. 6, 1937, p. 115.
12. Maloff, I. G., and D. W. Epstein, *Electron Optics in Television*, McGraw-Hill Book Company, Inc., New York, 1938.
13. Engstrom, E. W., and R. S. Holmes, "Television Receivers," *Electronics*, April, 1938.
14. Preisman, A., "Some Notes on Video Amplifier Design," *R.C.A. Review*, April, 1938, p. 421.
15. Seeley, S. W., "Effects of the Receiving Antenna on Television Reception Fidelity," *R.C.A. Review*, April, 1938, p. 433.
16. Engstrom, E. W., and R. S. Holmes, "Television I.F. Amplifiers," *Electronics*, June, 1938.
17. Engstrom, E. W., and R. S. Holmes, "Television I.F. Circuits," *Electronics*, August, 1938.
18. Benham, W. E., "Aerial Coupling Systems for Television," *Wireless World*, October, 1938, p. 555.
19. Engstrom, E. W., and R. S. Holmes, "Television Synchronization," *Electronics*, November, 1938.
20. Lyman, H. T., "Television R.F. Input Circuits," *R.M.A. Engineers*, November, 1938.
21. Fink, D. G., "Laboratory Television Receiver," *Electronics*, July, 1938, p. 16, to December, 1938, p. 16.
22. Engstrom, E. W., and R. S. Holmes, "Television Deflection Circuits," *Electronics*, January, 1939, p. 19.
23. Kauzmann, A. P., "New Television Amplifier Receiving Tubes," *R.C.A. Review*, January, 1939.
24. A Television Bibliography, *Electronics*, March, 1939, p. 47.
25. "Television Receivers in Production," *Electronics*, March, 1939.
26. Engstrom, E. W., and R. S. Holmes, "Power for Television Receivers," *Electronics*, April, 1939.
27. Cocking, W. T., "Magnetic Television Receiver," *Wireless World*, June 29, 1939, p. 602, to July 20, 1939, p. 57.
28. Mountjoy, G., "Television Signal Frequency Circuit Considerations," *R.C.A. Review*, October, 1939, p. 204.
29. Fink, D. G., *Principles of Television Engineering*, McGraw-Hill Book Company, Inc., New York, 1940.
30. Mountjoy, G., "Simplified Television I.F. Systems," *R.C.A. Review*, January, 1940, p. 299.
31. Strafford, F. R. W., "Ultra-Short Wave Aerial Systems," *Wireless World*, April, 1940, p. 224.
32. Foster, D. E., and J. A. Rankin, "Video Output Systems," *R.C.A. Review*, April, 1941, p. 409.

33. Edwards, B. J., "The Design of Television Receiving Apparatus," *J. Am. Inst. Elec. Engrs.*, Part III, September, 1941, p. 191.
34. Sandeman, E. K., "Coupling Circuits as Band-Pass Filters," *Wireless Engineer*, September, 1941, p. 361; October, 1941, p. 406; November, 1941, p. 450; December, 1941, p. 492.
35. Parr, G., *The Cathode-Ray Tube*, Chapman and Hall, London, 1942.
36. Wells, N., "Short Wave Dipole Antennas," *Wireless Engineer*, May, 1943, p. 219.
37. Sturley, K. R., *Radio Receiver Design*, Part Two: "A.F. Amplifiers, Television and F.M. Receiver Design," Chapman and Hall, London, 1945.
38. Noll, E. M., "Television Sweep Oscillators," *Radio News*, January, 1946.
39. Noll, E. M., "Synchronizing and Separation Circuits," *Radio News*, March, 1946.
40. Ware, Paul, "Inductive Tuning Systems for F.M.–Television Receivers," *Proc. Radio Club Am.*, May, 1946.
41. *The Servicing of Television Receivers* (Manual), Service Division, Philco Corporation, Philadelphia, August, 1946.
42. *Television*, Vol. III (1938–1941), *R.C.A. Review*, January, 1947.
43. *Television*, Vol. IV (1942–1946), *R.C.A. Review*, January, 1947.
44. Stolze, W. J., "Input Circuit Noise Calculations for F.M. and Television Receivers," *Communications*, February, 1947.
45. Wright, A., "Table Model Television Receiver," *R.C.A. Licensee Bulletin LB-704*, Feb. 15, 1947.
46. Friend, A. W., "Television Deflection Circuits," *R.C.A. Review*, March, 1947.
47. Mautner, R. S., and O. H. Schade, "Television High Voltage R.F. Supplies," *R.C.A. Review*, March, 1947.
48. Romero, R. F., "Television R.F. Tuners," *R.C.A. Licensee Bulletin LB-697*, March, 1947.
49. Williams, R. C. G., "The Servicing of Television Receivers," *J. Am. Inst. Elec. Engrs.* (London), March, 1947.
50. Wright, A., "Television Receivers," *R.C.A. Review*, March, 1947.
51. Maurice, R. D. A., "A Double Dipole for Television and F.M.," *B.B.C. Quarterly Review*, April, 1947.
52. Ehret, R. J., "Television Antenna Installations Giving Multiple Receiver Outlets," *Tele-Tech*, June, 1947.
53. Fink, D. G., "Television Receivers in Mass Production," *Electronics*, June, 1947.
54. Chauvierre, M., "R.C.A. Receiver Model 630," *Radio France*, July, 1947.
55. Kaufman, M., "Television Power Supplies," *Service*, July, 1947.
56. "The Philips (Television Receiver) with Screen Projection," *North American Philips Bulletin*, July, 1947.
57. Kronenberg, M. H., "Visual Alignment of Television Receivers," *Radio News*, August, 1947.
58. Maloff, I. G., "Pulsed Rectifiers for Television Receivers," *Electronics*, August, 1947.
59. Thiemann, H., "Theoretical Studies of the Use of Quasi-Insulating Ediphors

high-frequency component of the wave, any discrimination directed against the harmonic frequencies will impart a slope to the leading and trailing edges, and with but slight effect upon the flat top of the wave.

Figure 5.33 illustrates the action that takes place in a typical integrating circuit. It is seen that a square wave of definite width is introduced at the input of the delay circuit. The two components, series *R* and shunt *C*, operate to attenuate the higher-frequency components or harmonics of the wave, resulting in sloped, instead of precisely vertical,

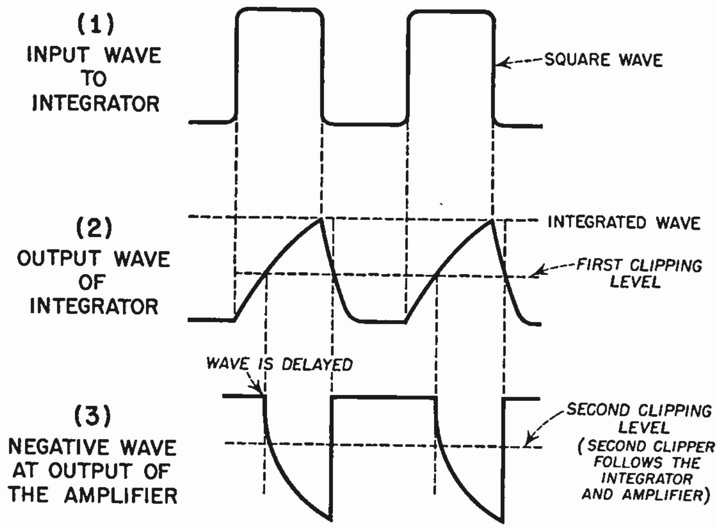


FIG. 5.33 Waveforms which obtain at the input of the integrator, at the output of the integrator, at the output of the amplifier and clipper (in the input circuit of which the integrator is connected), and the clipping level of a succeeding limiter are indicated.

leading and trailing edges. The top of the wave is then twice clipped to produce the resultant square wave of shorter time duration. The sloped wave, after passing through the integrating circuit, is introduced to a conventional clipper, or limiter, circuit, the tube of which is biased to considerably beyond cutoff. The output wave of the clipper takes the form of a peaked wave of negative polarity with the top clipped. This wave is passed to a second limiter where it is clipped again. The output wave at the second clipper takes the form of a flat-topped delayed wave of positive polarity. Fundamentally, the functions of differentiating, integrating, and clipping circuits are to produce the various components of signal required to make up the complete standard television signal. The waves are thus shaped, timed, and controlled with respect to maximum amplitude and duration to satisfy the requirements of the licensing authority.

5.15 Keying, or Gating, Circuits. To produce the synchronizing signal, certain voltage pulses must be keyed in or out. A simple keying circuit is shown in Fig. 5.34. It employs a 6F7 vacuum tube, which incorporates both a pentode and a triode section. The 15,750-p.p.s. signal is applied to the control grid of the pentode section. This signal constitutes the horizontal line-synchronizing impulses. It is desired to blank out these impulses 60 times per second for a duration of X horizontal lines. Therefore, a square wave at 60 c.p.s. having a width of X horizontal lines is fed in positive polarity to the control grid of the triode section of the 6F7. The pentode section of the vacuum tube is of conventional arrangement, except that the screen is reduced to about 30 v. positive.

The output of the triode section will be theoretically equal to μE_s, or equivalent to the product of the signal voltage applied to the grid and the amplification factor of the tube, and the circuit constants are so adjusted that the output of the triode section will be of negative polarity and greater than 30 v. This negative voltage is applied to the screen of the pentode section through coupling capacitor C_3, driving the screen-grid voltage to zero. Thus, operation of the pentode is effectively blocked for the required time duration. Therefore, the 15,750-p.p.s. signal is removed from the output of the pentode for the required number of lines.

To ensure that the 60-p.p.s. signal keys out the horizontal signal properly, both time-delay and width-control circuits are included in the circuit where the pulse has been generated, and before the signal is admitted to the gating circuit.

In television pulse and signal development it is also necessary to key, or gate, in certain pulses. One circuit that permits this operation to be accomplished in the system is shown in Fig. 5.35. It will be noted that the circuit is quite similar to that employed in keying out. If we assume that it is necessary to key in a group of 31,500 p.p.s. during a certain time interval in which X horizontal pulses are to be blanked out, we may obtain some idea of how this circuit functions. With 31,500 p.p.s. applied continuously to the pentode grid in negative polarity, a 60-p.p.s. signal of like negative polarity and of the desired pulse width may be applied to the control grid of the triode section. When these low-frequency pulses of the desired width are applied to the control grid of the triode section, they produce square positive pulses of the reverse polarity (positive) appearing in the plate circuit of the triode section. From the triode plate circuit they are coupled to the screen grid of the pentode section through capacitor C_3. The result is that the screen assumes positive potential during the time interval over which 60-p.p.s. square waves (of positive polarity) are applied to the screen grid, the pentode being opera-

for Large Screen Television Projection," *Sweig. Arch. Angew. Wiss. Tech.*, Vol. 13, May to August, 1947.
60. Wecker, L. S., and T. Gootee, "Build Your Own Television Receiver," *Radio News*, August, 1947.
61. Clark, E. L., "Projection Type Television Receiver," *Radio News*, September, 1947.
62. Zworykin, V. K., "Reflective Optical System for Projection Television," *Radio News*, September, 1947.
63. "Bush Model T91 Television Receiver," *Wireless World*, September, 1947.
64. "Television Receiver Construction," Part 8, *Wireless World*, October, 1947.
65. Norton, F. R., "Television Receiver Laboratory," *Electronics*, March, 1948.
66. Van Lieshout, L. J. A., "New Projection Package for Television," *Tele-Tech*, April, 1948.

REVIEW QUESTIONS

8-1. By means of a block schematic, show the principal circuits of a television receiver.

8-2. What are the requirements of a vacuum tube to make it especially suitable for use as a radio-frequency amplifier of a television receiver?

8-3. Describe (a) low pass filters; (b) high pass filters; (c) band-pass filters. How is the band-pass filter employed to couple radio-frequency amplifiers in the receiver?

8-4. Explain the superheterodyne principle as applied to the television receiver.

8-5. How does the d-c restorer function? What is its purpose in the system?

8-6. (a) Explain the necessity for two intermediate-frequency systems in the conventional TV receiver. (b) What is meant by "carrier difference" TV receiver?

8-7. Describe the operation of the Inputuner (Inductuner).

8-8. Discuss second-detector operation.

8-9. Define the following terms: (a) limiter; (b) double limiter; (c) discriminator; (d) sound intermediate-frequency amplifier.

8-10. (a) What is the separation with respect to frequency between the sound and picture carriers on each TV channel? (b) What is the bandwidth of each channel allocated for TV broadcasting purposes? (c) By what amount is the picture signal reduced at video carrier frequency? (d) Why is the video signal reduced?

8-11. Discuss the coaxial transmission line.

8-12. Describe several types of television receiving antenna.

CHAPTER 9

THE TELEVISION CAMERA CHAIN

9.1 Introduction. Whether the television program originates in the studio or at a remote point (in field operations), the resulting image as viewed in the home, depends to a great extent upon the proficiency of the television camera and its associated units of equipment in picking up and translating light energy from the televised scene into electrical energy with which to modulate the picture transmitter. The television camera chain, as the name implies, includes all those essential units of equipment which, when operated together, yield the standard television signal as defined by the F.C.C. Standards of Good Engineering Practice. In other words, a complete "chain" of equipment is described, each link of which is necessary in the production of a satisfactory picture, synchronizing, and blanking signal.

The television camera chain may be especially designed for either studio or field operations or both. The chain may make use of one of several types of electron tubes for image pickup, the two most general types being the Image Orthicon and the Iconoscope. Of the former, several tubes have thus far been placed in commercial operation. One is the R.C.A. 2P23 Image Orthicon tube, which demonstrates such exceptional sensitivity and stability at all light levels that it has found principal application in camera chains intended for field use. The R.C.A. type 5655 Image Orthicon has excellent sensitivity, though less than that demonstrated by the 2P23, and has been especially developed for applications with artificial illumination, such as exists indoors in the television studio.

The R.C.A. Iconoscope (type 1850–A) is employed both in the television studio camera and in the film pickup camera. Since it possesses less sensitivity than any of the Image Orthicons, it is rapidly being replaced by them in studio use, where lower light levels may be used. However, for the televising of motion-picture film, the Iconoscope has desirable characteristics that make it more suitable for film pickup work, and it remains the favorite camera tube for this application. Many television stations continue to use the Iconoscope in studio camera chains, though there is no doubt that it will be rapidly replaced by the more suitable studio Orthicon.

In Fig. 9.1 two of R.C.A.'s new Image Orthicon cameras are shown with the necessary control and auxiliary units mounted in a desk, ready for operation in the studio. The equipment includes all the necessary equipment making up a complete dual camera chain. For field pickup work, this identical equipment may be set up at the remote point. While the cameras are set up to cover the action that takes place, the control

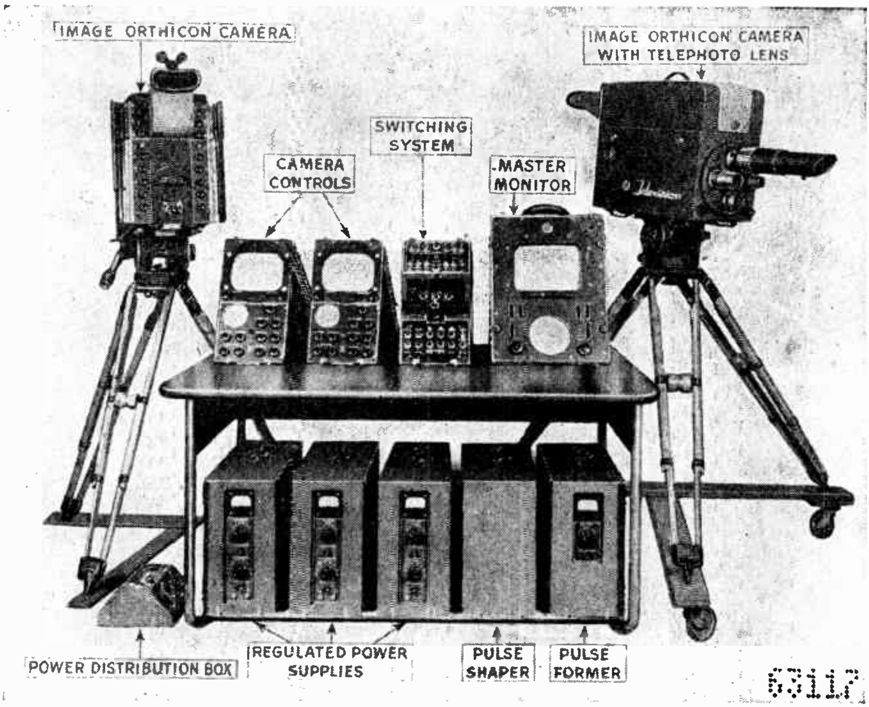


FIG. 9.1 An R.C.A. dual Image Orthicon camera chain. (Courtesy of R.C.A.-Victor.)

and monitoring equipment may be set up as much as 500 ft. from the camera location.

Shown in Fig. 9.1, are two individual camera control and monitoring units (one for each camera), a master signal switching and mixing unit, and a master monitoring unit. The units under the table are the individual camera power supplies, a master power supply, and the synchronizing generator. This last unit is made up of two individual units, namely, a pulse-shaping unit and a pulse-forming unit.

Each camera is mounted on a professional-type camera tripod with pan and tilt-top mechanism. The camera includes an electronic viewfinder, which provides the cameraman with an electronic image of the scene he is televising. A lens turret at the front of each camera mounts a maximum of four lenses, any one of which may be selected by mechanical rotation of the turret.

Camera chains may be made up to employ one, two, three, or four cameras in modern practice. As such, they are described as "single," "dual," "triple," or "quadruple camera chains." Ordinarily, all cameras will eventually work into a common line amplifier, through a suitable signal-mixing and monitoring unit, and a common synchronizing generator will supply the necessary (1) driving, (2) synchronizing, and (3) blanking signals.

9.2 Television Camera Pickup Tubes. Although a special section of the text has been devoted to electron tubes for image pickup, a more detailed study of the Image Orthicon tubes is required before the description of a typical Orthicon camera chain may be attempted. The Iconoscope has already been discussed thoroughly elsewhere in the text (pages 172–197).

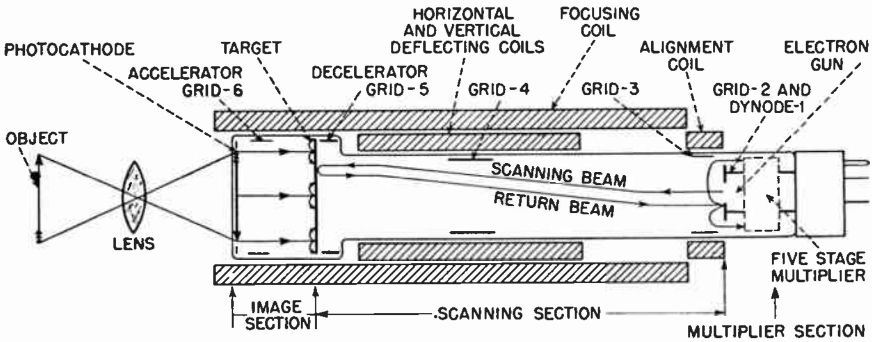


Fig. 9.2

The R.C.A. type 2P23 tube demonstrates very stable performance at all light levels normally encountered in field pickup work, i.e., from bright sunlight, where light levels of several thousand foot-candles may exist, to that of deep shadow, where the light level may be reduced to 1 ft.-c. or less. Compared with the type 1850–A Iconoscope, the sensitivity is approximately 100 times greater. The signal-to-noise ratio of the tube is less than that of other commercially available tubes. Its small physical size (3 in. diameter bulb, 15¼ in. length) has led to the development of lightweight, highly portable field cameras of small size and has made possible the practical use of the telephoto lens in field operations.

Essentially, the type 2P23 Image Orthicon tube has three principal sections: an image section, a scanning section, and a multiplier section. These are shown in Fig. 9.2.

The *image section* makes use of a semitransparent photocathode on the inside of the face plate of the tube. A grid is incorporated next, to provide an electrostatic accelerating field, and a target. This target is in the form of a very thin glass disk, a fine-mesh screen being close-spaced to it on the photocathode side. Magnetostatic focusing and deflection are employed. Focusing is obtained by means of a magnetic field produced by an external coil that surrounds the major portion of the glass envelope and also through variation of the photocathode voltage.

As with the Iconoscope camera, the reflected light from the scene that is being televised is optically focused upon the photocathode by means of a lens system. Under influence of the light energy, the photocathode copiously emits electrons from each illuminated portion of its surface. The electron emission from any given area of the photocathode is proportional to the intensity of the light striking that area. The streams of electrons emitted by the photocathode are focused onto the target by the magnetic and accelerating fields.

When the electrons strike the target, secondary electrons are emitted by the thin glass disk. The secondary electrons are collected by the closely spaced screen mesh, which is held at a fixed potential of approximately 1 v. Thus, stable operation is brought about, since the potential of the glass disk is *limited for all values* of light. A pattern of positive charges, due to the secondary emission already described, and corresponding to the pattern of light reflected through the optical lens system of the camera, is left on the photocathode side of the glass disk. The pattern of positive charges, therefore, is responsible for a complementary potential pattern being set up on the opposite side of the glass disk. This is the side that is scanned.

Unlike the high-velocity beam inherent in the Iconoscope, a *low-velocity* beam of electrons scans this opposite side of the glass disk, i.e., the side opposed to the light source. The beam of electrons is produced by a suitable electron gun, which is a part of the *scanning section* of the tube. The construction and operation of electron guns of all types have been discussed before. The gun of the Image Orthicon is conventional, comprising the following elements:

1. Cathode
2. Control grid (grid 1)
3. Accelerating grid (grid 2)

As has been discussed before, magnetostatic focusing is employed, the low-velocity electron beam (inherent in all Orthicon tubes) being suitably focused into a sharply defined stream of electrons by an external focusing coil, which surrounds the major portion of the glass envelope, as well as by the electrostatic field produced by grid 4.

Grid 5 is the next element to be considered. It functions to shape the decelerating field existing between the 4 grid and the target, resulting in a more uniform distribution of electrons over the target area. In operation of the tube, the forward motion of the electrons is interrupted at the surface of the glass disk; they are forced back and are then focused into a five-stage electron multiplier assembly. Electrons that approach the potential present at certain areas of the pattern on the glass disk do not follow this process, but are deposited from the scanning beam in sufficient number to neutralize the potential pattern on the glass. The glass is thus left with a negative charge on the surface being scanned, a positive charge obtaining on the photocathode side. Owing to conductivity through the glass, these opposed charges neutralize one another in less than the time duration of one picture frame.

A transverse magnetic field, also produced by a coil external of the glass envelope, and located at the gun section of the tube, provides alignment of the beam. Transverse magnetostatic fields provide deflection of the beam, and external horizontal and vertical deflection coils set up these fields. The electrons that are forced back at the target form the return beam, which has been amplitude-modulated by absorption of electrons at the target in accordance with the charge pattern. The more positive areas of the pattern correspond to highlights in the scene being televised. Thus, we have described two of the principal sections of the tube: the image section and the scanning section. A third, the multiplier section, must next have our attention.

The electron multiplier has been shown in some detail in Chap. 4, and in connection with a description of the Farnsworth Image Dissector. The *multiplier* of the Image Orthicon follows the same pattern, though new techniques are involved. The return beam of electrons (leaving the opposite or scanned side of the target) is propelled to the first dynode of a five-stage *electrostatically focused* multiplier. Secondary emission is employed to amplify the signals made up of electron beams. Beam electrons striking the surface of the first dynode produce other secondary electrons, their quantity being a function of the energy with which the propelled electrons bombard the dynode surface. These secondary electrons are directed to a second dynode where more secondary electrons are produced, and so on. The purpose of grid 3 is to provide a more efficient collection by dynode 2 of secondary electrons due to impact of the original beam at dynode 1. This same multiplying action proceeds throughout each stage of the five-stage electron multiplier. The result is that the stream of electrons are constantly increased in magnitude until those emitted by dynode No. 5 (the last stage) are collected by the highly positive anode, where a suitable current is made use of in the external circuit. The amplification factor of the electron multiplier is said to be approximately 500 and results in an improved signal-to-noise ratio. The limiting noise in the 2P23 Image Orthicon is that of the original electron beam multiplied by the amplification factor of the electron multiplier.

The signal output voltage across a suitable load resistor, across which the tube operates, changes in the positive direction as the beam moves from a less positive to a more positive portion of the target, this resulting in highlights in a televised scene producing a signal of positive polarity across the load resistor. Typical operating conditions for the 2P23 Image Orthicon are given in Table 6.

TABLE 6

Photocathode voltage	−300 v.
Grid 6 voltage (80% of photocathode voltage)	−240 v.
Target voltage	0 v.
Grid 5 voltage	25 v.
Grid 4 voltage	125 v.
Grid 3 voltage	210 v.
Grid 2 and dynode No. 1 voltage	210 v.
Grid 1 voltage	−45 v.
Dynode 2 voltage	525 v.
Dynode 3 voltage	850 v.
Dynode 4 voltage	1,150 v.
Dynode 5 voltage	1,450 v.
Anode voltage	1,500 v.
Target temperature range	35–40°C.
Min. peak-to-peak blanking voltage	10 v.
Field strength at center of focusing coil	60 gausses
Approximate focusing-coil current	60 ma.
Deflecting-coil current:	
Horizontal (peak to peak)	500 ma.
Vertical (peak to peak)	230 ma.
Alignment-coil current	0–45 ma.

The type 5655 Image Orthicon is in many respects similar to the 2P23. Its physical dimensions are identical, as is its electrical operation. It has, however, been particularly designed for use under conditions of artificial illumination such as will be found in the television studio. It employs a photocathode which demonstrates a nearly balanced spectral response for all colors throughout the visible range, although the tube is more sensitive in the violet-blue-green region. Colors are therefore reproduced in a television system with a more accurate gradation of black through grays to white. It may, in most cameras, be used interchangeably with the 2P23 (outdoor tube) with possible minor adjustments of external circuit potentials. Typical operating conditions for the 5655 tube are given in Table 7.

Wider element spacing is used in the 5655, as compared with the 2P23, which leads to its decreased sensitivity in comparison with the outdoor-type tube. Its resolution capability is greater than 500 lines at the center of the picture, and a following video preamplifier must be employed which has response of better than 1 mc. per sec. per 100 lines

TABLE 7

Photocathode voltage	−300 to −500 v.
Grid 6 voltage	−240 to −400 v.
Target voltage	0 v.
Grid 5 voltage	0–100 v.
Grid 4 voltage	160–240 v.
Grid 3 voltage	225–330 v.
Grid 2 and Dynode 1 voltage (for picture cutoff)	−35 to −100 v.
Dynode 2 voltage	600 v.
Dynode 3 voltage	800 v.
Dynode 4 voltage	1,000 v.
Dynode 5 voltage	1,200 v.
Anode voltage	1,250 v.
Anode current	100 μa.
Target temperature range	45–60°C.
Ratio of peak-to-peak highlight video signal to r.m.s. noise current	70
Minimum peak-to-peak blanking voltage	10 v.
Field strength at center of focusing coil	75 gausses
Focusing-coil current (approx.)	75 ma.
Deflecting-coil current for recommended R.C.A. deflection-coil assembly:	
Horizontal (peak to peak)	625 ma.
Vertical (peak to peak)	290 ma.
Alignment coil current	0–30 ma.

of anticipated resolution. Minimum illumination required on the studio scene will range from 20 to 60 ft.-c., although higher illumination is recommended so that the camera lens may be stopped down to obtain greater depth of focus. Some shading is recommended with both the 2P23 and 5655 to obtain a more uniformly shaded picture. Ordinarily, the introduction of a saw-toothed waveform at horizontal or line frequency (after the video preamplifier) is all that is required. Some provision must be made for controlling both the amplitude and polarity of the saw-toothed signal.

9.3 The Du Mont Image Orthicon Camera Chain. Allen B. Du Mont Laboratories has designed, manufactured, and operated complete camera chains employing both the 2P23 and 5655 Image Orthicon pickup tubes, and considerable experience has been gained with these recent types of electron tubes for image pickup. Since all the camera chains manufactured by several companies are, for the most part, similar in all principal respects, the author has chosen to describe the Du Mont equipment, with which he is more intimately concerned. Figure 9.3 indicates a block schematic of the dual, triple, and quadruple Du Mont Orthicon camera chains. It will be noted that the addition of other cameras merely involves the addition of five units of equipment for each additional camera included. The basic dual Orthicon camera chain includes the following individual units of equipment:

1. Image Orthicon pickup head
2. Electronic view finder
3. Pickup auxiliary
4. Low-voltage power supply
5. Image Orthicon control and monitor unit
6. Mixer amplifier and monitor
7. Distribution amplifier and low-voltage supply
8. Portable synchronizing generator

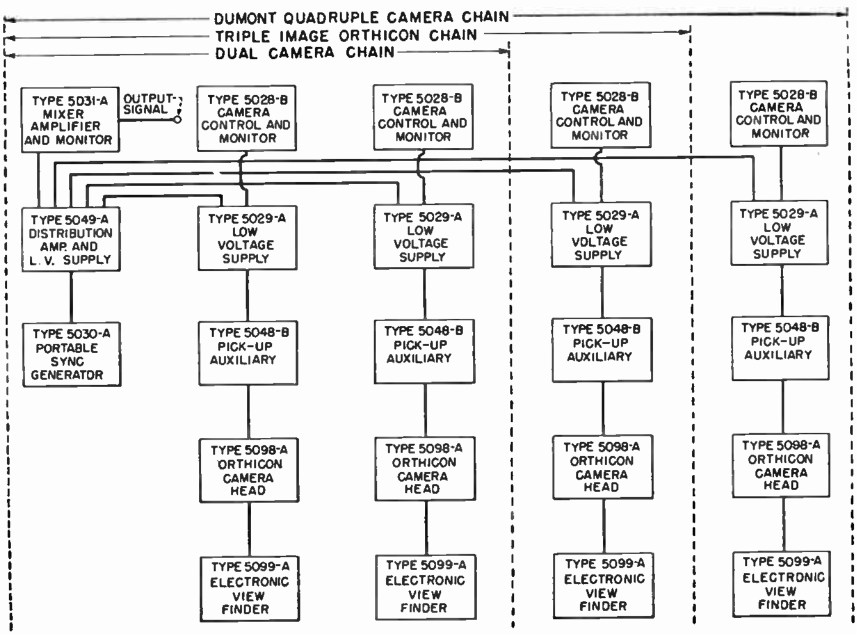


FIG. 9.3

For each additional camera added, to make up a triple or a quadruple camera chain, the first five units listed above must be added. It will be noted that one synchronizing generator and one distribution amplifier and low-voltage supply, as well as the mixer amplifier and monitor, are common to each chain, whether dual, triple, or quadruple. The reason for this will become evident as the discussion progresses.

Whether a dual, triple, or quadruple chain will be used depends, primarily, upon the pickup to be televised. The dual chain has found the widest acceptance and is satisfactory for all but the most unusual pickup problems that are encountered.

9.4 The Camera and Electronic Viewfinder. The type 5098–A Image Orthicon pickup head and type 5099–A electronic viewfinder are shown in Fig. 9.4, with the camera tilted forward to show the upper portion of the camera tripod, the Mitchell friction pan and the tilt-top mechanism.

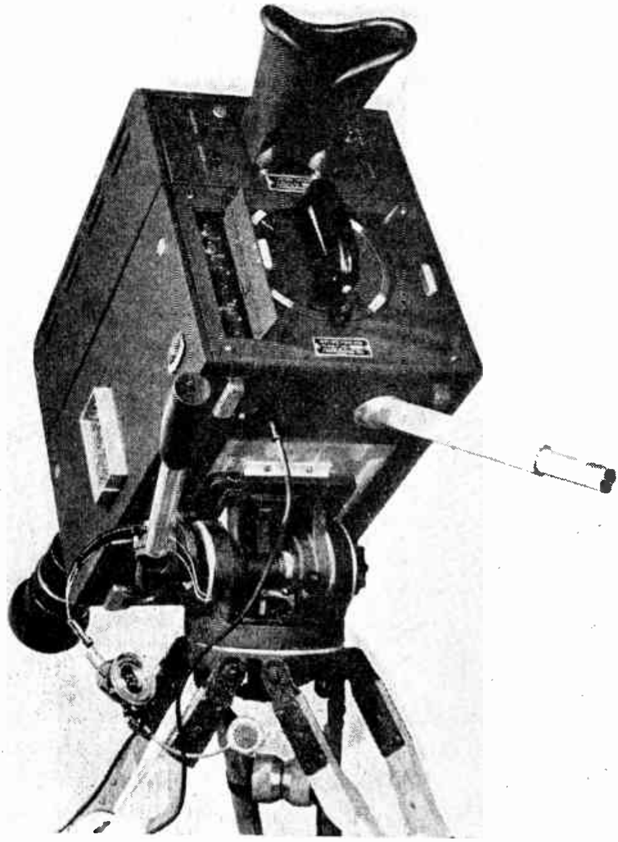


FIG. 9.4 Du Mont Orthicon pickup head with electronic viewfinder attached (rear view). (Courtesy of Allen B. Du Mont Labs., Inc.)

This camera has already been shown in Chap. 1, which should now be referred to in order that the lens turret and front of the camera may be examined. Figure 9.5 presents a view of the camera head proper with electronic viewfinder detached.

The camera head proper includes a video preamplifier, blanking multivibrator, and horizontal and vertical deflection circuits. The preamplifier employs six stages, the type 6AK5 tube being employed because of its high figure of merit as a video amplifier. The preamplifier makes use of the feed-back principle, which reduces distortion, improves the signal-to-noise ratio, and eliminates high-frequency peaking problems. As a matter of fact, the use of feedback results in gain, bandwidth, and transient response similar to that which would be obtained with conven-

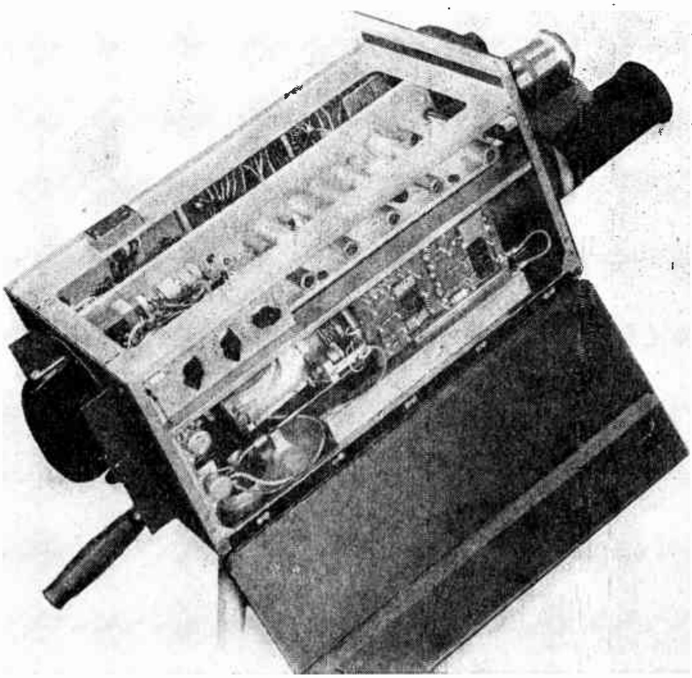


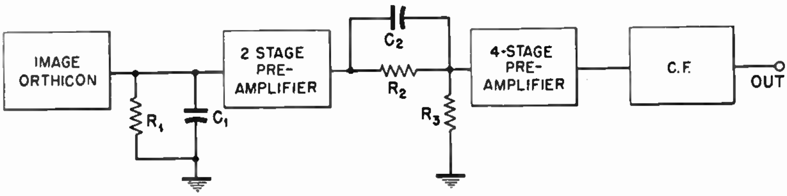
FIG. 9.5 Du Mont Orthicon camera head with electronic viewfinder detached (left-side and top views). The covers are removed for inspection of the circuits. (Courtesy of Allen B. Du Mont Labs., Inc.)

tional high-frequency shunt compensation. The six stages of amplification provide sufficient reserve gain for video equalization of long camera cables when they are required in remote or mobile operations.

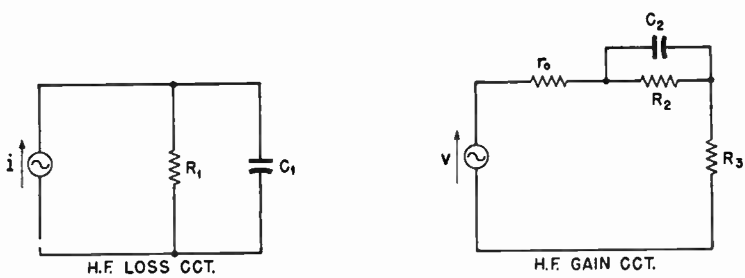
In the peaking circuit employed in the video preamplifier, a unique circuit arrangement has been used and has proved practical under actual operating conditions. This circuit is shown basically in Fig. 9.6. If $RC = R_2C_2$, then flat frequency response, limited only by the bandwidth of intervening amplifiers, is obtained. The frequency response will drop 3 db. at f_o (upper pass frequency) where

$$f_o = \frac{1}{2\pi C_2(R_3 + r_o)}$$

and where r_o is the equivalent internal resistance of the constant-voltage generator represented, in this case, by the video amplifier driving the peaking network. If R_3 is shunted by a finite capacitance, then it may be required that R_3 be shunt-peaked so as to make it appear resistive over the desired frequency range. With use of the 2P23 tube, the bandwidth should be 1 mc. wide for each 100 lines that it is desired to resolve in the reproduced image.



FUNDAMENTAL VIDEO CIRCUIT



THEORETICAL ELECTRICAL EQUIVALENT OF THE BASIC VIDEO CIRCUIT

Fig. 9.6

A blanking signal must be supplied at the camera, and this is obtained by means of multivibrators incorporated in the camera unit. Since it is impossible to blank at the Image Orthicon control grid, which would result in a white signal during the blanking interval, retrace lines are eliminated from the picture itself, the signal thereby corresponding to black during the blanking interval. The blanking at the camera is made more narrow than that set by R.M.A. as the final standard blanking width.

It is fortunate that deflection circuits for the Image Orthicon are for all practical purposes identical with those employed for 50-deg. cathode-ray tubes using magnetostatic deflection. A 6BG4 or 807 is employed as a sweep driver, a type 6AS7G serving as a horizontal damping tube (see Fig. 9.7). A type 6J6 vacuum tube is employed in the vertical deflection circuit. Its output is transformer-coupled. Du Mont has utilized a powdered-iron-core horizontal-deflection (output) transformer, which makes available sufficient voltage overshoot to develop the +1,500 v. required for the electron multiplier section of the Image Orthicon. A type 8016 rectifier is used to provide this high d-c potential. Horizontal and vertical driving signals are provided to the camera through two 75-ohm coaxial cables. A type 6J6 cathode follower at the camera preamplifier output provides a 1-v. peak-to-peak (black negative) signal to the Image Orthicon control unit and monitor.

The camera may be located at a pickup point as great as 1,000 ft. removed from the control apparatus through use of a camera auxiliary

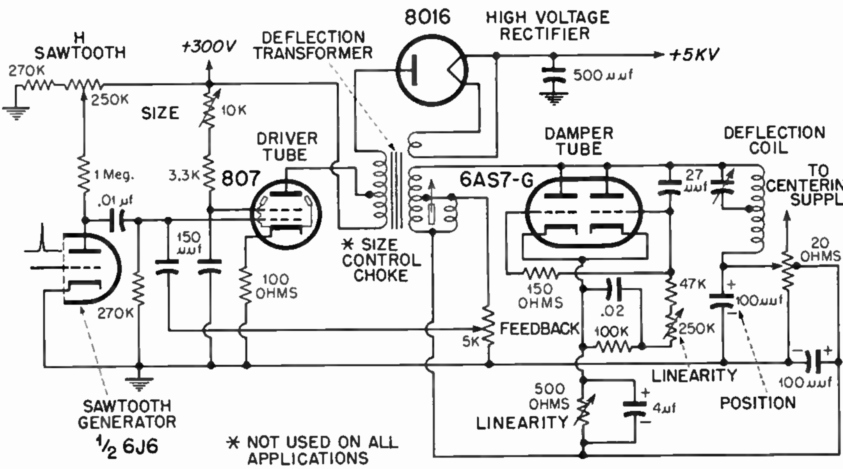


Fig. 9.7

unit (to be later described), by means of which compensation for cable length is effected. The pickup auxiliary may be located at a maximum of 30 ft. from its associated camera.

The type 5099–A electronic viewfinder and type 5098–A Image Orthicon pickup head are in a single housing and are electrically connected, one with the other, by means of a concealed plug and socket arrangement. The two units may readily be separated for servicing or inspection. At the right rear lower corner of the camera assembly is a rotating handle which provides two operations. It serves, first, to tilt or pan the pickup head. Its second function is to operate, through remote control, focusing of the selected camera lens at the turret. Rotating this handle clockwise or counterclockwise operates, by means of a mechanical drive system, a gear box associated with the selected lens at the turret. This gear box serves to focus the lens. Iris control of lens aperture is provided through use of a knob below the turret control handle.

The chassis, upon which electronic circuits are situated, is mounted behind push-lock side panels. When the side panels are removed, all parts become visible for inspection or servicing. The lenses are mounted on a highly refined four-position lens turret. Rotation of the turret is controlled by means of a pistol-grip handle at the rear center of the

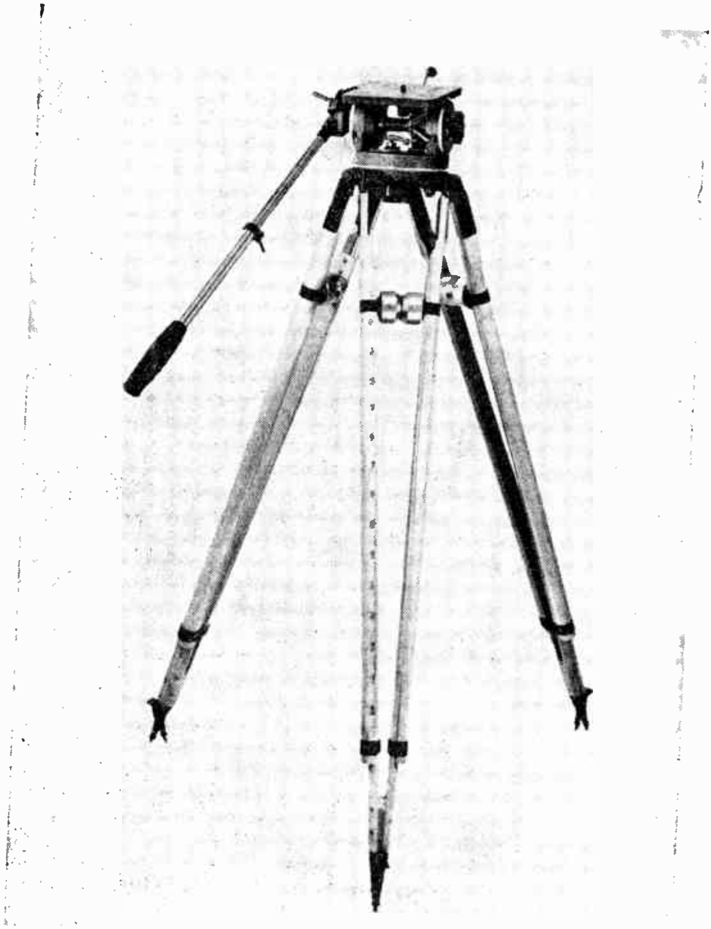


FIG. 9.8 The Mitchell professional camera tripod upon which the camera and viewfinder are mounted. (Courtesy of Allen B. Du Mont Labs., Inc.)

camera. Each lens may be brought into place and locked precisely into position. The camera pickup head and electronic viewfinder are mounted on a professional Mitchell camera tripod, as shown in Fig. 9.8.

The electronic viewfinder brings the televised image directly before the eyes of the cameraman on the fluorescent screen of a 5-in. 5FP4 cathode-ray tube (see Fig. 9.9). A type 6AS6 coincidence tube is used to amplify the camera output video signal to sufficient level for application to the control grid of the type 5FP4 viewing tube, and to supply sufficient blanking for the view-finder tube by suppressor-grid insertion. It will be recalled that blanking applied at the camera was made more narrow than R.M.A. standard and not as wide as the final blanking provided in the system. The deflection circuits for the 5FP4 view-

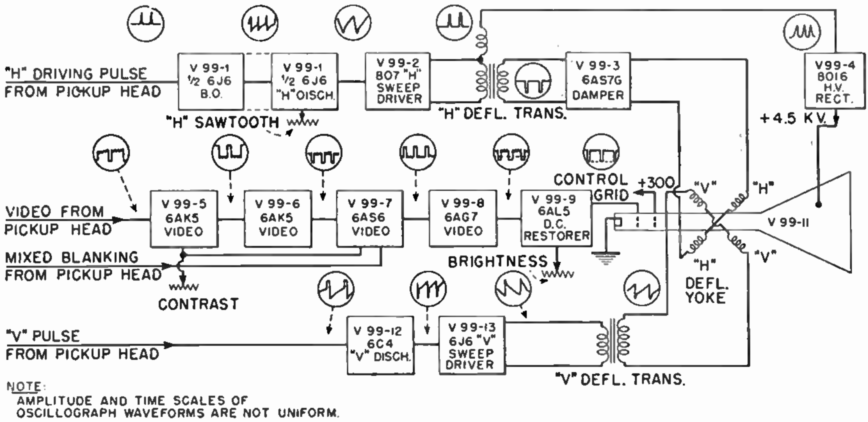


FIG. 9.9 Block schematic diagram of the type 5099-A electronic viewfinder.

finder monitoring tube are in many respects similar to those employed at the pickup tube. The +5,000-v. anode potential for the tube is provided by rectification of the horizontal overshoot voltage and from the horizontal deflection circuit.

A rubber-faced viewing shield extends from the rear of the viewfinder, completely shielding the screen of the monitoring tube from ambient light. Suitable brightness, contrast, and focusing controls for the cathode-ray tube, as well as other essential controls, are all placed at the rear of the camera for access to the operator. Magnetostatic deflection and

TABLE 8

Lens	Focal length	f/No.	Angular field, deg.
Wide angle	50 mm. (2 in.)	1.9	35 × 27
General	135 mm. (5.3 in.)	3.8	13 × 10
Telephoto	510 mm. (20 in.)	5.6	3.8 × 2.8

focus of the monitoring tube are used. Lens equipment that might be used with this camera to provide adequate coverage of any ordinary pickup is listed in Table 8.

Camera cables interconnecting the camera with other essential units make use of connectors of Du Mont design. They provide connections of coaxial as well as other electrical cable as shown in Fig. 9.10.

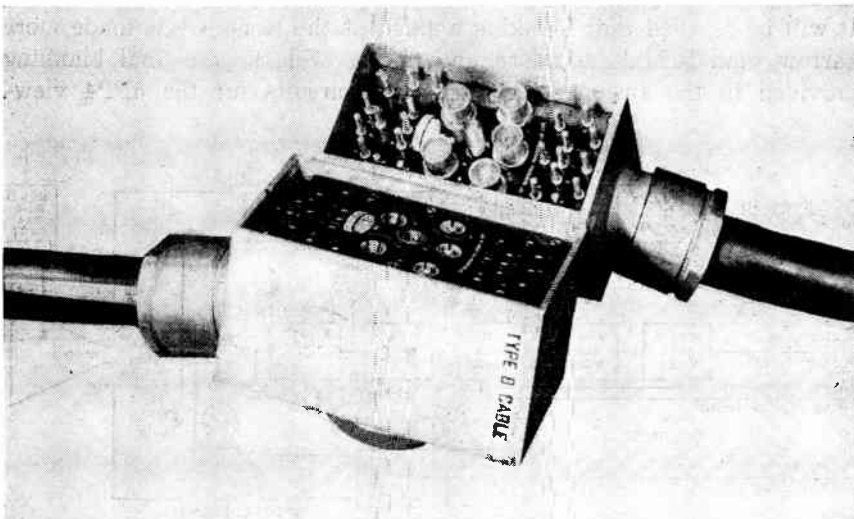


FIG. 9.10 Camera-cable connectors of Du Mont design. (Courtesy of Allen B. Du Mont Labs., Inc.)

9.5 The Camera Pickup Auxiliary. The Du Mont type 5048–B pickup auxiliary is shown in Fig. 9.11. It is connected electrically between the camera pickup head and the camera control and monitor

FIG. 9.11 Du Mont type 5048-B pickup Auxiliary. (Courtesy of Allen B. Du Mont Labs., Inc.)

unit. Although it is an auxiliary unit to the camera, as the name implies, it may be situated as distant as 30 ft. from the camera, thus providing freedom of camera movement on location. It provides circuits which can be incorporated in the camera proper, but which have been placed in a separate housing in order to reduce camera size and weight. Basically, it includes the following circuits:

1. The necessary circuits for separating the horizontal and vertical driving pulses.

2. A regulator circuit to provide precise regulation of the d-c power being supplied to the camera.

3. A delay circuit, incorporated to delay the horizontal driving pulse, to compensate for time delay in long cable runs between the camera-control position and the camera.

4. A circuit for regulating focus-coil current for the Image Orthicon.

In considering (1), above, the Du Mont synchronizing generator supplies mixed horizontal and vertical driving pulses to the camera-deflection circuits. This method is employed to reduce the number of coaxial cables required to be included in the principal cable connecting the camera-control position with the camera. The camera pickup auxiliary includes a circuit for separating these pulses, after which they are passed to the camera-deflection system. There are several methods by which driving-pulse separation may be achieved. These methods are described as "amplitude," "width," and "pulse coding" methods. Width separation is incorporated because of economy of circuit design as well as stability. The horizontal driving pulses are approximately 1 μsec. in width, while the vertical driving pulses are approximately 25 μsec. wide, measured at 50 per cent points. Integration and differentiation circuits are employed to separate these pulses at the camera auxiliary unit, after which they follow along coaxial cables to the deflection circuits of the camera pickup head. The vertical driving impulses are obtained directly from the cathode output circuit of a blocking-tube oscillator, while the horizontal impulses are delayed by suitable means.

The delay required is a function of camera cable length and must be made adjustable. As the horizontal driving pulses are generated at the synchronizing generator, they occur at a point midway between horizontal sync pulses, which is a time phase believed proper for equalizing impulses. Thus, half-line driving pulses arrive at the camera auxiliary unit. Here, they are delayed by an amount equivalent to one half line minus the cable delay to be compensated for. A multivibrator delay circuit, the time of delay of which is continuously variable from 25 to 32 μsec., is made use of at the auxiliary unit. This connection brings about the loss of one active line as compared with an undelayed system. The refined circuit, shown in Fig. 9.12, has been described by Leonard Mautner.*

Pulses of negative polarity at the suppressor grid of V_1 operate to

* Mautner, Leonard, "Portable Camera Chain for Field Use," *Tele-Tech*, May, 1947.

cut off the plate current of the tube. This vacuum tube constitutes the normally operative section of a triggered multivibrator. As the plate current of V_1 increases, it brings about an increase in the magnitude of plate current at V_3a. V_3a is the normally inoperative section of the triggered multivibrator. V_1 is cut off and V_3a is made operative through regeneration. The negative excursion of the grid of V_1 is limited by a

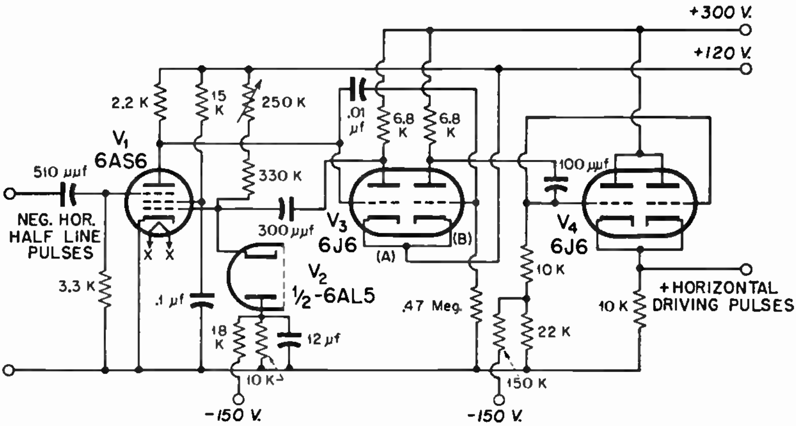


FIG. 9.12

diode V_2, which functions effectively to stabilize the delay time of the multivibrator for incremental changes in operating characteristics of V_3a. Delay time is essentially determined by the time constant in the control-grid circuit of V_1. The rear edge of the resultant gate on the plate of V_1 is increased in magnitude, to be selected by a cathode follower V_4. A positive impulse which can precede the actual synchronizing impulses by a time constant as great as 5 µsec. is then transmitted through coaxial cable from the cathode of V_4 to the camera unit.

A type 807 vacuum tube is electrically connected in series with the focus coil at the Image Orthicon and the +300 d-c supply at the camera auxiliary unit. The focus-coil current is then capable of fixation at a constant of value through adjustment of the cathode bias of the 807. This has been deemed necessary in the original design (according to Leonard Mautner) because of ambient gradient at the focus coil about the envelope of the Image Orthicon, such a change bringing about incremental changes in focus current.

The low-voltage power supply unit supplies +425 and +260 v. to the camera auxiliary unit. These voltages are then reduced in magnitude to +300 and +120 v. for relay to the circuits associated with the camera proper. A voltage-regulation circuit in the pickup auxiliary unit provides an extremely stable voltage supply. The internal resistance of the +120-v. supply to the camera preamplifier is less than 0.05 ohm, the ripple content being less than 1 mv. r.m.s.

A switch is provided on the face of this unit to select primary transformer tabs, enabling the unit to be used at practically any average location with suitable adjustment for line-voltage variation. Jacks from eight key circuit inspection points are located on the front panel of the unit and prove useful in isolating and correcting circuit or operating irregularities.

FIG. 9.13 Du Mont type 5028-B Image Orthicon control and monitor unit. (Courtesy of Allen B. Du Mont Labs., Inc.)

9.6 The Camera Control and Monitoring Unit. The Du Mont type 5028–B Image Orthicon control and monitor unit is shown in Fig. 9.13. This unit includes a 7 in. diameter Du Mont 7BP4 picture-monitoring tube, so that the image at this point in the system may be previewed by the control operator before mixing and switching. It incorporates all the circuits incidental to the operation of such a monitor. Also, a 3-in. cathode-ray waveform monitor (3JP1 tube) is provided, which is normally operated to inspect (continuously) the video waveform at either line or frame frequency. This monitor may be switched so that its input is connected to either VIDEO SIGNAL IN or VIDEO SIGNAL OUT. When the waveform monitor is switched to the TEST position, it operates as a cathode-ray oscillograph, and the vertical amplifier input of the monitor may then be connected to external signals or waves for investigation during troubleshooting.

A video amplifier is included in the unit, and the camera preamplifier feeds into it. This amplifier is provided with line-to-line clamping, blanking, and sync insertion or mixing facilities, provided that single camera operation is desired, and a mixer amplifier and monitor is not included in the desired system. Remote adjustment of image orthicon camera pickup tube potentials is also made possible at the camera control unit.

The video picture monitor, already broadly discussed, includes a video amplifier capable of grid modulation of the 7BP4 tube. Deflection circuits for this tube are also a part of the unit, centering current for the magnetic deflection yoke being obtained from a low-voltage, high-current power supply which incorporates a selenium rectifier. The suppressor-grid voltage of a type 6AS6 pentode in the video amplifier is varied to bring about contrast control of the system.

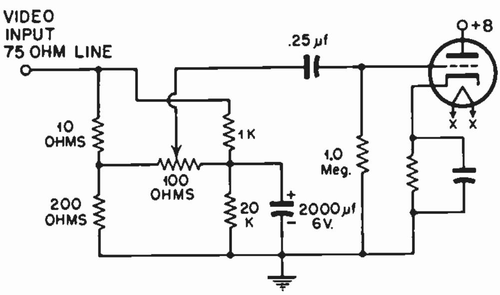


FIG. 9.14

The high potential for the 3JP1 waveform monitor cathode-ray tube, is obtained from the video-monitor deflection system, a sweep flyback supply making available +3,000 v. for this purpose. Two complete lines or frames may be viewed on the screen of this monitor, a multivibrator-triggered sweep being made use of.

In providing control of potentials at the Image Orthicon, the following results are obtained:

1. Photocathode focus of the electron image in the tube's image section.

2. Variation of beam current through adjustment of G_1 potential.

3. Control over electron-beam focus in the scanning selection of the pickup tube.

4. Adjustment of blanking through control over the d-c potential at the target mesh.

A pedestal control makes possible adjustment of pedestal level, and the contrast control has already been described.

The input attenuator is unique and worthy of special consideration. This circuit is shown in Fig. 9.14. While the attenuator is of the low-impedance type, the cathode follower driving the line does not provide d-c isolation. This condition necessitates provision in the circuit design to eliminate the possibility of the d-c potential difference occurring across the input potentiometer from being transmitted to the video amplifier, particularly when the control operator must make fast changes in gain settings. Without such provision, the transient produced by the fast-gain chain might be of sufficient magnitude to paralyze the video amplifier stages that follow. Such transients result in picture bounces, or bops.

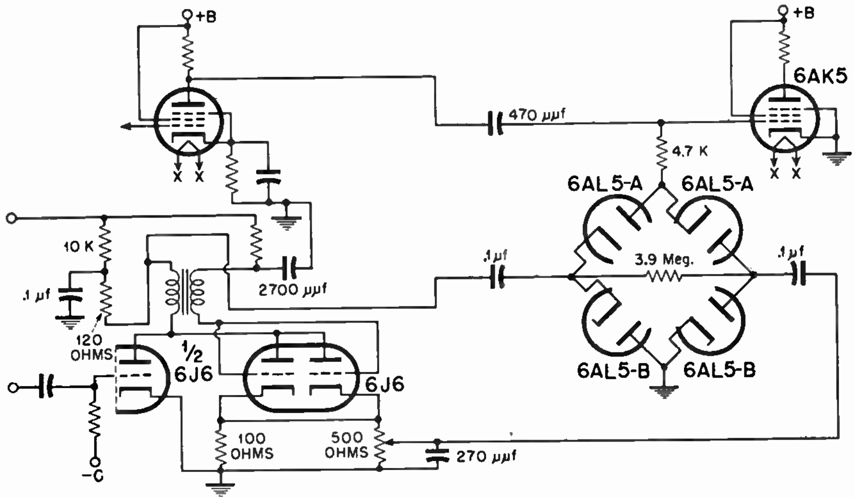


FIG. 9.15

In the attenuator used in the Du Mont system, the d-c potential at both extremes of the attenuator winding remain identical, even when the wiper is rapidly moved across the winding. Thus, no transient, resulting in a "bounce," can be developed at this point in the system. The circuit, while effective, makes use of 95 per cent of the input gain, and there occurs a loss of 1 db. in signal voltage.

A unique line-to-line clamping circuit is utilized in the camera control and monitor unit. It is known as the "four-diode clamp" and is shown in Fig. 9.15. Its merits are those of reducing balancing problems, operation at low impedance, and the taking of no power from the circuit being clamped. Through clamping to the black level available during the time duration of the blanking interval, the control operator is not required to make frequent adjustments of the pedestal control. This is the black level present during the blanking interval and is roughly equivalent to absolute black level. Hum is also removed from the system by means of the clamper, and greater low-frequency response can be employed in the design of video amplifiers preceding the clamp.

The operation of the clamp circuit is quite simple. The three half sections of the 6J6 vacuum tubes act as a trigger tube and horizontal blanking oscillator. The positive and negative current impulses obtained from the low resistances in the plate and cathode circuits provide the necessary driving impulses for the clamp. When these driving impulses obtain, the four diode sections conduct, thereby producing a rapid-discharge path for the 470-$\mu\mu$f. coupling capacitor. The diodes do not conduct during the time interval that occurs between driving impulses, and the grid impedance of the 6AK5 is of fairly great magnitude. Because the coupling capacitance is discharged at the conclusion of each scanning line, the time constant, comprising the product of the coupling capacitance and the forward clamp impedance need only be long as compared with the line interval.

FIG. 9.16 The Du Mont type 5031-A mixer-amplifier and monitor. (Courtesy of Allen B. Du Mont Labs., Inc.)

The input signal to the camera control and monitor unit is approximately 0.5 v. (peak to peak), and the output signal is standard R.M.A. composite, provided that a synchronizing signal is mixed at this point in the system (not usually the case). The output signal amplitude is 2 v. (peak to peak), black negative.

9.7 The Mixer Amplifier and Monitor. The Du Mont type 5031–A mixer amplifier and monitor is illustrated in Fig. 9.16. This unit accepts the outputs of as many as four Image Orthicon control units, providing mixing and camera chain output-monitoring facilities as well as a line amplifier. It provides an R.M.A. standard (composite) output signal of 2 v. peak to peak with which to drive the video transmitter, or to provide a feed to a centrally located master control equipment. It may also be used to drive a microwave relay transmitter directly, no intermediate video amplifying facilities being required. Normally, the standard R.M.A. synchronizing signal is inserted at this unit after mixing and switching of video signals from as many as four cameras have been effected.

The type 5031–A mixer amplifier and monitor unit allows the control operator to select the output of any camera through its associated camera control unit, since it is possible to feed a single or mixed signal to the output terminals. Selection of desired camera outputs and mixing, may be accomplished either electronically or manually. By means of the use of a unique all-electronic mixing and switching system, a preselector switch may be set to result in the fading of one image into another or in lap-dissolve. The speed at which the lap-dissolve or fading is made is predetermined by a simple switch, slow, medium, or fast operation being possible. Instantaneous switching of one signal to another may be preset, the switching being accomplished electronically. No electrical or mechanical relays are employed.

A 7-in. cathode-ray tube, with its associated circuits, provides a means of monitoring the output of the line amplifier, permitting the control operator to see the result of his switching and mixing technique.

Included, also, is a 3-in. video waveform monitor. The monitor will indicate the information in one horizontal line or in one vertical frame of the output signal. Thus, the ratio of picture signal to synchronizing signal may be determined at the output of the system, and a means whereby blanking may be inspected is provided. A switch permits the monitor to be converted into a conventional cathode-ray oscillograph, the vertical amplifier input terminals being available for the introduction of test signals in trouble shooting. A signal system, with indicating pilot lamps on the front panel of the unit, indicate which camera is on the air. This system operates automatically with camera switching.

The schematic of the all-electronic four-camera fading circuit is shown in Fig. 9.17. It will be noted that four type 6C4 tubes are followed by four type 6AK5 pentodes. The plates of the latter tubes are common and plate voltage is supplied through a common "peaking" coil and plate load resistor. When switching from channel 1 to channel 2, switching is accomplished by gradually increasing the bias for the pentode amplifier through which the signal from channel 1 input is passing, the bias on the pentode passing signal 2 being gradually reduced. Automatic control of the rate by which automatic fading from one channel to another is accomplished is made possible through the use of RC circuits which control the rates of rise and fall of the bias voltages.

Lap and fade is made possible by a unique method. If the crossover potential is permitted to fall into such position that an interval exists during which both pentodes are conducting, then the two pictures are superimposed for a short interval during the crossover. This superimposition provides a lap-dissolve. Also, if the crossover voltage is allowed to fall at the effectively zero gain position for both channels, the resulting image will appear to drop to black level during the crossover period.

To obtain an instantaneous switch between channels, the rapid change of plate current brought about by cutting off the plate current of one tube and increasing that of another would ordinarily result in a bounce

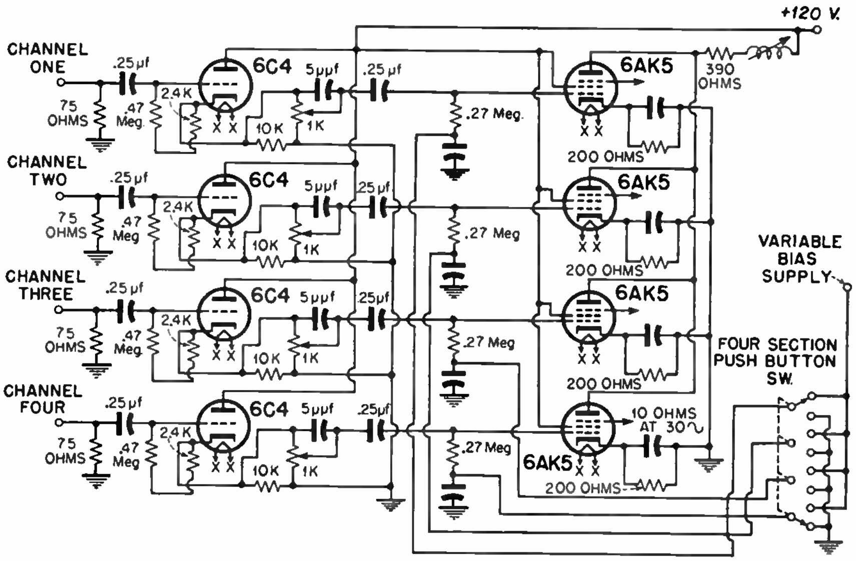


Fig. 9.17

or bop being introduced. This condition is eliminated through the use of a clamping circuit at the input of the final cathode follower in the line amplifier.

9.8 The Low-Voltage Power Supply. The Du Mont type 5029–A low-voltage supply provides highly regulated d-c voltage to its associated monitor and control unit, unregulated d-c power being made available to the camera and electronic viewfinder. This voltage is regulated by means of circuits that are a part of the camera auxiliary unit already described. An autotransformer is provided at the a-c input to the power supply with a tap switch, so that line voltages of 105 to 125 v. alternating current (60 c.p.s.) may be used in the field (see Fig. 9.18).

The Du Mont type 5049–A distribution amplifier and low-voltage supply (Fig. 9.19) provides regulated d-c voltage to the mixer amplifier and monitor unit. It also distributes signals from the synchronizing generator. Composite blanking, mixed camera-driving pulses, and synchronizing signals are normally supplied to each camera and its associated units. Cathode followers are provided in this unit to effect proper

FIG. 9.18 Du Mont type 5029-A low-voltage power supply. (Courtesy of Allen B. Du Mont Labs., Inc.)

FIG. 9.19 Du Mont type 5049-A distribution amplifier and low-voltage supply. (Courtesy of Allen B. Du Mont Labs., Inc.)

isolation of the various feeds to the units of equipment being served with these signals.

9.9 The Portable Synchronizing Generator. The Du Mont type 5030–A synchronizing generator is shown in Fig. 9.20 with the front cover removed. A view of the generator with the side panels removed is in Fig. 9.21. The chassis may be dropped to a horizontal position on either side of the unit for inspection of all tubes, components, and circuits and for ease in servicing the equipment.

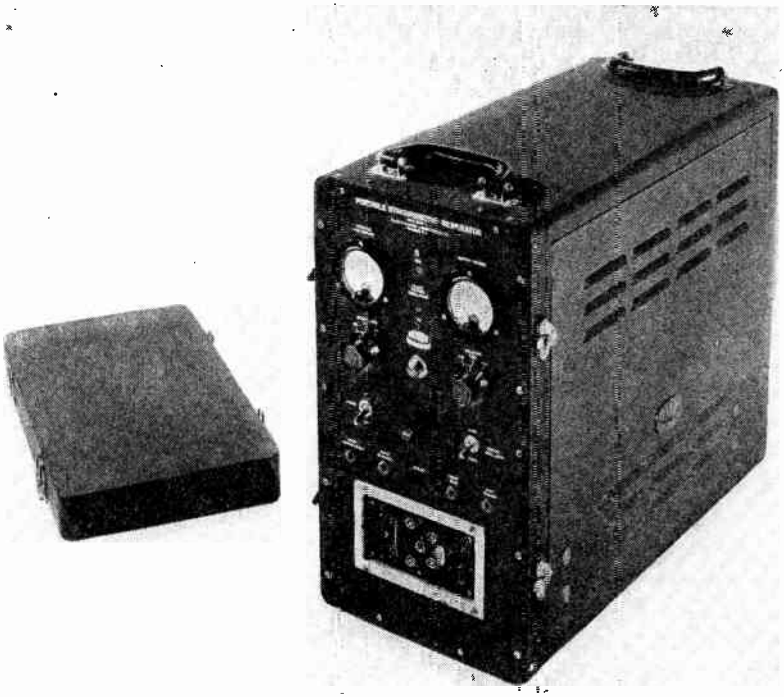


FIG. 9.20 Du Mont type 5030-A portable synchronizing generator. (Courtesy of Allen B. Du Mont Labs., Inc.)

Diode-stabilized multivibrators are employed in a four-stage frequency-divider system. The type 6AS6 coincidence tube is used extensively in the shaper as are miniature delay lines, and the diode-stabilized pulse generators ensure constant pulse width and amplitude. Since the design of synchronizing generators, in general, has been treated in a special section of the text, no elaborate description of this unit will be attempted here. It suffices to say that the unit provides the standard R.M.A. synchronizing signal, as well as the required blanking and driving signals for the camera chain. The permissible power-frequency variation to the unit is ±5 per cent, and the permissible power-line voltage variation to the unit is also ±5 per cent. The power source is normally 105/115/125 v. at 60 c.p.s. alternating current.

9.10 Televising Motion-Picture Film.* Since the F.C.C. has promulgated Standards for Commercial Broadcasting and has allocated channels throughout the nation, a greatly augmented operating schedule has become the obligation of the television station to the public and will be required by the licensing authority which safeguards the "interest, convenience, and necessity" of that public.

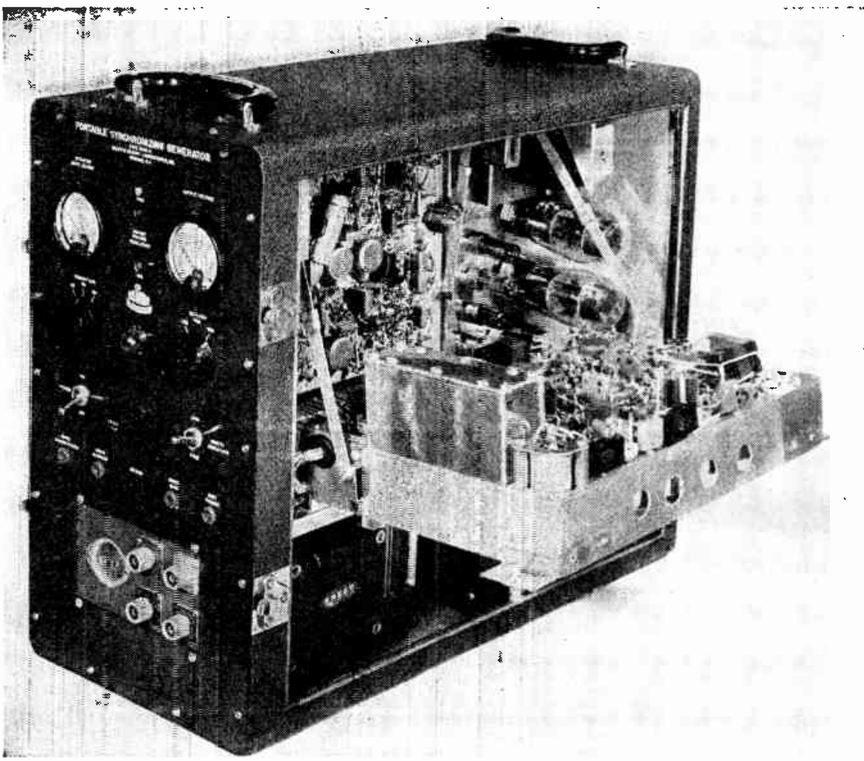


Fig. 9.21 The Du Mont portable synchronizing generator with side panels removed and chassis in position for servicing. (Courtesy of Allen B. Du Mont Labs., Inc.)

Because of the considerable rehearsal time necessary before live-talent shows may be successfully aired, and the consequent great expense in making available such an extended schedule of live-talent production per week per station at the commencement of commercial activity, particularly when the viewing audience is yet to be developed and a clientele of advertising accounts built up in order to sustain the television station financially, it is practical to assume that a great part of the time required

* Helt, Scott, "Televising Motion Picture Film." Principally from a paper delivered at the Sixth Annual Broadcast Engineering Conference, Ohio State University, Mar. 20, 1946.

on the air will be consumed in the televising of motion-picture film and remote events.

If the proper financial and other arrangements can be made between the motion-picture producers and distributors on the one hand and the television industry on the other, a vast storehouse of suitable and entertaining film is already available for transmission into the American home. The average television licensee who is just venturing into the new commercial video operation could not, in producing a studio live-talent show, hope to spend a fraction of the production costs that are expended in making an entertaining motion picture of feature length.

The present television stations that have operated commercially have made available to their audiences both 16-mm. and 35-mm. motion pictures. Although the quality of film has not always been of the best, owing to unsatisfactory arrangements for obtaining better material, it has served the purpose of maintaining the stations on the air when live talent was not always available. There has been a demonstration, however, of what can be done with film, and there has been consistent improvement in the methods employed in transmitting motion-picture film.

From the engineering point of view, it is unfortunate that the standards that are mandatory for a successful all-electronic television system have made it necessary to develop special motion-picture projection equipment or have necessitated the modification or redesign of equipment already available. The reason is that the frame frequency, as employed in television, is not in agreement with the frame frequency adopted as standard throughout the motion-picture industry.

The present high-definition 525-line monochromatic television system is operated at 30 frames per second, each frame being made up of two fields interlaced. Thus, the field frequency is 60 c.p.s., while the frame-frequency standard has been set at 30. Standard sound motion pictures are projected at 24 frames per second. Television engineers found it technically expedient to adopt the frequency of 30 frames per second, since 30 is a submultiple of 60, and the video apparatus employed in transmitting a suitable visual signal is conveniently based upon the standard 60-c.p.s. power-line frequency. The latter frequency is suitable for use in synchronizing the video transmitter with receivers in the field. Thus, there has arisen the necessity of designing or modifying existing equipment to transmit standard motion-picture film that is projected at a frame frequency of 24 per second at television's frame frequency of 30 per second.

A number of optical-mechanical systems have been satisfactorily developed for accomplishing the frame-frequency transition. One such system obtains the desired result by providing 60 scannings of the film per second while the film moves at a speed of 24 frames per second. This is accomplished at a conventional motion-picture projector by so modifying the mechanical system that one film frame is held in place while it is scanned twice and the succeeding frame is held in place while it is scanned three times, the process being repeated alternately. The picture is projected onto the mosaic of the camera pickup tube during the return time of the scanning beam. The scanning beam is so synchronized with the shutter that the image is flashed on the mosaic only during the time between the end of one scanning pattern and the beginning of the succeeding one, when the beam is biased to cutoff, the projector being equipped with a shutter in the form of a revolving disk, which is slotted. The disk allows light to pass 60 times per second for a period of about 1/1,000 sec. Thus, there are 60 scannings of the film during 1 sec. Twelve of the 24 frames per second are scanned twice, giving a product of 24. The alternate 12 frames are scanned three times, with a product of 36. The numerical sum of 24 and 36 is 60. This corresponds with television's standard field frequency of 60 and is twice the required frame frequency of 30.

Another system employed to bring about the transition from a standard projection frame frequency of 24 per second to a television frame frequency of 30 per second operates so that the film is passed through the projector at constant speed. An especially designed lens system follows each frame down, keeping it in focus. The series of special lenses is mounted on the periphery of a disk which is made to rotate perpendicularly to the film and the source of illumination. The lenses are placed adjacent to each other about the circumference of the disk, so that one succeeds another in coming into focus. The disk rotates in synchronism with the speed of the film. The only disadvantage of the system lies in the expensive lens system used. (Recently, a pulsed-light system has been developed and will be described later.)

In the televising of motion-picture film, the frame image is focused directly upon the photosensitized mosaic or target of the pickup tube in the television camera. This tube is usually the Iconoscope, although other tubes are available for the purpose. It is common practice to have a projection room at the television station suitably equipped with both 16- and 35-mm. projectors. There should be two of each, so that it is possible to project a full-length feature film without interruption. These projectors are physically arranged so that they are at right angles to one wall of the projection room, this wall having small square apertures, or ports, in its face, through which images are projected onto the targets or mosaics of the pickup tubes mounted in cameras facing the opposite side of the apertures, or ports. Usually, only two cameras are employed, and they are moved from one aperture to another in order to accommodate four projectors, the number required for the continuous projection of both 16- and 35-mm. film.

For average lighting in normal operation, a minimum of at least 25 ft.-c. of light are required at the Iconoscope mosaic, although satisfactory illumination is possible with a light level of 1.5 millilumens per sq. cm. for average conditions and 3.5 millilumens per sq. cm. for highlight conditions. The mosaic of the standard Iconoscope has an area of approximately 100 sq. cm. In one commercial type of modified 35-mm. film projector, a 900-w. type T–20 projection lamp was found capable of supplying this light demand with a safety factor of at least 2 : 1. In another modified 35-mm. projector, a 55-v. d-c arc operated at 25 amp. provides the necessary illumination. For a source of light in a modified 16-mm. projector employed at Station WABD, a 1,000-w. lamp provides the requisite illumination.

A 3,600-r.p.m. shutter with one slot was chosen in one design and an 1,800-r.p.m. shutter with two slots in another. Since the television image provides 60 elementary views per second, it is evident that to synchronize the shutter speed with the film cycle, permitted speeds are submultiples of 3,600 r.p.m. A powerful source of light is necessary because of the short time interval during which light is permitted to project to the mosaic of the pickup tube by the vertical blanking timer in front of the projection-lens system. This timer is a solid, opaque disk except for an arc of about 7 per cent. In the typical projector the disk travels at the speed referred to above, the translucent arc of the disk permitting light to filter through to the mosaic of the Iconoscope when it is in position before the light source. And the shutter is so adjusted that the light reaches the mosaic only during the time interval when the scanning beam is moving from the lower edge of one frame to the top of the next frame, i.e., when horizontal scanning recurs.

It is interesting to note here that the standard aspect ratio in television is 4 : 3; i.e., the numerical ratio of frame width to frame height is 4 : 3. Thus, the quotient of width over height must be 1.333. The standard size of 35-mm. motion-picture film is 0.825 in., or 20.96 mm., horizontally and 0.60 in., or 15.24 mm., vertically. Thus, the quotient of width over height is 1.375. The standard frame size of 16-mm. film is 0.380 in., or 9.65 mm., horizontally and 0.284 in., or 7.21 mm., vertically. Therefore, the quotient of width over height for standard 16-mm. film is 1.334.

The R.C.A. type 1850–A Iconoscope has a mosaic of approximately 16.922 sq. in. upon which the film frame image is to be projected. The quotient of horizontal dimension ($4\frac{3}{4}$ in. $\pm$ $\frac{3}{32}$ in.) over the vertical dimension ($3\frac{9}{16}$ in. $\pm$ $\frac{3}{32}$ in.) is 1.333. Thus, it is clear that the aspect ratio of neither standard 35-mm. nor standard 16-mm. film precisely satisfies the standard aspect ratio employed in television. A serious error does not occur, however, since the amplitude of the horizontal sweep voltage in the television system need be only slightly altered to compensate for the error—and without visible geometric distortion of the image. Also, it is possible to mask off some of the edge of the film frame when focusing it upon the mosaic without losing an important amount of the film frame area.

When the light image from the projector is focused upon the mosaic of the Iconoscope, a potential image is formed. This potential image is translated into the picture signal at the Iconoscope. It is then amplified and, with pedestal, blanking, and synchronizing signals added, is finally made to suitably modulate a radio-frequency carrier in an amplitude manner. The television receiver converts the electrical equivalent of the motion-picture image back into the original light image by causing a cathode ray to trace out the picture in consecutive horizontal lines upon the fluorescent screen of the cathode-ray tube. The beam of electrons making up the ray is modulated at the picture tube and deflected by horizontal and vertical deflecting voltages which are synchronized with the deflection potentials employed in transmission.

Unlike amplifiers employed in regular AM broadcasting, those employed in the television system which follow the pickup tube in the television camera must contain an even or odd number of stages, this being a function of the polarity of the signal transmitted. Each stage reverses the polarity of the signal voltage, so that if additional amplification is desired, two stages must be added in order to maintain the correct polarization at the transmitter or receiver output. Therefore, if a single stage is added, the result can be a negative picture, and the "white" portions of the original picture will be reproduced in black. Du Mont has taken advantage of this in providing a "chain" for the transmission of negative film instead of positive film. With the proper number of amplifier stages, the picture is reproduced through the receiver as a positive. The advantages of the system are at once apparent. It means that on-the-spot news film need not be printed before transmission, and the negative can be used. Thus the time required to get motion pictures of important events "on the air" before they lose news value is greatly reduced.

Possibly the most serious problem involved in utilizing the Iconoscope as a motion-picture image pickup tube is that of *shading*. A spurious shading signal is developed at the tube's output as a result of the irregular rain and fall of secondary electrons upon the mosaic, resulting in nonuniform distribution of potential over the mosaic. These secondary electrons are dislodged by the high-velocity beam employed in the Iconoscope gun, and the light and shade in the picture are not then a duplicate of that found in the image being televised. It must be corrected by the use of special circuits and the services of a highly skilled shading operator to control these circuits. Since motion pictures are projected at such a rapid frame frequency, scenes are rapidly changing. Thus, the shading operator must be very skillful in making the necessary rapid adjustments in compensation so that the entertainment value of the film is not impaired.

Back lighting at the rear of the mosaic of the Iconoscope is more important in the televising of motion-picture film than in the televising of live talent in the studio. The reason is that suitable back lighting improves the secondary emission characteristic of the Iconoscope, thereby reducing the shading problem to proportion. Back lights are tungsten lamps which are operated just to the rear of the mosaic signal plate, though the light is not focused directly upon the signal plate. The result is to improve not only the secondary-emission characteristic of the tube, but also the amplitude of the video signal at the output of the tube is seen to increase.

Pickup tubes employing low-velocity scanning beams operate without the necessity of shading, but they have not yet come into widespread use in the televising of motion-picture film.

Rim lighting must also be employed at the mosaic of the Iconoscope to reduce edge flare of the picture. For this purpose, lamps are located so that the illumination can be focused in a thin pencil of light along the top and left side of the mosaic where scanning begins and without any of the light striking the sensitive mosaic itself. The illumination is focused upon the metal rim to which the sensitized mica-based target is riveted for mechanical support.

Proper rim lighting is very important when the Iconoscope is used for motion-picture film scanning, since the edges of dark scenes where the light level from the projector is low will demonstrate very disagreeable edge flare.

Leaving the electronic aspects of the subject for the moment, let us examine the problem introduced by any mechanical vibration imparted to the film. There are 525 horizontal lines for each television frame, and since the picture is developed by first causing the beam to traverse the odd-numbered lines and then the intermediate even-numbered lines, we may see that the detail of the picture will suffer if the alternate lines are allowed to overlap. Therefore, the limit of displacement between alternate lines must be equal to one half of their respective spacing. Thus, a vertical displacement of $\frac{1}{10}$ of 1 per cent is the maximum that can be satisfactorily tolerated. This vertical-motion tolerance must be maintained in the motion-picture camera, in the printer, and in the complete video system responsible for the line structure.

To eliminate vibration at the projector, a recent 16-mm. projector, modified by Du Mont engineers, has been constructed upon a carefully and accurately machined base, all equipment above the base having been carefully aligned to it. Such care in the elimination of vibration has resulted in projection that is without vertical frame displacement of any kind that can be observed in the resulting picture.

Because so much detail is lost when a film frame is subjected to vertical motion, the television studio should never accept film that is badly mutilated or has sprocket holes missing. The television studio should insist upon first-run film because of the serious loss of definition due to wear at sprocket holes or due to abrasion of the film. A vertical displacement of the film in the projection aperture of 0.0014 in. from its proper position is equivalent, in one instance, to the television picture shifting one scanning-line pitch, which is twice the upper desirable limit. It is also very important in the maintenance of projection equipment that all parts be kept within close tolerances at the pull-down mechanism, should one be employed.

The sprocket teeth in the projector are on the periphery of a small-diameter drum that is geared in one design, to a special camshaft and eccentric, so that it rotates at the speed necessary to time the film passing before the light source. The speed with which the transition between adjacent frames is made is prevented from interfering with sound transmission by means of a rotary stabilizer in the projection unit. The light reaches the mosaic only during the blanking interval.

Leaving the subject of image projection, and entering a general discussion of sound pickup from the film, a standard exciter lamp, photoelectric cell, and optical system is employed. Since frequency modulation is the aural system employed in television, it is essential that the fullest use be made of the system in order to realize the high quality inherent in this modulation system. The secret of the improvement of frequency modulation over amplitude modulation lies largely in the greater signal-to-noise ratio that it makes possible. The greater the swing allowed, the more reduced is the noise level. Also, background noise at the source of sound must be kept as low as practicable. The noise level should be at least -60 db. below the audio level necessary to produce the ± 25 kc. per sec. swing employed in the television transmitter. This is the F.C.C. requirement concerning noise level measured at the output of the sound transmitter with the visual transmitter inoperative at the time measurements are made. It is essential, therefore, that film for television transmission be not only acceptable for the proper resulting video signal; it must also possess a sound track with low inherent background noise.

The photocell output of the television film projector is normally connected at high impedance through a coupling capacitor to the control grid of the first tube in the preamplifier, or sound head, or it is transformer-coupled to a low-impedance line. In the latter case, the line feeds the sound to a low-level mixer position in a standard broadcast type sound console.

If the first system is employed, i.e., coupling at high impedance into the control grid of the first preamplifier stage, there is the possibility of electrostatic linkage between the connecting lead of the coupling capacitor and the filament circuit of the preamplifier, the fan motor, and projection motor. Coupling with any of these sources will introduce noise into the system. If the connecting lead and coupling capacitor are thoroughly shielded to eliminate the hum pickup, then the capacity reactance between the lead, or the coupling capacitor, to ground may be so low as to offer a shunting effect to the high frequencies. The reason is that the capacity reactance of the shielded lead or capacitor to hum sources decreases with an increase in pass frequency. Thus, it is difficult with such a coupling system to satisfactorily reduce the noise level and at the same time preserve the high-frequency response.

If the second method is used, i.e., coupling the photoelectric cell to the control grid of the first tube of a transformer, the electrostatic capacity between the photoelectric cell and the primary of transformer must be held below 50 $\mu\mu$f. The transformer, therefore, should be placed very close to the projector. It should be of well-balanced design and in a partly shielded location, since the voltages that it will pass are at extremely low level.

A third method of coupling the photoelectric cell has been found useful. The preamplifier is eliminated entirely. Instead, the photoelectric cell is coupled through a short cable of low electrostatic capacity directly to the high-impedance primary of a matching transformer, the secondary of which is connected directly to a 30-ohm audio circuit. This circuit, in turn, is connected at a mixer input position of the standard broadcast sound console. The low level obtained is comparable to that of a high-quality microphone and is within the normal range of the mixing potentiometer. Great care must be exercised in balancing the low-impedance line to ground and eliminating extraneous noise pickup in the circuit.

It is sometimes useful to provide equalization of the line between the projector sound system and the sound console. This equalization is carried out in the conventional manner, a series-resonant equalizer being used in shunt with the line.

The Du Mont type 5130–A 16-mm. sound motion-picture projector is shown in Fig. 9.22. Actually, this is a Victor Animatograph type 40B projector modified to make possible the projection of standard 16-mm. 24 frame per second film onto the mosaic of an Iconoscope or Image Orthicon tube. The latter pickup tubes are employed in a standard television system operating at 30 frames per second. The conversion of frame frequency is made possible by scanning the film in the manner already described, i.e., scanning alternate frames twice, the other alternate frames three times.

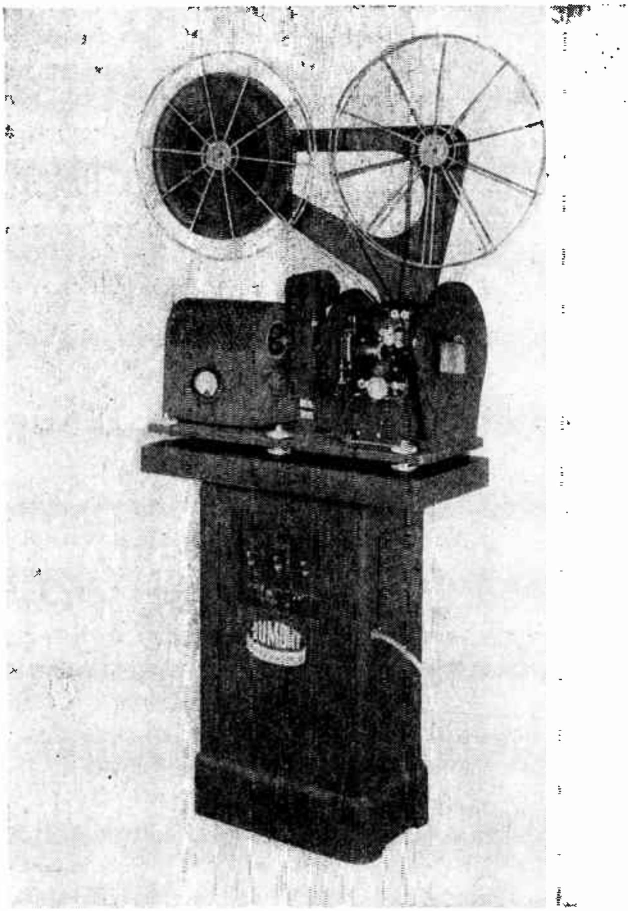


FIG. 9.22 Du Mont type 5130–A 16-mm. sound motion-picture projector. (Courtesy of Allen B. Du Mont Labs., Inc.)

The film frame is actually projected upon the mosaic of the pickup tube by a burst of light during the vertical blanking time. According to present R.M.A. standards, the blanking time has been established as 5 per cent of $\frac{1}{60}$ sec. or 833.33 μsec., and with a tolerance of +3–0 per cent, or +500 μsec. The burst of light is provided by a shutter in front of the projection lamp, and the housing of this shutter may be seen in Fig. 9.23 (just in advance of the lamp). The lamp housing is removed in this view so that the lamp is exposed. In this particular projector, the shutter comprises two rotating disks properly adjusted to result in the desired duration of light burst.

The reels are 19½ in. in diameter and will handle 3,600 ft. of 16-mm. film, or a continuous run of 1 hr. 40 min. Each reel has a capacity of 2,000 ft. of film, enough for a full-length feature 16-mm. presentation.

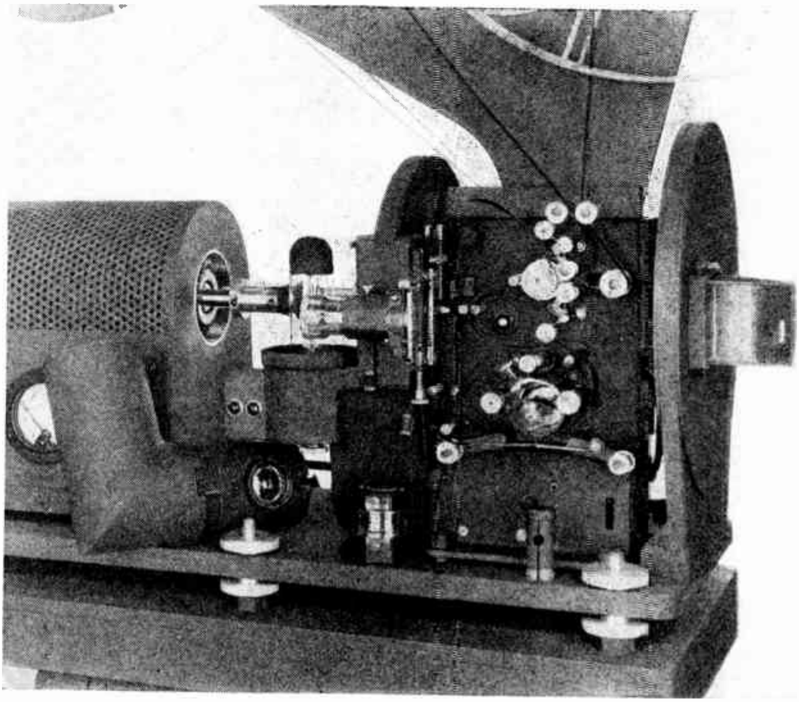


FIG. 9.23 Film transport system mechanism of the Du Mont type 5130-A projector. The position of the two shutters with relation to the light source and optical system is shown. The lamp house has been removed. (Courtesy of Allen B. Du Mont Labs., Inc.)

Sound is taken from the film in the conventional manner. In noting the film transport system (Fig. 9.24), it will be seen that no irregular pull-down cycle is used, no special pull-down mechanism being required. Thus, there are no special elliptical gears or cams involved.

Dual shutters operating on a common shaft and rotating at 1,800 r.p.m. are employed. The shutter shaft is directly coupled to a synchronous motor. Reduction gears of 4 : 5 ratio transmit the movement from this shaft to the 1,440-r.p.m. shaft driving the standard projector mechanism. A 2-in. f/1.9 coated projection lens is employed.

The required 60 light bursts per second are provided by the dual shutters. Each shutter has two projection apertures. The dual shutters provide an approximately square-shaped burst of light, the result being an increase in the amount of light projected per burst. The shutters are so placed that the rear shutter interrupts the light between the lamp house

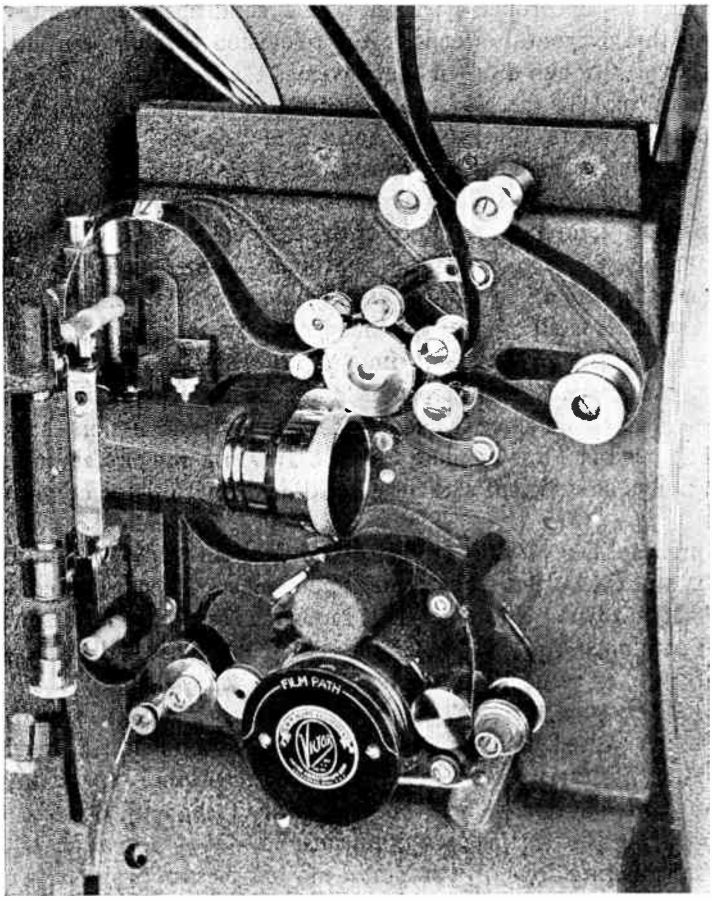


FIG. 9.24 The relation of the projection lens with reference to the film-transport mechanism is shown. (Courtesy of Allen B. Du Mont Labs., Inc.)

and the film, the front shutter interrupting the image beam in front of the lens.

With proper adjustment, the light pulse will be concealed within the vertical blanking period and will not spill over the vertical blanking period. The duty cycle of each light burst is made $6\frac{1}{2}$ per cent or approximately 1,080 μsec. It can be determined that the light pulse rests within the blanking period by noting the position of the light burst when examining the vertical blanking by means of a television waveform or picture monitor.

If the television camera "looks" directly into the projection lens, the resulting picture will be reversed—left hand for right hand—because the motion-picture film is printed reversed so that the image on the projection screen will be in proper position. This condition necessitates either reversing the horizontal sweeps in the television camera or allowing the image to pass through a prism that reverses the image, so that the television camera may be directed precisely toward the projected image. The usual practice is to reverse the horizontal "sweeps" if an Iconoscope pickup tube is employed in the camera chain or to employ a prism if an Image Orthicon pickup tube is used. In the illustrations in the text, the prism may be seen just in advance of the forward shutter of the projector. When an Image Orthicon is used, a ground glass is placed between the prism and the camera to form a visual image, so that the projector and Image Orthicon camera may be independently focused. This arrangement is important if excellent images are to be had in sharp focus. Usually, the ground-glass screen is made of the Eastman Kodascreen translucent material, since it has excellent light-transmission characteristics. The ground glass is placed 2 to 3 ft. from the projector in order that an image of sufficient size may be formed to allow for adjustment of focus.

The preamplifier of this projector provides an audio output level of —40 db., and the output transformer impedance may be adjusted between 50 and 500 ohms. The over-all frequency response is made useful through an upper limit of 10 kc. per sec. Film noise will usually limit the useful upper response to about 5 kc. per sec.

The R.C.A. type TP-16A Film projector uses an entirely different principle. A pulsed light source is employed, and no shutter mechanism is required. Referring to operation of the conventional type of television projector with shutter, it will be seen that if the pull-down could be effected during the vertical blanking interval ($\frac{1}{750}$ sec. each $\frac{1}{60}$ sec.), no further modifications of a standard motion-picture projector would be required. Since this arrangement is not practically possible, R.C.A. makes use of short light flashes, or pulses, so timed that the film picture is projected upon the pickup tube mosaic for only 1/1,200 sec. each $\frac{1}{60}$ sec. These pulses of light energy occur during the vertical retrace time and are provided by a rotating shutter made of a metal disk 18 in. in diameter, a slot being cut in its periphery. The disk is precisely driven at a speed of 360 r.p.m. by means of a 3-phase synchronous motor. Such a system is possible because the photosensitized mosaic of the camera pickup tube stores the picture during the time interval occurring between flashes of light energy. Synchronization of the projector with the TV system is assured since both the system synchronizing generator and the synchronous motor operate from the same power source. To ensure that the shutter will be in synchronism at all times, a large-sized electric motor employing a separately excited d-c field is used. Since the d-c field is polarized, the motor will always lock in proper phase relationship with the synchronizing generator. Pulsed-light projectors are rapidly coming into prominent use, though mechanical-optical systems are the most widely used.

Fig. 9.25 Du Mont dual Iconoscope camera control console for film pickup. (Courtesy of Allen B. Du Mont Labs., Inc.)

Figure 9.25 illustrates a modern Du Mont Film Iconoscope dual camera control console. It will be noted that three sections make up the console, namely, two picture preview, shading, and monitoring sections and a final monitoring and signal-mixing section. Waveform monitors for checking both picture line and frame information are provided, as well as 12-in. picture monitors to allow previewing of the output of each of the two projectors and pickup cameras employed.

Shading controls are conveniently arranged for ease of operation. All-electronic signal mixing is provided at the input to the final line amplifier, which provides standard R.M.A. output to master control or to the picture-transmitter input. All of the units may be pulled out of the desk on railways, so that each unit and all components are exposed for ease in servicing. This arrangement is indicated in Fig. 9.26.

9.11 Engineering Problems of Local Remotes.* In this period of transition, when television is emerging from its war years into full commercial operation, some truths are becoming self-evident with respect to the type of program receiving the widest public acceptance. Every indication seems to single out remote or field operations outside the studio as

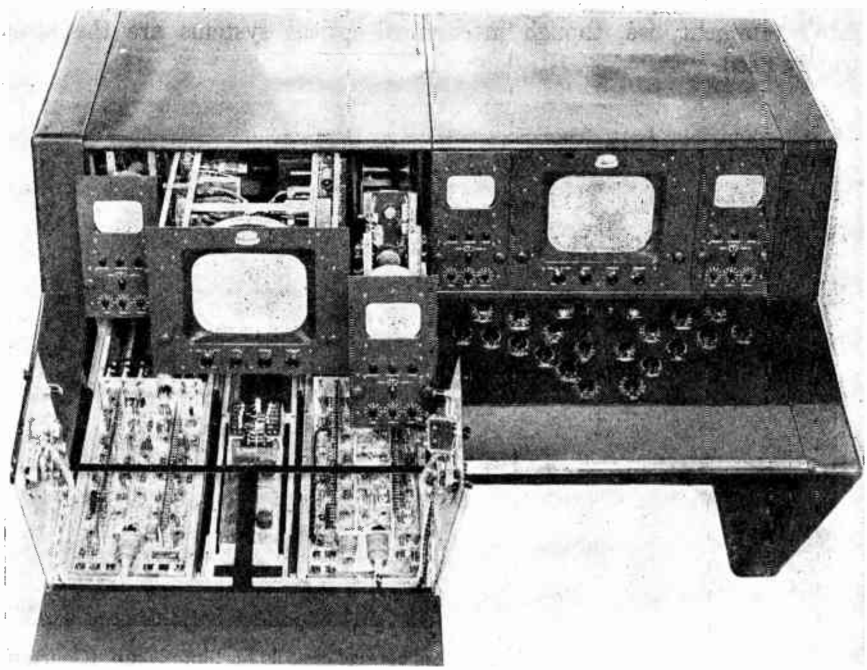


FIG. 9.26 The various units on "railways" so that they may be pulled out for inspection or servicing. (Courtesy of Allen B. Du Mont Labs., Inc.)

providing the most interesting type of program material thus far available to the public. The televising of the Democratic and Republican National Political Conventions in Philadelphia (1948) provided television with the greatest acceleration the industry has yet experienced.

Since the immediate future of television will depend to a great extent upon the excellence with which remote operations are executed, field problems will become of increasing importance to everyone associated with the industry.

From an engineering point of view, the average pickup outside the

* Helt, Scott. "Engineering Problems of Local Remotes," a paper delivered at the Television Clinic of the Television Broadcasters Association at the Waldorf-Astoria, New York, Dec. 10, 1947. It was read for the author by John McNeil.

studio is an undertaking of the greatest magnitude. In viewing the program at home, the television-receiver owner does not realize that more than half a ton of technical equipment, valued at $50,000 or more, must be moved on location to be manned by five to ten highly skilled television engineers.

The engineering problems of local remotes are many. Of preliminary consideration is the actual location where the pickup will originate. A complete survey must determine a great many factors that were never a part of even the most involved remote pickup in strictly sound broadcasting.

Of primary importance is the physical situation of the originating point itself. The vagaries of propagation in that portion of the frequency spectrum allocated by the licensing authority for TV radio-relay purposes dictate that line of sight must obtain between the pickup point and the studio or transmitter location. If a microwave radio relay is to be used, such as is shown in Fig. 9.27, this requirement must be met. Even though a profile graph, indicating the nature and elevation of the terrain and structures along the contemplated transmission path, indicates that line of sight does exist, it is necessary in practically every case to test the location initially. This means actually setting up the intended relay and transmitting test signals between the two points. Often, more than one radio relay is required because of the distance involved, and stepped relays are often necessary in order to connect the two terminals of the relay route.

Permanent or semipermanent installation of the relay, once the transmission circuit is tested and closed, usually presents a problem in itself. The parabolic reflectors, or dishes, which beam and accept the signal must ordinarily be elevated above all surrounding structures at either end of the transmission circuit. This involves the use of rigid mounting facilities capable of satisfying the requirements, whatever the location. In one instance, the transmitting antenna might require mounting atop the stands at a baseball park or football stadium, atop a sports arena or even the superstructure of a destroyer under way at sea. Whatever the case, it always requires special consideration. The two parabolic reflectors, or dishes, must be oriented or moved about in the horizontal and vertical planes until the maximum possible signal amplitude results at the microwave receiver. This requirement necessitates the provision of a telephone circuit to connect the pickup point and master control room. This supervisory telephone circuit will later be used to establish communication between the two points when the cameras are active.

If a balanced wire circuit or coaxial line is chosen to connect the pickup point with the final terminus of the transmission circuit, the local telephone company must be called upon to determine whether the facilities can be made available. There is also the economic problem of whether the use of the wire or coaxial facilities is feasible, since the toll increases almost in direct proportion to the increase in length of the circuit. It is ordinarily possible to obtain a better over-all transmission characteristic, insofar as bandwidth and noise level are concerned, if the microwave

FIG. 9.27 R.C.A.'s microwave-link equipment for television relaying. (Courtesy of Radio Corporation of America.)

relay is chosen. A demonstration of the New York-to-Boston microwave relay has led to comparison with transmission via the New York-to-Washington coaxial-cable facility, which has resulted in some interesting observations with respect to the two modes of operation.

In a preliminary engineering survey of a remote pickup, it must be determined if sufficient power is available with which to operate the equipment. A dual-image Orthicon camera chain of one manufacturer requires 3.17 kw. of 60-c.p.s. a-c power. The relay transmitter, control equipment, and audio facilities will require a lesser amount. Ordinarily 5 kw. of power will suffice at any location where a dual camera operation is anticipated. In some instances an additional 5 to 10 kw. of lighting is required, even though the Image Orthicon is employed as the pickup tube. At least 200 ft.-c. of light are desired on the scene to be televised, though a minimum of 50 ft.-c. may be used. The greater the light level, the more the camera lenses may be stopped down, resulting in a greater depth of focus.

In some areas direct current is still in use. At some pickup points power lines are not available, and a portable gasoline-engine-driven a-c generator must supply the power. In any case, it is usually necessary to install expensive electrical wiring and conduit in order to satisfy the city electrical code and the requirements of the Board of Fire Underwriters. Sometimes permits from several authorities are necessary before setting up at a given location.

The selection of vantage points for the cameras is an important consideration. The number of cameras employed will depend upon the particular pickup, and the camera requirements and placement can usually be worked out in concert with the program people. In general, the problem resolves itself into a study of all possible camera angles and positions and the selection of those which yield the optimum coverage. It is often necessary to construct operating platforms in order to achieve the best possible vantage points.

Another problem to be settled is whether the camera control equipment will be operated in a mobile unit at the location or at a position adjacent to the pickup cameras themselves. If the mobile unit is brought into use, a location for it must be chosen, the lengths of camera cables to reach it determined, and a communication system set up connecting the mobile unit and the camera locations. A typical mobile unit is shown in Figs. 9.28 and 9.29.

The selection of proper lenses for the Image Orthicon cameras is another problem. Generally, it is one of determining the distance between the cameras and the subjects to be televised, the field to be covered, and the nature of the program. With turret-head cameras, a complete complement of lenses is instantly available. Ordinarily, a 3½- or 5¼-in. lens will cover close-up action 50 to 150 ft. distant from the cameras. A 6-in. lens will cover double plays, while a 14-, 16-, or 20-in. telephoto lens will adequately cover individual plays on the football or baseball field and action in the outfield. For boxing or wrestling, a 5¼-in. lens at 50 ft. will effectively cover the ring. In football, a 9-in. telephoto lens will cover a considerable portion of the playing field, the 20-in. lens bringing in individual plays for closeups. A 6-in. lens will cover practically the entire field of play. Most of the telephoto lenses will have speeds ranging from f/4.5 to f/5.6. The 2-, 3½-, 5¼-, and 6-in. lenses should have speeds of not less than f/3.5.

In considering the aural or sound pickup from the remote point, the types and numbers of field amplifiers, microphones, and other audio

FIG. 9.28 A mobile television truck which is used to cover such events as baseball games, parades, etc., for television audiences. Atop the truck are two technicians operating the television camera. (Courtesy of General Electric Company.)

facilities must be determined. A microphone with parabolic reflector must be used where crowd noise and atmosphere are desired, and a suitable location and mounting must be determined. A high-quality audio transmission circuit must be installed by the telephone company to connect the remote position and master control room.

There is no field of engineering requiring more skill and training than demanded of a television staff charged with operations outside the studio. They must know something of optics, lighting, electronics, and photography, as well as how to get along with the people with whom they come in daily contact. The equipment these men will carry to the point of pickup will run the gamut of everything from a flashlight and a pocket knife to a complete high-frequency transmitter capable of beaming the signal that is derived through the cameras back to the main transmitter of the television station.

FIG. 9.29 Pictured above is a technician operating portable camera monitors inside a mobile television truck. The monitor at the extreme right is the master monitor. (Courtesy of General Electric Company.)

The steady research and development programs of the equipment manufacturers toward reducing both the weight and complexity of the circuits of remote equipment must go forward at a rapid pace. Progress is essential in view of the increasing demand for the type of program originating outside the studio, which has found such wide public acceptance.

BIBLIOGRAPHY

1. ROSE, A., P. K. WEIMER, and H. B. LAW, "The Image Orthicon—A Sensitive Television Pick-up Tube," *Proc. I.R.E.*, July, 1936.
2. *Television*, Vol. III (1938–1941), *R.C.A. Review*, January, 1942.
3. *Television*, Vol. IV (1942–1946), *R.C.A. Review*, January, 1947.
4. LITTLE, R. V., JR., "Film Projectors for Television," *J. Soc. Motion Picture Eng.*, February, 1947.
5. LITTLE, R. V., JR., "Film Projectors for Television," *International Projectionist*, May, 1947.
6. MAUTNER, L., "Portable Camera Chain for Field Use," *Tele-Tech*, May, 1947.
7. ROE, J. H., "Image Orthicon Field Equipment," *Broadcast News*, June, 1947.

8. Poch, W. J., "Sync Generator Frequency Stability and TV Remote Pick-ups," *Communications*, July, 1947.
9. Taylor, J. P., "Camera Placement and Switching for Baseball Broadcasting," *Broadcast News*, September, 1947.
10. Wankel, F. A., and E. C. Wilbur, "How N.B.C. Uses the R.C.A. Image Orthicon Camera," *Broadcast News*, September, 1947.
11. Roe, J. H., and N. J. Bean, "Television Field Equipment," *FM and Television*, November, 1947.
12. Blewitt, J. P., and J. H. Rubel, "Video Delay Lines," *Proc. I.R.E.*, December, 1947.
13. Helt, S., "Engineering Problems in Local TV Remotes," T.B.A. Symposium, Hotel Waldorf-Astoria, New York, December, 1947.
14. Roe, J. H., "New Television Field Pick-up Equipment Employing the Image Orthicon," *Proc. I.R.E.*, December, 1947.
15. Smith, J. R., "Television Field Equipment," *FM and Television*, December, 1947.
16. Helt, S., "Televising Motion Picture Film," A paper delivered at the Sixth Annual Broadcast Engineering Conference (Ohio State University), March 20, 1946.

REVIEW QUESTIONS

9–1. (a) What is meant by "camera chain"? (b) Define the following: (1) single camera chain; (2) dual camera chain; (3) triple camera chain.

9–2. What are the principal units of equipment that make up the conventional camera chain?

9–3. At what point in the system is the synchronizing signal usually introduced? What is its purpose?

9–4. Describe the following units of equipment: (a) camera; (b) camera control unit; (c) picture monitor; (d) line amplifier.

9–5. (a) What is meant by the camera "dolly"? (b) What is the usual lens complement of the TV camera when it is used in the field? (c) Describe the use of each lens.

9–6. Explain some of the important considerations when "locating" in the field for the televising of a program remote from the studio.

9–7. How is the film frame frequency converted to the television frame frequency in film scanning?

9–8. How does the TV film projector differ from that commonly used in motion-picture projection?

9–9. (a) What is a television mobile unit? (b) Describe its functions in the field.

9–10. (a) Enumerate the communication circuits ordinarily used in setting up a "remote" for programing outside the studio. (b) Describe each circuit used for communication purposes.

CHAPTER 10

THE TELEVISION TRANSMITTER

10.1 Introduction. The term "television transmitter" means the radio transmitter or transmitters for the transmission of both visual and aural signals. Ordinarily, both the visual and aural transmitters are housed in a common transmitter housing or metal enclosure for operating convenience, the complete television transmitter being made up of a number of visual and aural units, each in an individual metal frame, each unit serving a particular function in the over-all transmitting system. The presence of two separate and distinct transmitters at the television broadcasting station location imposes an operating problem which is far more severe than that encountered in standard AM or FM broadcasting. The equipment is more complicated, the circuitry more complex, far greater skill and knowledge being required of the station engineer. He must be familiar with both visual and aural transmission, with both AM and FM systems of modulation, and must be versed in all aspects of modern broadcast engineering practice.

The Picture Transmitter. The picture transmitter employs amplitude modulation, while the sound or aural transmitter makes use of frequency modulation. Two systems of modulation are employed not only to make use of the best possible mode of transmission for each service, but also to prevent "cross-talk" or interaction of the two individual transmitters —both equipments being termed the "television transmitter." The equipment must be designed and operated in the band extending from 54 to 216 mc., a specific channel 6 mc. wide being assigned by the federal licensing authority to each individual television broadcasting station. In the United States, a construction permit for the station is first obtained from the F.C.C., and proof-of-performance tests are conducted after the station is constructed. If the proof-of-performance tests indicate that the station is capable of operating in accordance with the F.C.C. Standards of Good Engineering Practice Concerning Television Broadcasting Stations, a station license is granted, which permits regular commercial operation.

It is common practice at the present time to operate the very high frequency picture transmitter with 5 kw. peak power output, although in the upper portion of the television band (174 to 216 mc., channels 7 through 13) a 3.5-kw. picture transmitter has been provided in some instances. The F.C.C. in the United States requires that the radiated power of the aural or sound transmitter shall be not less than 50 per cent nor more than 150 per cent of the peak radiated power of the visual transmitter. Currently, the output power of the aural transmitter is made 50 per cent of that of the picture transmitter in most installations. This refers to the output power of the transmitter proper, since the effective radiated power of the television transmitter means the product of the antenna power (transmitter output power less transmission line loss) times either the antenna power gain or the antenna field gain squared. Thus, a picture transmitter rated at 5 kw. peak power output, when modulated with the standard television signal, may produce an effective radiated power of 21.5 kw. peak when operated into a typical bat wing superturnstile antenna system having a power gain of 4.3. It is at once evident that it is far more economical to employ a high-gain antenna system with the television transmitter to develop a desired field intensity over a specific service area than to depend upon installed tube capacity in the transmitter final amplifier to produce the same field intensity.

The modern television transmitting antenna structure is a highly efficient radiator of energy, resulting in a remarkable conservation of power. Little power is dissipated to no useful purpose in the typical system in use today. It will be described in greater detail later in the text. It suffices to say here that such a structure can be made to develop an omnidirectional pattern, with little energy directed in the vertical plane. Most of the signal will be found to lie in the horizontal plane where it will serve to provide good coverage of the area surrounding the transmitter location. Elevation of the antenna structure is most important in providing effective coverage of a desired area, the height of the antenna above mean sea level being of greater importance in most instances than installed transmitter power. Not only is the area of the region receiving the signal increased as the antenna elevation is increased, but greater freedom from ghosts or echoes is attained. Generally, it is desirable to elevate the transmitting antenna structure above all surrounding buildings or other structures that might result in multipath transmission difficulties.

A vestigial sideband signal is developed by the picture transmitter. In other words, a system of transmission is involved wherein one of the generated sidebands is partially attenuated at the transmitter and is radiated only in part. The field strength or voltage of the lower sideband as radiated or dissipated and measured must be no greater than —20 db. for a modulating frequency of 1.25 mc. or greater. This means that the lower sideband must be attenuated by 20 db. at 1.25 mc. below the visual carrier frequency. The undesired portion of the lower sideband produced by the AM picture transmitter is removed either by a high-level vestigial filter in the antenna circuit or through careful tuning of the linear amplifier circuits of the transmitter, in order to provide the vestigial sideband characteristic required by the licensing authority. If the latter procedure is followed, the band-pass characteristics of the video transmitter radio-frequency tuned circuits are so chosen that proper tuning of the linear amplifiers brings about the required suppression of the lower sideband. When this method is used, it is current practice to employ a notching filter at one or more of the linear-amplifier tuned circuits to ensure proper attenuation of the side-

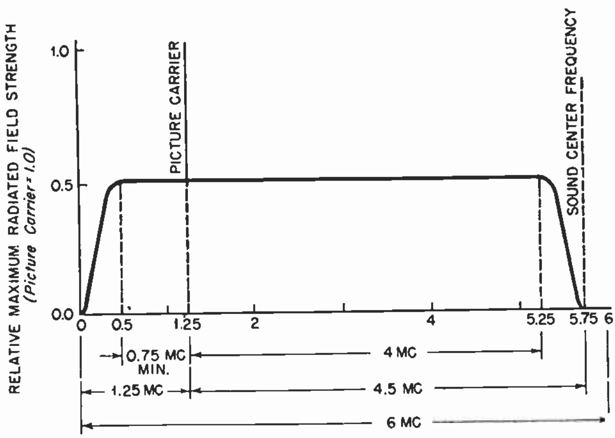


FIG. 10.1 A channel 6 mc. wide is provided by the licensing authority for television broadcasting purposes. The figure illustrates the relative positions of the picture and sound carriers and also the approximately single sideband transmission involved. Actually, the lower sideband is attenuated 20 db. at 1.25 mc. below the visual carrier.

band energy. Determination of whether or not satisfactory attenuation is achieved is brought about through an exploration of the frequency spectrum in the portion of the band in which the station operates and at some distance from the transmitter. Field-intensity measurements are made to determine the amplitude of signal voltage at spot frequencies both above and below the channel, as well as throughout the channel itself. This will indicate the relative field voltage at the various signal frequencies at which measurements are made, a curve being prepared from the data to indicate the lower sideband attenuation characteristic of the transmitter.

Of the commercial television transmitting equipments now in use in the United States, three manufacturers have employed three separate and distinct means of complying with the requirements insofar as transmitter design and circuits are concerned. All achieve the same result. The radio-frequency carrier frequencies of Du Mont, R.C.A., and General Electric visual transmitters are all obtained through use of precision crystal-controlled oscillators and frequency-multiplier stages. The current R.C.A. visual transmitter makes use of narrow-band frequency multipliers up to the output or final stage of the transmitter; high-level AM modulation at the grid of the final amplifier being employed. The General Electric visual transmitter incorporates a system wherein frequency multiplication to carrier frequency is carried out at low level in the transmitter, with amplitude modulation occurring at the approximately 1-w. carrier power level. A system of plate modulation is made use of. Five linear radio-frequency power amplifiers follow the plate-modulated stage, bringing the rated transmitter peak power output up to the 5-kw. level. The high-power linear amplifier stages are wide-band grounded-grid amplifiers, the pass-band characteristics of each linear stage being so developed with respect to the visual carrier frequency that proper lower sideband attenuation is obtained and held constant without the use of a vestigial sideband filter.

The Du Mont visual transmitter incorporates a system whereby modulation is effected at neither strictly high level nor low level. Grid modulation is employed at a 500-w. amplifier stage, the modulated stage being followed by two class B linear grounded-grid amplifier stages. The modulated stage and the two following linear amplifier stages are all tuned so as to result in the proper vestigial sideband signal. The elimination of additional linear power-amplifier stages makes for greater operating economies. Fewer high-power tubes are used, tube costs are reduced, and there is a conservation of amplifier plate input power for the over-all transmitter. In addition, maintenance problems are minimized, since fewer stages are used.

Of the several types of transmitters in current use, much can be said pro and con about the relative merits of the modulation systems employed. If modulation is employed at a high radio-frequency level in the transmitter, a high-powered modulator is required to develop the requisite video voltage required for complete modulation of the carrier. At the same time it may be said that transmitters employing high-level modulation are easier to tune, each stage that precedes the modulated stage constituting a narrow-band amplifier which may be easily and quickly adjusted. Tuning is accomplished through merely observing meter readings during the process.

Moreover, the stages preceding the final amplifier may be operated at high efficiency. A disadvantage is imposed by the necessity for a vestigial sideband filter in the antenna circuit, its purpose being to attenuate the lower sideband of the carrier by the amount prescribed by the F.C.C. It is an expensive item, which must be included in the cost of the transmitting equipment. At the same time, the filter is a positive means for assuring the desired lower-sideband characteristic. In comparing the relative merits of television broadcasting transmitters, it is well to obtain from each manufacturer a list of the tubes employed in the transmitter, together with a statement as to the net cost of the tubes to the broadcaster. These data will afford a comparison of installed-tube costs and will also provide an estimate as to the replacement costs under operating conditions. Generally, tube replacements are an important item in operating costs.

The visual transmitter, which employs low-level modulation, makes use of a number of wide-band amplifier stages which must be critically tuned through reference to a sweep pattern on a cathode-ray oscillograph. This critical tuning is necessary in order that the transmitted signal may be of the proper sideband characteristic; that is, the lower sideband is to be attenuated at least 20 db. at 1.25 mc. below the visual carrier. Another disadvantage lies in the possibility that the tuning may change with aging of components and temperature change, once the desired characteristic has been obtained and the proper tuning established. This condition dictates the use of components in critical circuits that are not materially affected by the ambient gradient within the transmitter enclosures during normal operation. Unquestionably, such a transmitter can be produced at lower cost and is at the same time more economical in operation because fewer stages need be used employing expensive tubes, and the cost of the vestigial sideband filter is eliminated.

Cooling methods employed at the vacuum tubes of the several television transmitters in current production varies somewhat. The Du Mont Master Series transmitter makes use of air-cooled tubes throughout, resulting in operating economies, since no water-cooling system is required at the transmitter location. The water-cooled tubes used in the General Electric transmitters are both small in physical size, and efficient. The R.C.A. transmitter makes use of a water-cooled tube in the final amplifier, which is unique in that the plate, the grids, and the filament seals are all cooled by water. A cooling system that utilizes very carefully filtered distilled water is required. This is so that minute dirt particles will not block the narrow passages through the grids, such blocking resulting in possible tube failure. On the other hand, failure of the air blowers, where air-cooled tubes are made use of, can also result in possible tube failure.

All transmitters are provided with protective systems so that failure of air or water supply will result in the transmitter being automatically taken out of operation. Thus, the station engineer must exercise a diligent maintenance program in seeing that equipment supplying either air or water and the associated protective circuits are always operated in top-notch condition. If air cooling is used some means must be provided for exhausting the warm air developed through heat dissipation at typical air-cooled tubes. This means the installation of an air-duct system and a motor-driven blower. The warm air may be used in heating the building during the winter months and it may be directed outdoors during summer. If the transmitter room is large and difficult to heat, the use of this warm air during winter months may lead to operating economies. The engineer must decide which transmitter he prefers from the facts stated herein, although many other points may be made in favor of one or the other of the transmitting equipments.

The aural transmitting equipment of the television station employs frequency modulation, the merits of which are well known. The sound transmitter is designed to satisfactorily operate with a frequency swing of ±25 kc. about the mean carrier, which is equivalent to 100 per cent modulation. In the actual design of the transmitter, however, the unit must be capable of a frequency swing of at least ±40 kc. This provides assurance that complete modulation under normal operating conditions will occur without appreciable distortion being introduced.

The FM transmitting system must be capable of transmitting a band of frequencies from 50 to 15,000 c.p.s. This condition applies to the over-all response of all equipment from the input terminals of the microphone preamplifier to the antenna, including studio audio facilities, program lines connecting studio and transmitter, the audio terminal facilities at the transmitting location, but not including equalizers for the purpose of correcting microphone response. It is important when making measurements to determine the operating characteristics of the complete transmitting system that over-all measurements be made of the entire system. Otherwise, the introduction of distortion or noise may be cumulative, if individual portions of the system are measured, leading to an incorrect conclusion as to the over-all fidelity characteristics of the system.*

Pre-emphasis is employed in the sound transmitter, a 75-μsec., series inductance-resistance network being used. The deviation of the *over-all* system response from the standard pre-emphasis curve of F.C.C. must lie between an upper and a lower limit as shown in Fig. 10.2. The upper limit is to be uniform from 50 to 15,000 c.p.s. The lower limit is made uniform from 100 to 7,500 c.p.s. and 3 db. below the upper limit. Between 100 and 50 c.p.s. the lower limit must fall from the 3-db. limit at a uniform rate of 1 db. per octave (4 db. at 50 c.p.s.). From 7,500 to 15,000 c.p.s., the lower limit must depart from the 3-db. limit at a uniform rate of 2 db. per octave (5 db. at 15,000 c.p.s.).

The maximum percentage harmonic distortion has been specified by the licensing authority. Between 50 and 15,000 c.p.s. and at modulation

* Helt, Scott, "What Is Wrong with TV Sound?" *Communications*, September, 1948.

percentages of 25, 50, and 100 per cent, the total audio-frequency harmonics measured in the *output of the system* must not exceed the r.m.s. values shown in the following table:

Frequency Range, c.p.s.	Per Cent Distortion
50–100	3.5
100–7,500	2.5
7,500–15,000	3

Measurement of the total harmonic distortion must be made, employing 75-μsec. de-emphasis in the measuring equipment, and 75-μsec. pre-emphasis in the transmitting equipment. *No* compression is em-

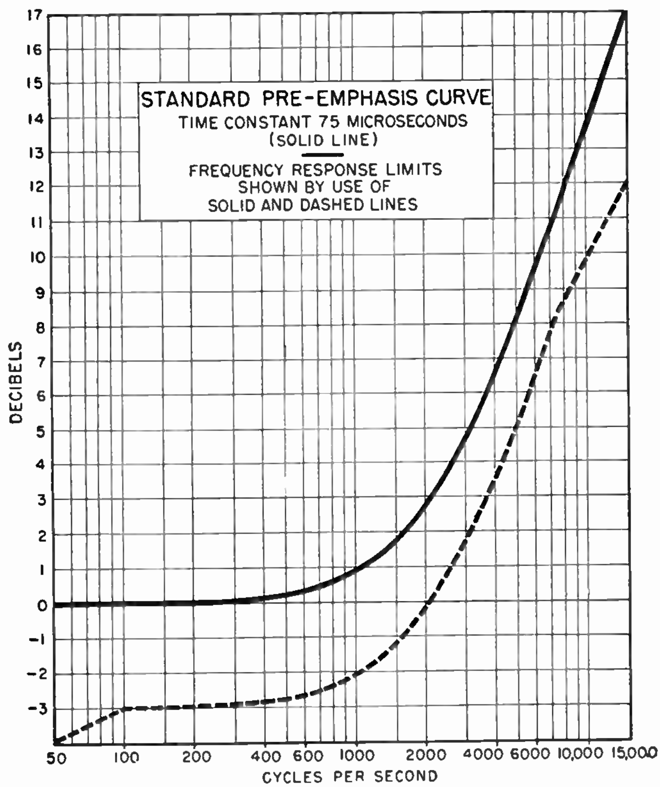


FIG. 10.2

ployed anywhere in the system. If a compression amplifier is used, the compression feature must be removed when measurements are attempted, since in some installations a so-called compression amplifier is used as the line-terminal audio amplifier for purposes of driving the transmitter. Harmonics must be measured out to 30,000 c.p.s. It is important to note that the permissible distortion figures are given for the *entire* system and not for the transmitter alone. The F.C.C. recommends that no main division of the entire transmitting system contribute more than 50 per cent of the total maximum distortion allowable in any of the audio-frequency ranges indicated. Noise level in the band of 50 to 15,000 c.p.s. for the *complete* aural transmitting system (FM noise) must be at least 55 db. below the level representing 100 per cent modulation, or the level required to swing the carrier ±25 kc. The AM noise shall not be less than 50 db. below the level representing 100 per cent modulation. The carrier frequency must be held constant within ±0.002 per cent of the assigned value. For channel 5, this means that the carrier frequency must not deviate more than 1,545 c.p.s. from the assigned visual carrier frequency of 77.25 mc. The same frequency tolerance is required of the sound transmitter. Suitable frequency-monitoring equipment is maintained at the television transmitter to assure that the station operates within the prescribed limits.

10.2 The Du Mont Master Series TV Transmitter. The design of the Du Mont transmitter is such that modulation is effected halfway between points in the system where high- or low-level modulation usually takes place. This design was originally chosen because it was considered too expensive to provide wide-band video amplifiers capable of furnishing voltage and power necessary for high-level modulation. Tubes that have the requisite power rating for use in a high-level modulation system are both expensive and relatively inefficient, adding to the cost of transmitter construction. Such tubes ordinarily have relatively high inter-electrode capacitances, which makes the neutralizing problem a difficult one to deal with. When the available tubes are employed in a high-level system, it has ordinarily been found necessary to employ unique methods for high-frequency compensation and to provide low-value load impedances for the tubes to work into. Water-cooled load resistors have been used in some transmitters where high-power levels are involved. The use of water-cooled resistors to broad-band high-power amplifiers is both expensive and inefficient.

A system of progressive circuit attenuation is used in the Du Mont Master Series transmitter to ensure adherence to the F.C.C. requirements respecting the desired lower sideband characteristic. The radio-frequency band-pass characteristic of all amplifiers following the modulated stage are adjusted for proper attenuation of the lower sideband. This was considered less expensive than the provision of a vestigial sideband filter, since the design results in operating economies as well as conservation of power.

The Du Mont Master Series transmitter is described by the block diagram in Fig. 10.3. It will be seen that the three principal divisions of the transmitter may be considered as the section devoted to generation of the carrier frequency, the section devoted to modulation, and that portion of the transmitter devoted to amplification after the modulation process. It will be seen that the minimum number of class B linear radio-frequency amplifiers are necessary with this particular transmitter design.

The production of the required radio-frequency carrier is provided by means of a precision temperature-controlled crystal in a suitable oscillator circuit, followed by a frequency-multiplier chain with a mul-

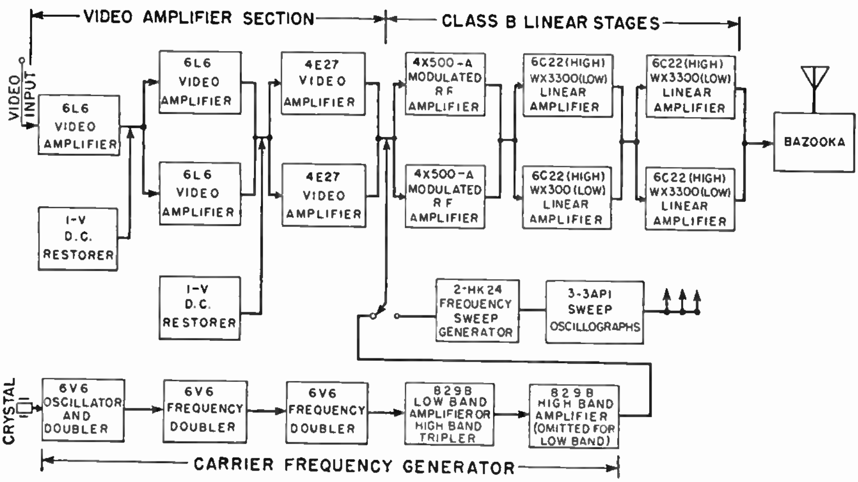


Fig. 10.3

tiplication factor of 8. A double-ended amplifier, making use of a type 829–B vacuum tube, is employed as a straight-through amplifier (at normal carrier frequency) to drive the modulated amplifier. This latter amplifier makes use of two type 4X500–A vacuum tubes in push-pull.

The modulator unit incorporates a three-stage wide-band amplifier, the final stage of which operates as a direct coupled amplifier. The cathode is at negative potential so that bias and d-c restoration can be applied to the modulated amplifier. It will be noted that the drive from the video modulator and the radio-frequency drive from the exciter unit are both applied to the grids of the modulated-amplifier tubes. Proper adjustment of the latter amplifier stage provides a modulated radio-frequency signal of finite power level. The output of the modulated stage may be used to drive the antenna directly for low-power operation, or it can be used properly to drive successive linear class B radio-frequency amplifiers in tandem to produce any practical desired power level. Linear class B radio-frequency amplifiers follow the modulated stage, since nonlinear amplifiers will result in distortion of the applied signal. This distortion is usually in the form of sync compression or white saturation. The required linear amplifiers necessitate careful tuning for optimum operation where radio-frequency voltages are present. Such tuning is accomplished while observing the

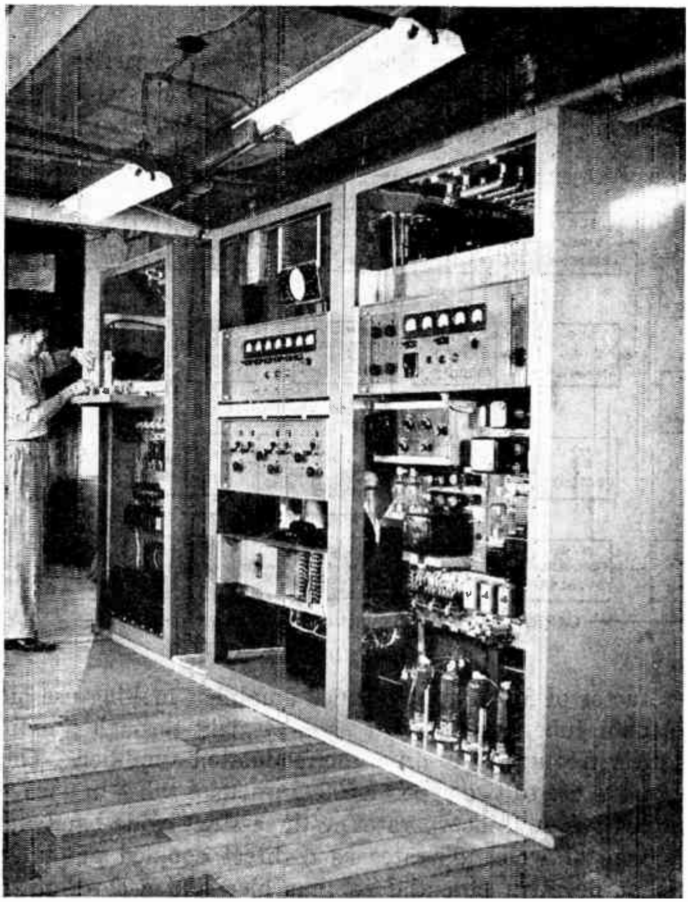


FIG. 10.4 Three frames housing the video exciter 5-kw. video final amplifier, and 5-kv. power supply. The units are set up for test. A metal cover, or "skin," houses the complete transmitter. (Courtesy of Allen B. Du Mont Labs., Inc.)

display on the screen of a cathode-ray oscillograph, since it is suitably connected and provided with a sampling voltage to indicate the resulting wave shape due to tuning. Built in cathode-ray oscillographs are provided for this purpose. Usually three are used. By this means the wave shape at three points in the system may be viewed simultaneously while tuning is being accomplished. The input to the oscillographs may be switched from point to point.

Two class B linear radio-frequency amplifiers follow the modulated stage in the Du Mont Master Series transmitter. Each stage incorporates two Westinghouse type WX3300 vacuum tubes. The grounded-grid type of the radio-frequency amplifier circuit is made use of, since

FIG. 10.5 Tuning up the video exciter unit of the Du Mont master series TV transmitter. The front panels and "skin" have been removed to facilitate final factory test. (Courtesy of Allen B. Du Mont Labs., Inc.)

it results in simplified tuning and provides an amplifier that is relatively easy to neutralize. It is very important that any linear amplifier carrying video-modulated radio frequency be most carefully neutralized, otherwise picture distortion is likely to result.

The F.C.C. in its Standards of Good Engineering Practice Concerning TV Broadcast Stations requires that the frequency of the transmitted carrier be held within a tolerance of ±0.002 per cent of that assigned.

In this transmitter, a relatively low frequency crystal is temperature-controlled at the oscillator, the crystal frequency being multiplied eight times up to carrier frequency. An AT-cut zero temperature coefficient crystal is made use of to insure the requisite frequency stability. A type 6V6GT/G vacuum tube is employed in a tri-tet oscillator circuit (see Fig. 10.6). This is a well-known and conventional circuit. The plate circuit of the oscillator is made resonant at twice the crystal frequency, thereby operating as a doubler. The crystal controlled oscillator is succeeded by two frequency-doubler stages, each incorporating a type 6V6GT/G vacuum tube. Radio frequency energy at carrier frequency drives the 829–B push-pull stage, which functions as a typical

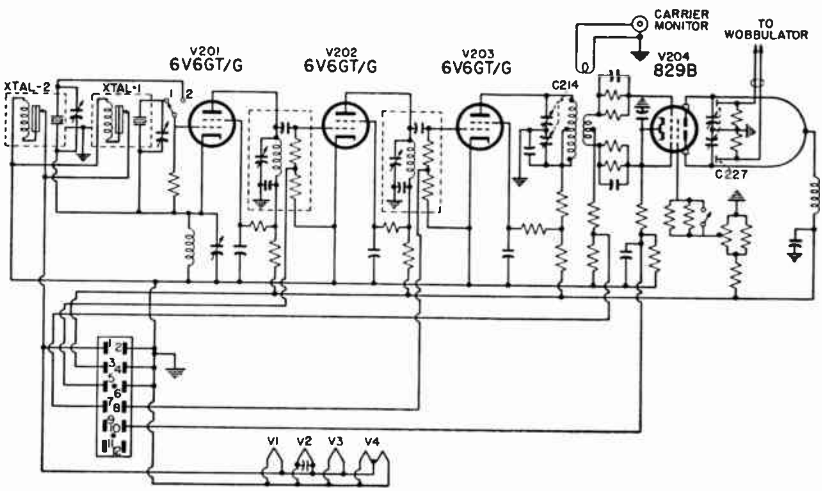


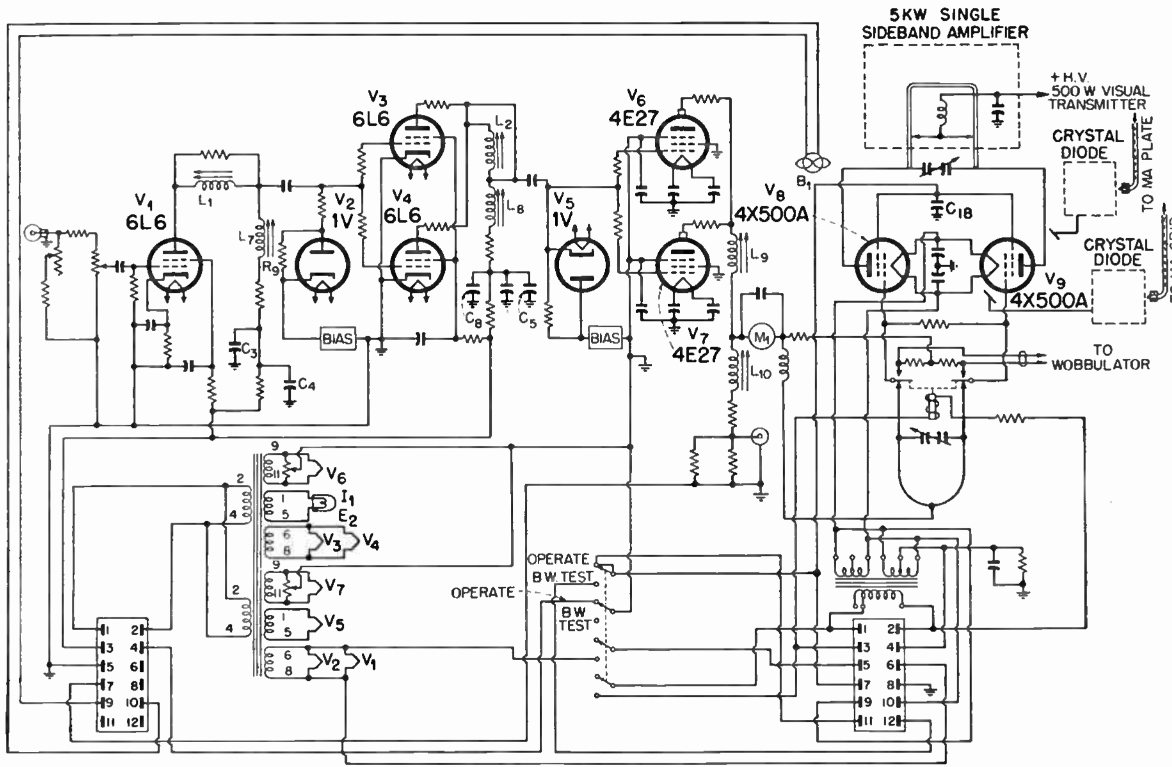
Fig. 10.6

buffer amplifier. The output of the 829–B stage is, in turn, coupled to the modulated amplifier, and this stage makes use of two type 4X500–A tetrodes in a conventional push-pull circuit. All the exciter amplifiers in the transmitter are adjusted as class C amplifiers and frequency doublers and employ lumped circuit constants such as are usually found in low-level very high-frequency amplifiers of this type. Class C operation provides high operating efficiencies. For ease of tuning, each stage is metered through use of a suitable switching arrangement whereby maximum grid current indication may be used to indicate resonance in the tuned circuits. The cathode current is metered at the 829–B stage. The modulated-amplifier grids are loaded with a noninductive resistor which accomplishes a twofold purpose. The 829–B driver stage is properly loaded by means of the resistor, so that the radio-frequency driving voltage is constant. At the same time, this loading broadens the response curve. The result is that any sum and difference frequencies developed in the grid circuit, due to the modulation process, will not suffer attenuation. Grid tuning is adjusted at the modulated amplifier for an indication of maximum grid current, indicating a condition of resonance.

The video modulator circuit is shown in Fig. 10.7. In order to provide a means of tuning, a radio-frequency sweep signal may be substituted for that of the radio-frequency driver, the sweep signal being furnished by a built-in wobbulator. It will be noted that three stages of video amplification are made use of. The first stage employs a type 6L6 vacuum tube V_1 low-frequency compensation being used in the plate circuit of the amplifier, together with series-shunt or combination high-frequency peaking. The input stage is followed by a parallel-connected video amplifier which incorporates two type 6L6 tubes. Combination high-frequency peaking is used again here, together with conventional low-frequency correction in the plate circuit. To refer the video signal to the bias level of this stage, in order to permit full realization of the available grid bias without distortion when high-amplitude signals are passed through, a type 1V d-c restorer is employed. Two type 4E27 vacuum tubes are parallel connected as the modulator. A minimum of one volt of signal from the paralleled 6L6 amplifiers will drive the modulator to plate current cutoff.

The modulator plate load serves to provide video signal to the modulated amplifier as well as to furnish a negative d-c voltage to the modulator for biasing purposes. The plates of the 4E27 tubes employed in this stage must be held negative with respect to ground, so that the grids of the modulated amplifier tubes will be negative with reference to their filaments. The filaments are at ground potential. The requirements are satisfied by connecting the plate load return and the positive plate potential of the 4E27 to ground, requiring that the 4E27 cathodes be referred to a negative potential with reference to ground. A regulated power supply provides the negative potential for the purpose, its output being made variable so as to satisfy the operating requirements.

The bias voltage of the modulated amplifier stage is adjusted by means of the variable potential, varying the quiescent plate current. This adjustment alters the voltage drop across the plate load. The video sync signal is restored to the bias reference level by means of the type 1V restorer tube. The modulator functions as a d-c coupled amplifier. Thus, the restored signal is carried through to the plate load and operates to maintain the sync tips at the quiescent bias level of the modulated amplifier when signal amplitudes are subject to change. The over-all frequency response of the video modulator-amplifier is essentially flat from approximately 10 c.p.s. to an upper limit in the vicinity of 5.5 mc.


5KW SINGLE
SIDEBAND AMPLIFIER
+H.V.
500 W VISUAL
TRANSMITTER
CRYSTAL
DIODE
TO MA PLATE
CRYSTAL
DIODE
TO MA GRID
TO
WOBBULATOR
V1
6L6
V2
1V
V3
6L6
V4
6L6
V5
1V
V6
4E27
V7
4E27
V8
4X500A
V9
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L1
L2
L7
L8
L9
L10
R9
C3
C4
C5
C8
C18
B1
M1
BIAS
BIAS
I1
E2
OPERATE
BW TEST
OPERATE
BW
TEST

Fig. 10.7

Grid-bias modulation is employed in the Du Mont Master Series transmitter. The operation of the grid-bias modulated stage is similar to that of a class B amplifier in some respects. The vacuum tubes are biased near the point for plate current cutoff. Therefore, changes of signal about the operating point result in the delivered waveform varying over the linear portion of the grid-plate transfer characteristic. If the bias is excessive, operation will obtain about the lower knee of the grid-voltage plate-current characteristic curve, and nonlinear distortion will occur. This results in compression of the "whites" in the picture. If the grid bias is adjusted below optimum, sync compression will occur owing to operation about the upper knee of the grid-voltage–plate-current curve. Improper biasing of the modulated stage may be determined through observing the output waveform of the modulated amplifier through use of a cathode-ray oscillograph. The waveform should, in all respects, be a reproduction of the input waveform. A diode is employed to demodulate the signal so that the video plus blanking plus sync signal may be examined. A diode pickup system is coupled to the output of the amplifier for this purpose. Figure 10.7 shows the essential video amplifier, d-c restorer, and video modulator system of the Du Mont Master Series transmitter.

This transmitter makes use of two Westinghouse WL3300 air-cooled tubes as a class B linear amplifier, following the modulated stage. A second linear amplifier, incorporating two additional type WL3300 vacuum tubes, follows the first class B amplifier. Both stages are grounded-grid connected for simplicity and to ensure proper neutralization. A much greater over-all apparent efficiency occurs, since a direct transfer of modulated energy passes from the first class B amplifier into the output stage. This type of connection reduced the number of linear amplifiers following the modulated stage and results in efficient provision of the required power level at the output-amplifier stage. It will be noted that the stages are both cathode-driven. This results in proper loading of the preceding stage without resistive loading in the output of each stage to obtain the desired bandwidth. Coupled circuits with resonant primaries and secondaries, variable coupling, and adjustable secondary loading facilitate the provision of proper bandwidth in amplifier design.

The transmitter output is essentially of the balanced type, push-pull operation being employed. This is shown in Fig. 10.8. Depending upon the antenna system to be excited, either a balanced or unbalanced output is provided. If balanced output is desired, dual transmission lines are connected to the output coupling network. If an unbalanced output is desired, a bazooka must be used. This bazooka comprises a quarter-wave isolation transformer, which essentially places the output trans-

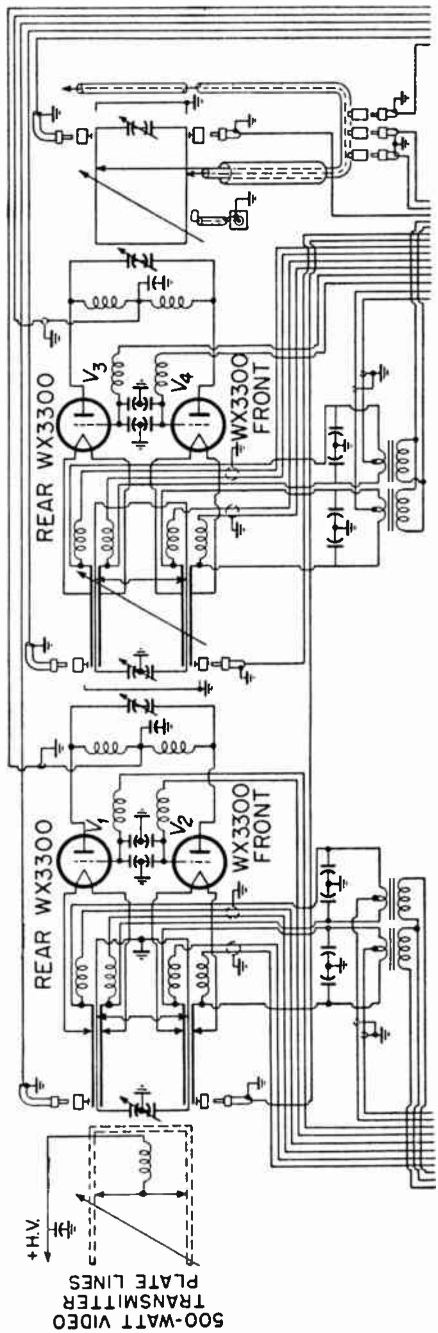

REAR WX3300
V_3
V_4
WX3300 FRONT
REAR WX3300
V_1
V_2
WX3300 FRONT
+H.V.
500-WATT VIDEO TRANSMITTER PLATE LINES

Fig. 10.8

mission line at a higher impedance with respect to the transmitter chassis or frame. Through capacitive end loading for channels 2 and 3 and stub shortening for channels 4, 5, and 6, the electrical length of the bazooka is made variable. To ensure optimum transfer of power, together with optimum bandwidth, the antenna must constitute a zero

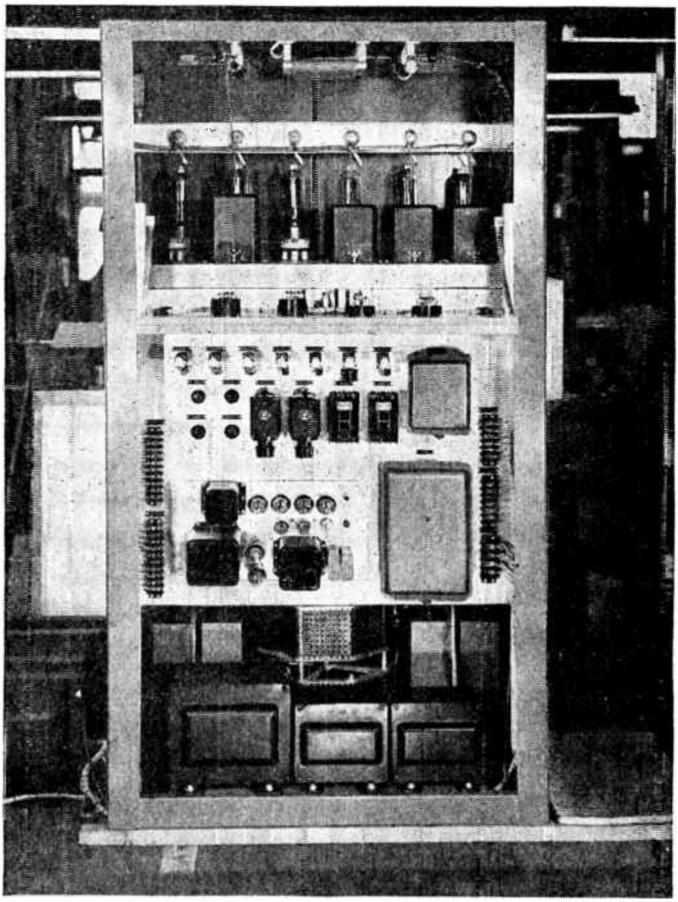


FIG. 10.9 The high voltage power supply for the power amplifier of the Du Mont master series transmitter. Covers have been removed. (Courtesy of Allen B. Du Mont Labs., Inc.)

reactive load at the far end of the transmission line. The standing wave ratio (S.W.R.) must be better than 1 : 1.01 through a pass band which extends at least 4.5 mc. above the video carrier frequency, if optimum picture quality is to be ensured. A greater S.W.R. will result in reflections back into the output circuit of the final amplifier. Multiple imaging, or ghosts, will then most likely obtain.

10.3 The R.C.A. Type TT-5A Television Transmitter. The visual transmitter employs high-level modulation. Figure 10.10 indicates the essential design of the equipment. A crystal-controlled oscillator, the crystal of which is precision-ground and carefully temperature-controlled, provides the requisite frequency stability of the transmitted carrier. Three temperature-controlled crystals are actually made use of. One is used for tuning of the final stage; one is termed the "operate" crystal;

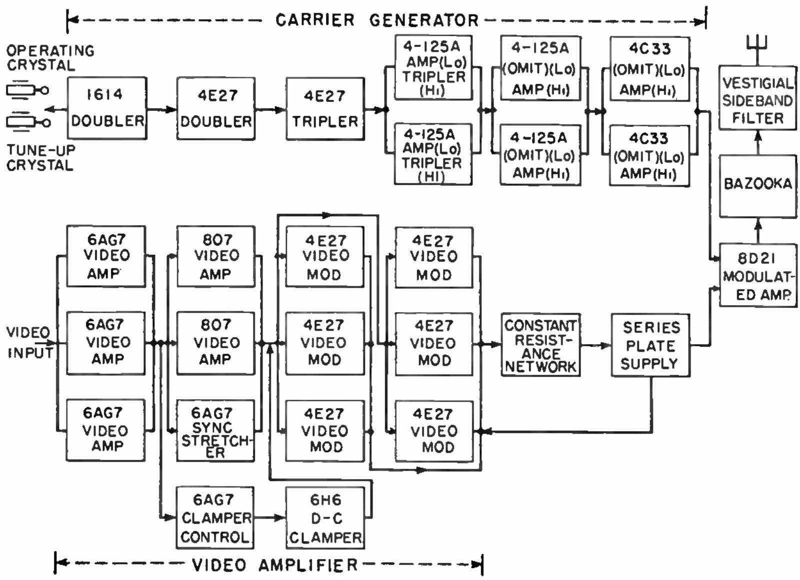


FIG. 10.10

the third is a spare. The crystal frequency is doubled in the oscillator stage, then followed by a conventional frequency doubler. The doubler is followed by a frequency tripler. The tripler is succeeded by a straight-through amplifier when operation in the lower band is desired. If operation is intended on one of the higher channels, a second tripler follows the tripler already referred to. Two additional amplifiers are included to provide the requisite driving power at carrier frequency. Before the final amplifier, two type 4033 vacuum tubes furnish approximately 400 w. of radio-frequency power at carrier frequency to drive the output amplifier adequately. This output amplifier incorporates an R.C.A. type 8D21 water-cooled vacuum tube.

The R.C.A. type 8D21 vacuum tube is of unique design. Water is forced through the plate and through both the control and screen grids (which are hollow) in order to dissipate the heat developed under operating conditions. A flow of approximately 1.7 gal. of distilled water per minute are required for optimum cooling. Water is also used to cool the filament seals. The cooling system employed permits the tube to operate at a plate dissipation of approximately 370 w. per sq. cm. of tube anode surface. High plate efficiency is obtained, and operation at full power rating is obtained through channel 13.

To impart a thorough understanding of the R.C.A. TT–5A Visual Transmitter, a complete description of the circuits will be given. Later, information will be included concerning the Sound Transmitter, the two separate units comprising the complete television transmitter that has

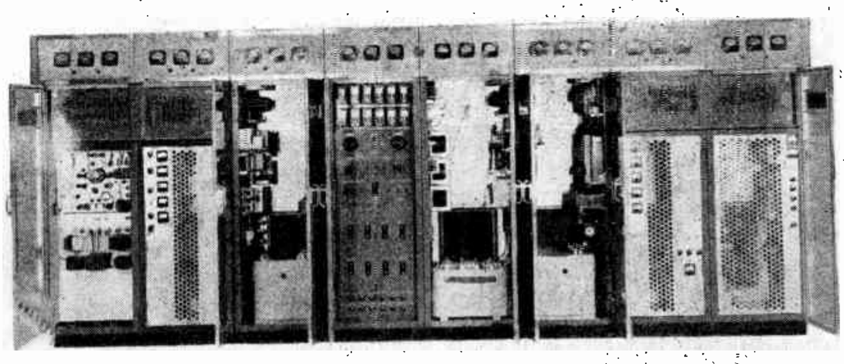


FIG. 10.11 Front view of RCA TT–5A transmitter with all doors open. (Courtesy of Radio Corporation of America.)

been designed for operation on all channels allocated by the F.C.C. for commercial television broadcasting.

The crystal-controlled oscillator of the visual transmitter uses a type 1614 vacuum tube. The plate circuit of the oscillator stage is tuned to double the frequency for which the quartz plate is ground. Thus, the frequency of the radio-frequency energy at the output of this stage is twice that of the crystal supplied with the transmitter. This output is link-coupled to a doubler that incorporates a type 4E27 tube. The doubler, which is conventional in that the output frequency of the energy developed is twice that present at the input, drives a type 4E27 tripler stage. Here, the carrier energy is tripled through suitable tuning of the amplifier output circuit.

The tripler amplifier is inductively coupled to the tuned grids of two 4-125A/4D21 vacuum tubes that are operated in a conventional push-pull circuit. For operation on the lower television channels, 54 to 88 mc. per sec., the push-pull stage drives the type 8D21 power-amplifier stage directly. This latter output stage makes use of the water-cooled tube which has been previously described.

For operation on television channels 174 to 216 mc. per sec., the push-pull 4-125A/4D21 driver stage is operated as a tripler, two additional radio-frequency stages being added to get the carrier power level up to that proper for efficient drive of the 8D21 power amplifier or output stage. The first added push-pull stage employs an additional pair of type 4-125A/4D21 tubes. The second added stage makes use of two type 4C33 tubes, also connected in push-pull. No neutralization is required because of the adequate shielding within the power-amplifier stage and between the input and output circuits of the amplifier stage.

FIG. 10.12 R.C.A. transmitter control console. (Courtesy of R.C.A-Victor.)

The grid tank circuit of the 8D21 power-amplifier stage tunes to ¼ wavelength on channels 2 through 6 and to ¾ wavelength on channels 7 through 13. The picture signal, for purposes of amplitude modulation of the radio-frequency carrier at power-amplifier level, is applied to the grids of the type 8D21 water-cooled tube.

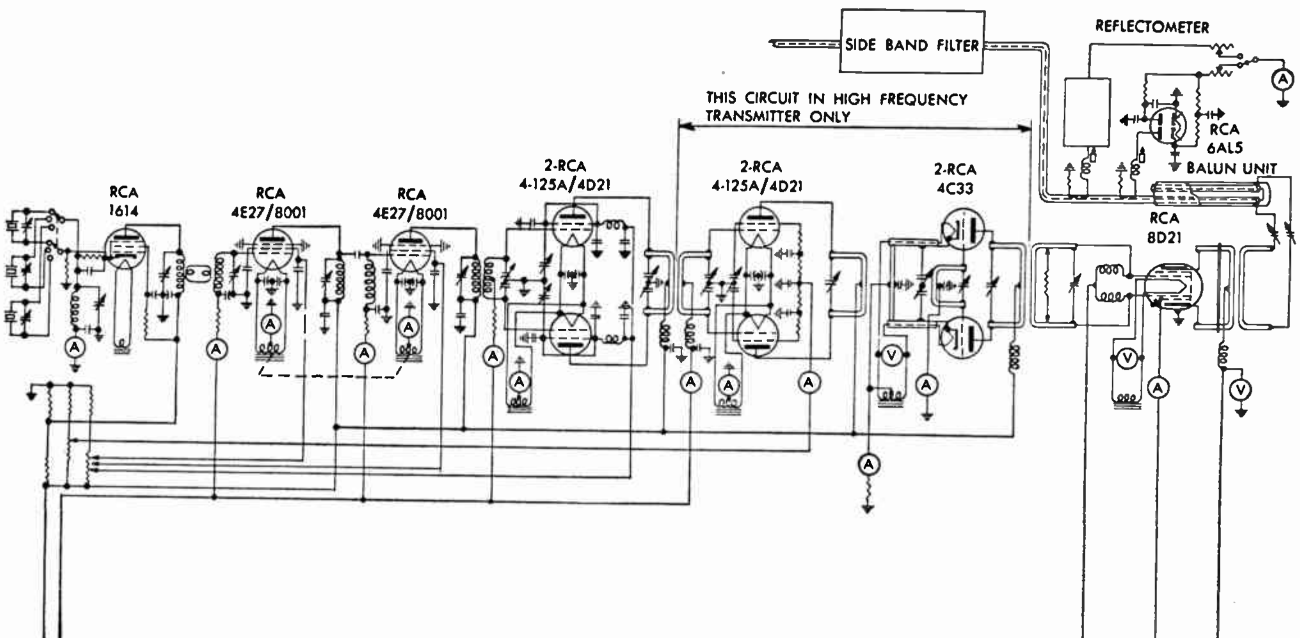
One feature of this visual transmitter is a damping circuit located in the grid circuit of the 8D21 power-amplifier stage. This circuit is arranged to absorb a constant amount of radio-frequency energy from the driver stage. This serves to reduce to the absolute minimum, or to damp out, any significant changes in loading that might occur during the modulation process. An appreciable magnitude of power-amplifier grid current flows at sync peaks, as compared with the time interval when white-picture elements are transmitted when no grid current flows. Consequently, with the use of the damping circuit, the radio-frequency driving voltage is held almost constant throughout the range of modulation. This serves to improve the modulation linearity in the high-output region.

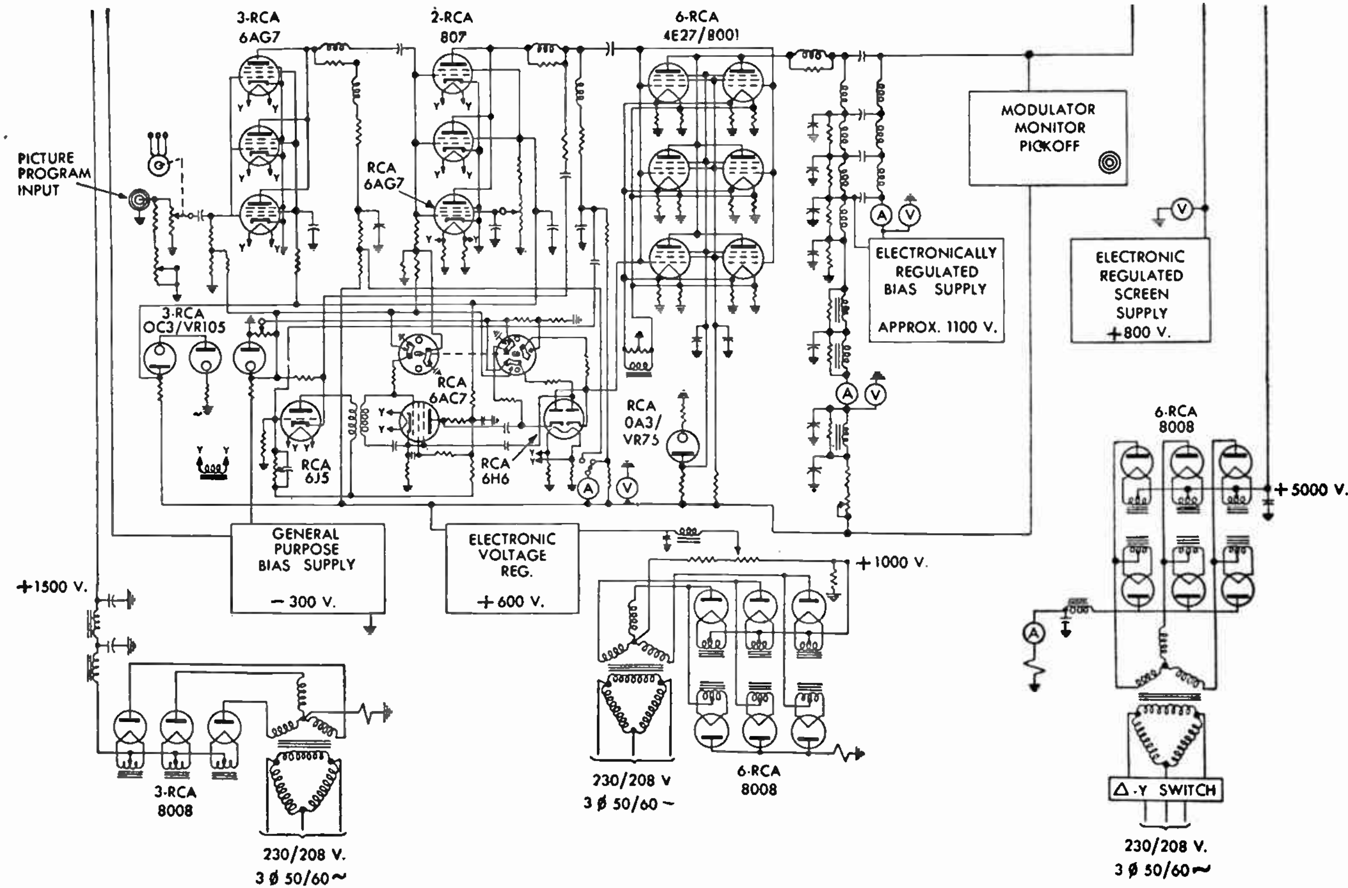
The radio-frequency power from the power-amplifier plate tank is coupled to a series-tuned output tank from which it is fed to the coaxial transmission line. Broad-band response is achieved through slightly overcoupling the plate tank and the output tank circuits. The controls for effective tuning of these circuits are brought out to the front panel of the transmitter for ease of adjustment. As a matter of fact, all tuning controls of the exciter, multiplier, and driver stages are similarly brought to the face of suitably interlocked screen doors, which are located back of the front doors of the transmitter. Adequate protection is afforded against the operating personnel coming into contact with high-voltage circuits. A Balun (balanced-to-unbalanced) unit serves to provide a match between the push-pull output circuit and the single-ended coaxial transmission line. Two reflectometers, located within the transmitter cabinet proper, are coupled to the coaxial transmission line. These provide a suitable means for measuring the standing-wave ratio as well as the relative power output of the transmitter. They also serve to protect the coaxial transmission line from possible injury due to high-potential surges that might be brought about through improper termination of the line or to lightning entering from the antenna system. The latter possibility is not likely to occur except in rare instances when the super-turnstile type of antenna is employed, since the super-turnstile is so constructed that the central steel pole supporting the elements is at ground potential.

The reflectometer is essentially a peak-reading vacuum-tube voltmeter. The pickup coil for the device is so designed that when coupled to a properly terminated line, where no standing waves are present, the potential pickup due to inductive coupling is equivalent to that due to capacitive coupling. A suitable meter connected in the output circuit of the diode rectifier indicates a value that is proportional to the sum of these voltages. Should the polarity of the potential on the transmission line be changed or the connections of the pickup coil reversed, the output meter will indicate zero. Because the waves traveling from the transmitter to the antenna, through the transmission line, are of opposite polarity to the waves returning from the antenna, the outgoing, as well as the incoming, waves can be measured. For this reason, two reflectometers are present in the transmitter. One has its pickup coil oriented to indicate the incident wave, and the other is so oriented as to indicate the reflected wave.

Once the incident-wave reflectometer has been calibrated in the field, employing a dummy antenna or load, the transmitter peak-power output may be directly obtained. The other reflectometer, that responsive to

FIG. 10.13 Schematic diagram of the R.C.A. TT-5A picture transmitter.




3-RCA
6AG7
2-RCA
807
6-RCA
4E27/8001
PICTURE
PROGRAM
INPUT
RCA
6AG7
MODULATOR
MONITOR
PICKOFF
ELECTRONICALLY
REGULATED
BIAS SUPPLY
APPROX. 1100 V.
ELECTRONIC
REGULATED
SCREEN
SUPPLY
+800 V.
3-RCA
OC3/VR105
RCA
6AC7
RCA
0A3/
VR75
RCA
6J5
RCA
6H6
6-RCA
8008
+5000 V.
GENERAL
PURPOSE
BIAS SUPPLY
− 300 V.
ELECTRONIC
VOLTAGE
REG.
+600 V.
+1000 V.
+1500 V.
3-RCA
8008
230/208 V.
3 ø 50/60 ~
230/208 V
3 ø 50/60 ~
6-RCA
8008
Δ-Y SWITCH
230/208 V.
3 ø 50/60 ~

the reflected wave, may be employed to control the bias voltage of an R.C.A. type 2050 vacuum tube. It fires and operates overload relays when the voltage traveling toward the transmitter exceeds some predetermined value. Thus, protection is afforded against surges back into the transmission line from the antenna due to a lightning hit or due to a mismatch condition, when reflected energy would be injurious to the output circuits.

If we refer to the diagram describing the circuit arrangement of the R.C.A. type TT–5A Visual Transmitter, we shall see that the picture amplifier and modulator unit comprises two video amplifier stages, the video modulator stage, sync expander, sync separator, sync amplifier, and a d-c insertion diode. The first video stage makes use of three type 6AG7 vacuum tubes parallel-connected. Series-shunt high-frequency compensation is employed in the plate circuit, and conventional low-frequency compensation ensures against frequency distortion originating in this part of the system. The peak video input voltage may be controlled either at the transmitter or at the transmitter console. The latter unit is usually situated so as to face the transmitter. When control of the amplitude of the input signal is effected at the transmitter, a reversible motor drives the gain-control potentiometer. This arrangement allows the transmitter engineer to correct quickly any appreciable change in the video signal level whether he is seated at the console or on duty in front of the transmitter.

The video signal from the first video amplifier is suitably coupled to the second video stage in a conventional manner. This second stage employs two type 807 tubes which are parallel-connected. Since some reduction in sync-pulse amplitude is likely to occur in the succeeding modulator and video power-amplifier stages, a type 6AG7 vacuum tube is parallel-connected with the two type 807 amplifiers. Since the 6AG7 possesses high transconductance and essentially sharp cutoff, it is employed to expand the sync-pulse amplitude. This expansion is accomplished through employing the plate current of the 6AG7 to increase the combined plate currents through the amplifier plate load during the sync-pulse interval. The system is so arranged that an increase of approximately 30 per cent, with reference to the amplitude of the sync pulse, may be achieved without any increase of the picture signal. The plate current of the 6AG7 is controlled through provision of a potentiometer in the screen-grid circuit.

The grids of the power-amplifier stage are modulated by six type 4E27 tubes which are parallel-connected. The modulator plate load comprises a constant-resistance network made up of four high-frequency sections and three low-frequency sections. The constant-resistance network serves to provide a constant impedance of 500 ohms throughout the video band. The section of the network that is tuned to the lowest frequency in the band employs the internal resistance of the modulator power supply as a portion of the plate load. This arrangement ensures excellent frequency response down to and including direct current.

The modulator stage of the picture transmitter incorporates a clamp-type d-c restorer circuit. This system makes use of a type 6J5 sync separator, a type 6AC7 sync amplifier and inverter, and a type 6H6 biasing and restorer tube. The system operates to disable the modulator tubes effectively during the latter portion of the horizontal blanking signal which occurs immediately succeeding the sync interval. The clamping action serves to reduce to the minimum above average amplitudes of spurious low-frequency signals, such as those due to microphonics, 60-c.p.s. hum, or power supply surges which inevitably occur in the preceding stages of this or any other visual transmission system. The clamper has already been described in some detail in the preceding chapter on the synchronizing generator, and the reader is now referred to this previous information, as well as to the appropriate definitions referring to clamping which have been included in the glossary of terms. This glossary of terms will be found following the text.

The horizontal sync separator is transformer-coupled to the sync amplifier and phase inverter, the transformer being tuned through use of associated tube and stray capacitances so that one half cycle at its resonant frequency possesses a duration of about 2 μsec. The transformer, through high damping by core losses, and to a lesser extent by circuit losses, dissipates its stored energy in the nature of a pulse. This pulse is amplified and inverted by the type 6AC7 vacuum tube, phase inversion being necessary to result in the 6H6 clamping the modulators on the rear portion of the horizontal blanking signal. It has already been pointed out elsewhere in the text that this is the preferred method of clamping. Clamping on the sync tips is not recommended because of the fact that the sync amplitude is likely to change owing to compression in any television transmission system. This compression serves to change the reference amplitude previously set in a sync clamper, i.e., one employing clamping at the sync tips. Through the system used in this transmitter, the modulator bias is automatically corrected to the same predetermined value for each blanking pulse transmitted, and the d-c component of the composite television system is effectively restored.

When transmitter tests are being conducted, it is the usual practice to modulate the transmitter with a signal that is symmetrical above and below the reference axis. Such a signal usually is in the form of a sine wave, square wave, or video sweep signal. When such signals are used, special adjustments are required throughout the transmitter, since the usual standard television signal is a complex one and differs quite considerably from those signals used for test purposes. When such test signals must, of necessity, be employed, the transmitter is adjusted for what is known as "mid-characteristic" operation, and the changeover from normal "d-c restorer" operation is brought about through use of an "a-c, d-c" switch. When the switch is operated in the a-c position, the grids of the second video-amplifier, the sync-amplifier, and the modulator-stage tubes are returned to a manually adjusted bias source, the clamping tubes being biased to cutoff. A type 6AG7 suitably coupled through a resistance attenuator to the output of the picture modulator serves as a phase inverter by providing video signals of negative polarity for the picture monitor located at the transmitter console.

Frames 5, 6, and 7 of the transmitter house the power supplies that provide plate and screen potentials for the visual radio-frequency portion of the transmitter. Frame 6 houses a 5,000-v. d-c power supply for the plates of the power-amplifier tube, a regulated 800-v. d-c supply which provides screen potential for the power amplifier, and a 1,500-v. supply for the plates and screens of the oscillator stage and the frequency multipliers and drivers. The driver-plate transformer is located in frame 5, the voltage dividers for this supply being located in frame 7. Three-phase full-wave rectification is employed at both the 1,500- and 5,000-v. supplies. The 5,000-v. supply for the final stage makes use of six type 8008 rectifier tubes, and the 1,500-v. d-c supply makes use of this same type tube. The 800-v. supply is voltage-regulated and employs two type 816 tubes that are connected in a single-phase full-wave rectifier circuit. The primary of the high-voltage transformer for the final stage may be changed from delta to wye connection for tune-up operation.

The modulator plate potential is developed through the use of six type 8008 rectifier tubes, which provide an output potential of 1,000 v. d-c. Voltage dividers at this power supply permit use of 600 v., electronically regulated, for the modulator screens and for the plates and screens of the video amplifiers. A regulated 300-v. supply provides bias potential for both the radio-frequency and video stages of the transmitter.

A single-phase full-wave rectifier provides regulated potential of 1,100 v. d-c as the negative reference voltage which opposes the variable (with d-c component) positive potential at the modulator plates. This bias supply is suitably connected between the plates of the modulators and the grids of the power-amplifier stage through the high-frequency portion of the previously described constant-resistance network.

The tubes and circuits of the sound driver and power amplifier are identical with those employed in the visual driver system and power amplifier. The carrier frequency of the sound transmitter is 4.5 mc. per sec. higher than that of the visual transmitter in accordance with the requirements set down by the licensing authority. The sound carrier is

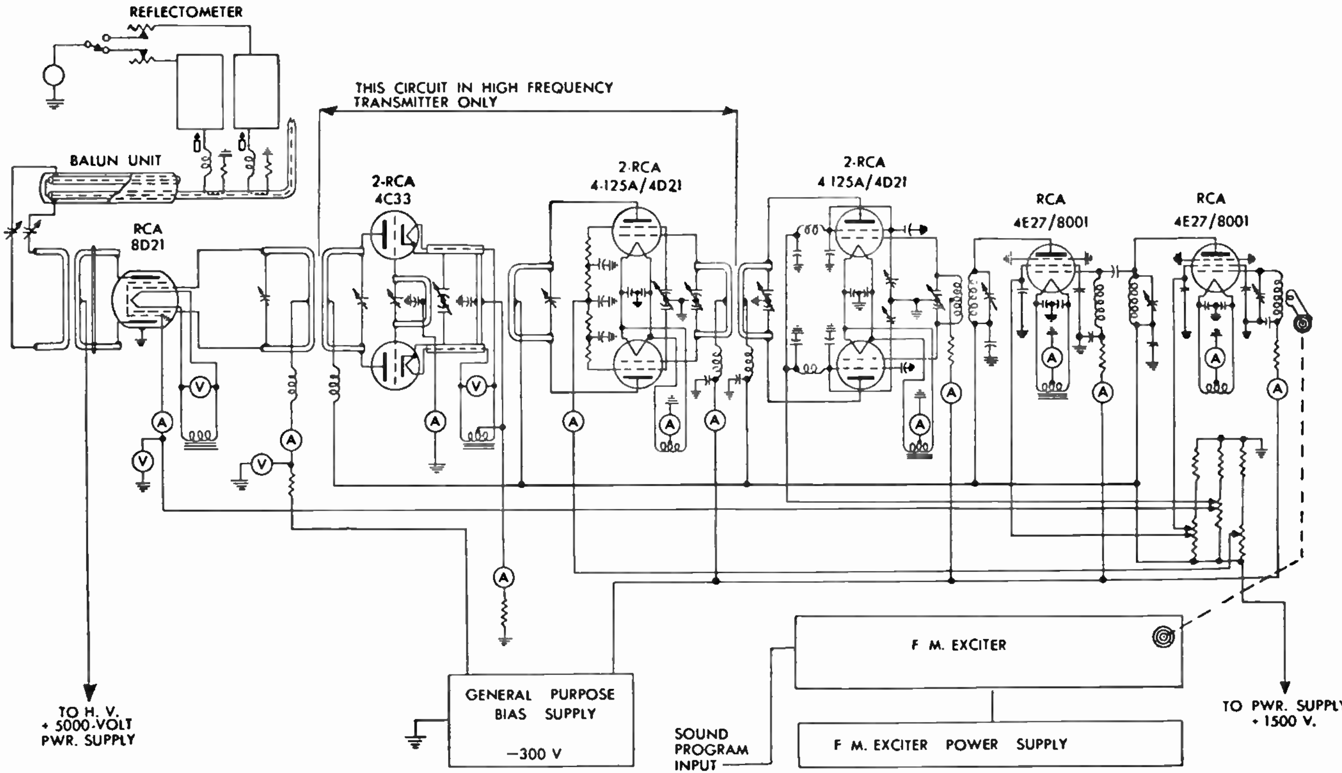


FIG. 10.14 Schematic of R.C.A. TT-5A sound transmitter.

not generated by a crystal-controlled oscillator, such as is used in the picture transmitter. Instead, a "direct-FM" exciter is used. The power amplifier is not directly modulated as in the case of the visual transmitter, since an FM system is made use of. Although crystal control of an oscillator is not employed, the transmitter provides a sound radio-frequency carrier which is well within the frequency tolerance of 0.002 per cent, as prescribed by the F.C.C. for both the visual and sound transmitters, both making up the complete television transmitter. Although the frequency tolerance is rigid, it is well met today in the practical operation of all commercial television transmitters. For instance, on channel 5, where the assigned carrier frequency is 81.75 mc. per sec., the mean carrier frequency must not deviate more than 1,635 c.p.s. plus or minus the assigned frequency.

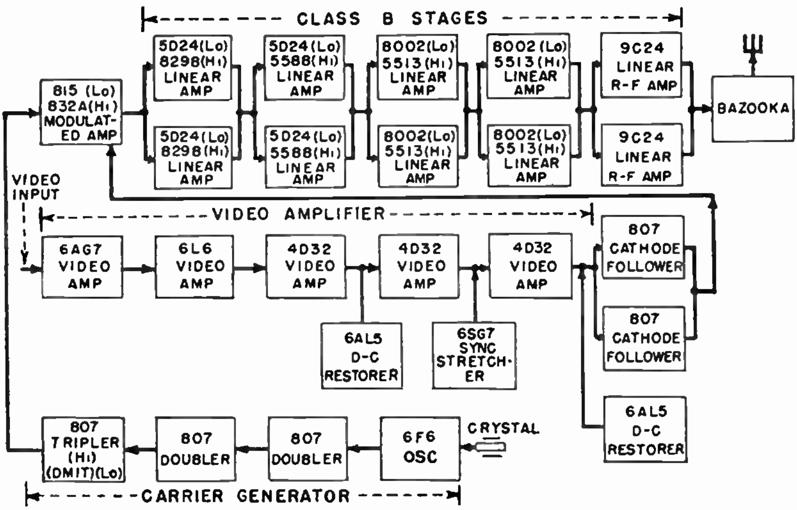


FIG. 10.15

10.4 The General Electric Television Transmitter. The General Electric type TT-7-A/B television transmitter is shown in the block schematic (Fig. 10.15). The carrier frequencies of both the visual and aural transmitters are precision crystal-controlled to ensure strict adherence to the assigned carrier frequencies. The crystal-controlled oscillator output circuit of the picture transmitter is arranged to triple the fundamental crystal frequency, which is succeeded by two frequency doublers in the case of the low-band transmitter, and by an additional frequency tripler if operation is desired on one of the high channels. This arrangement is shown in the block diagram. The second doubler or the tripler, as the case may be, provides radio-frequency drive to the modulated amplifier.

The modulated amplifier employs a type 815 vacuum tube if operation is desired in the band that includes channels 2 through 6; or a type 832–A vacuum tube, if operation is desired in the high band (channels 7 through 13). The radio-frequency energy admitted to the input of the modulated stage is at the desired carrier frequency and at a modulation level of approximately 1 w. peak to peak. The peak-to-peak voltage applied to the plate of the modulated radio-frequency amplifier is 80 v. Plate modulation is employed. Thus, modulation in this transmitter is effected at a lower level than in the Du Mont television transmitter and at substantially lower level than in the R.C.A. picture transmitter.

The modulated signal at the output of the modulated stage is further amplified in being admitted through five class B linear radio-frequency amplifiers in the case of the low-band transmitter. These stages are wide-banded so as to provide no appreciable discrimination to the standard television signal. The first two linear amplifiers in the low-band transmitter incorporate type 5D24 or 4–250–A air-cooled vacuum tubes; the two succeeding linear amplifiers use type 5513 water-cooled tubes. The final linear amplifier employs a water-cooled type 9024 amplifier tube. In General Electric television transmitters designed for operation in the high band, the tubes employed are types 829B, 5588, 5513, 5513, and a final type 9024 tube. The modulated radio-frequency output of the type 9024 water-cooled power amplifier, in either case, is fed by means of a coaxial line to the diplexer unit and turnstile antenna.

Five video amplifiers and a cathode follower constitute the video amplifying system preceding the modulated amplifier. This amplifier accepts the standard R.M.A. composite signal at its input, delivering a suitable level at the output of the cathode follower to provide complete modulation of the carrier at the 1-w. level in the modulated amplifier. A diode-type d-c restorer is made use of at the second stage from the output of the system to achieve d-c restoration. A unique feature of the video amplifying system lies in the provision of a sync-stretching system in one of the video amplifiers, permitting an increase in the amplitude of the synchronizing signal, and thereby compensating for any compression of the sync signal that might occur prior to this point in the system. It also allows the station engineer to increase the sync amplitude if insufficient peak sync level is available at the transmitter input and ensures that the sync amplitude will be maintained at 25 per cent of the peak-to-peak standard television signal, as required by the licensing authority. The complete transmitter is shown in Fig. 10.15*A*.

A built-in wobbulator or sweep generator provides a test signal for tuning purposes. The output signal of the transmitter is viewed on the screen of a cathode-ray oscillograph during the tuning process. The wobbulator is designed to produce a signal at the assigned carrier frequency and sweeps over a range of 12 mc. The over-all bandwidth of the five linear amplifier stages is 4.75 mc., sufficient to result in a transmitted picture of excellent quality. It has been shown earlier that a bandwidth of this order will result in the transmission of the complete information available in a 525-line frame. To provide an easy means of applying the sweep generator, terminal jacks are permanently connected

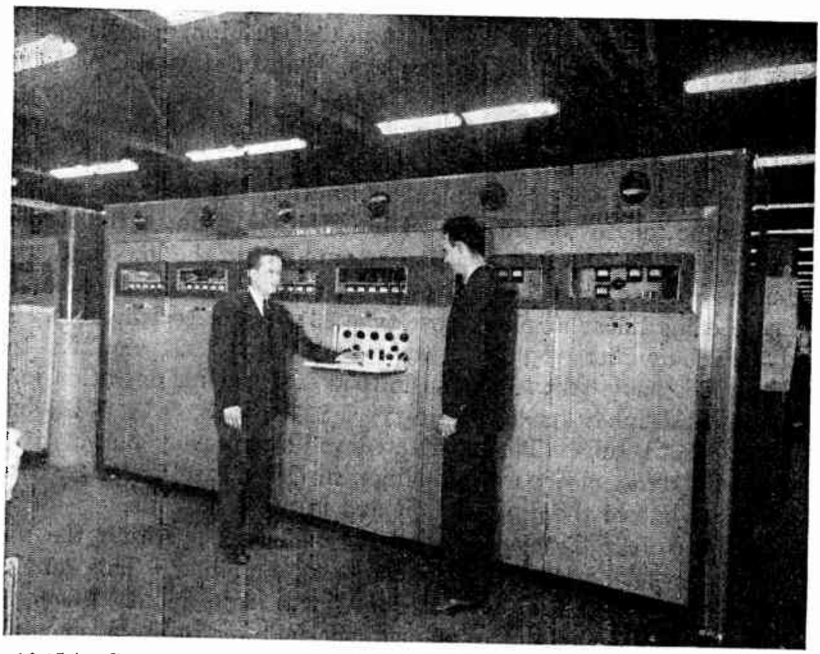


FIG. 10.15A General Electric 5-kw. Low-channel television transmitter, type TT-6-C. (Courtesy of General Electric Company.)

to the plate tank of each wide-banded stage. A crystal diode connected within the bazooka at the transmitter output furnishes the sampling voltage for connection to the vertical deflection plates of the oscillograph. All tuning and loading adjustments are made from front of panel, providing protection against accidental contact with high potentials and making for ease of transmitter adjustment.

In employing low-level plate modulation in this transmitter, a highly linear modulation characteristic is achieved, and the circuit of the modulated stage is such that the radio-frequency energy fed through the modulator at the minimum point of the modulation cycle to the absolute minimum, results in a rather high modulation capability. Grounded grid linear amplifiers are used since the low impedance resulting with this type of amplifier connection provides wide banding with conservation of power, and there is complete freedom from parasitic oscillation. The transmitter has many unique electrical and mechanical features which make it a highly acceptable type of transmitting equipment.

10.5 Transmission Lines. Rigid air dielectric coaxial transmission lines are commonly employed to connect the aural and visual transmitter outputs with the television antenna or diplexer unit. If a diplexer is used (which will be described in detail later) a line of this type will extend from the outputs of both transmitters to the diplexer input (or from the vestigial sideband filter), and between the diplexer output and the antenna. Four transmisison lines will be required where a diplexer unit and super-turnstile antenna are made use of.

Standard line sizes for transmitting purposes are ⅞, 1⅝, 3⅛, and 6⅛ in., reference being made to the outside diameter of the outer conductor of the coaxial line. The surge impedance of the line is the impedance looking into an infinite length of line, and is indicated in the following table for standard line sizes employed in television broadcasting:

Surge Impedance

Line size, in.	50–100 mc.		200 mc.	
⅞	51.5	1.5 ohms	51.5	1.5 ohms
1⅝	51.5	1.0 ohms	50.9	1.0 ohms
3⅛	51.5	1.0 ohms	50.9	1.0 ohms
6⅛	51.5	1.0 ohms	51.5	1.0 ohms

The power rating of the rigid air dielectric coaxial line, as employed in television broadcasting, is as shown below.

Standard Line Sizes

Line size, in.	50 mc.	100 mc.	200 mc.
⅞	4.5 kw.	3 kw.	2 kw.
1⅝	16.0 kw.	10 kw.	7 kw.
3⅛	64.0 kw.	42 kw.	27 kw.
6⅛	235.0 kw.	166 kw.	118 kw.

The above power ratings of the line are for *average* power, for a safe temperature rise on the outer conductor, and without arc-over within the line (inner to outer conductor). The values are for black-level power, sufficient safety factor being provided to handle synchronizing signal peaks.

There is always some power loss when energy is transmitted over a coaxial line, and the loss is expressed in decibels per 100 ft. at 25°C. Maximum losses, established as the minimum standard, are included in Table 9.

TABLE 9

Losses	Decibels per 100 ft.		
	50 mc.	100 mc.	200 mc.
⅞ in. diameter line:			
Copper loss	0.273	0.386	0.548
Insulation loss	0.016	0.032	0.064
Total	0.289	0.418	0.612
Total, plus 10 per cent derating	0.318	0.460	0.673
1⅝ in. diameter line:			
Copper loss	0.137	0.195	0.279
Insulation loss	0.009	0.018	0.036
Total	0.146	0.213	0.315
Total, plus 10 per cent derating	0.161	0.234	0.346
3⅛ in. diameter line:			
Copper loss	0.071	0.100	0.145
Insulation loss	0.016	0.032	0.064
Total	0.087	0.132	0.209
Total, plus 10 per cent derating	0.096	0.145	0.230
6⅛ in. diameter line:			
Copper loss	0.0343	0.0485	0.0685
Insulation loss	0.0013	0.0026	0.0051
Total	0.0356	0.0511	0.0736
Total, plus 10 per cent derating	0.039	0.056	0.081

The copper loss of a rigid air-dielectric line is determined by the following equation:

$$\text{Decibels per 100 ft.} = \frac{443(a + b)\sqrt{f_{mc.}}}{abZ_0}$$

where a and b are conducting-surface diameters in inches. Z_0 is the surge impedance of the line. A conductivity of 95 per cent I.A.C.S. is assumed.

Insulation loss is determined by the following equation:

$$\text{Decibels per 100 ft.} = \frac{2.77\, L_f\, f_{mc.}}{\sqrt{K}} \cdot \frac{k - 1}{K - 1}$$

where L_f is the loss factor (assumed to be 0.044), $K = 6$, and k is the average dielectric constant.

The derating factor is applied to allow for aging of the line and joints. The amount of attenuation will increase when the operating or ambient temperature increases over 25°C.

To ensure continuous operation, transmission lines are often pressurized. Pressurization means the application of positive pressure in the form of dry gas to the inside of the line to prevent the entrance of moisture or other foreign material. In some installations, nitrogen is the inert gas employed; in others, dry air is forced into the line under pressure.

In the installation of a transmission line of the coaxial type at television broadcasting stations, a special type of fitting is employed between the line and elbows, between sections of the line, and between the line and end fittings, terminals, and so on. Flange connections are provided at the ends of each standard length of line and fitting. These flanges are securely fastened together in such a manner that no soldering or brazing is required. If a length of line must be cut to fit in a particular installation, special flange adapters and gaskets are provided which obviate the necessity for brazing or soldering.

Possible expansion of the inner conductor of the line with temperature change is anticipated by the use of spring-loaded inner-conductor connectors, as employed with one type of rigid line. These are provided at each flanged joint. The spring-loaded inner-conductor connectors permit differential expansion of each section of the line. (A line section is usually 20 ft. in physical length.) Expansion of the outer conductor of the line is provided for by the use of spring-suspended hangers, which permit the line to move longitudinally. The differential expansion of the line with reference to the tower takes place at the base of the tower, the point at which the line run changes from horizontal to vertical. In some installations, the rigid coaxial line has been supported on the tower by means of spring-suspended hangers, which are attached to suitable members of the tower, such as ladder risers. When the steel of the supporting tower for the antenna is provided with ½-in. holes at 2½-in. intervals, a sufficient number of holes will be provided to mount the hangers 10 ft. apart. The hangers referred to are R.C.A. MI-19112-14 for 1⅝-in. line and R.C.A. MI-19113-14 for 3⅛-in. line. Either hanger will accommodate twin lines of the outside diameter specified. The top two hangers provided in a typical installation are of the fixed type, ensuring against vertical movement at the top of the tower. When towers are more than 400 to 500 ft. in height, a second anchor point is established midway between top and bottom of the supporting tower. This second anchor point permits the vertical run to expand and contract in two individual vertical line sections. Inside the transmitter building or operating room, the line is rigidly fixed by means of heavy-duty clamps to the building wall or ceiling. Ordinarily, when a diplexer unit is employed between the transmitter power-output stage and the antenna, twin coaxial lines extend between the diplexer unit and the antenna. These lines are necessary because two separate feeds are required to the antenna in quadrature relationship, particularly when the super-turnstile type of transmitting antenna is employed.

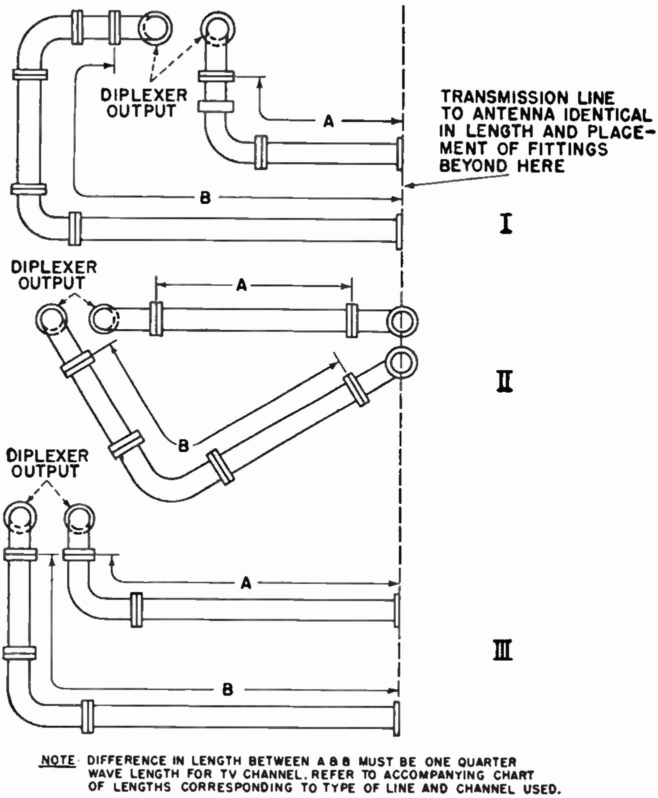


Fig. 10.16

If it is necessary to isolate the tower, where the television antenna is mounted upon an existing tower operating in the AM broadcast band, this can be accomplished by insulating the transmission line or lines from the tower for a quarter wavelength at the AM operating frequency or for less than a quarter wavelength if capacity loading is used at the base of the broadcast tower. If it is desired to completely isolate the rigid transmission line from an existing tower upon which the television antenna is to be supported, it can be done by using stand-off insulators of suitable dielectric material between the tower steel and the line hangers. Each particular transmission-line installation will dictate the type of mechanical installation required.

Where a diplexer and super-turnstile batwing antenna of the conventional type manufactured by R.C.A. is employed, the antenna must be fed in quadrature. The 90-deg. phase difference is provided by making one transmission line one quarter wavelength or 90 electrical degrees longer than the other at the center frequency of the television channel. The quarter wave section is, of course, provided in one of the lines connecting the diplexer with the super-turnstile antenna. It is very important that the twin transmission lines to the two sets of radiators of the super-turnstile be of identical length and construction up to the point where the quarter wavelength section is added. The 90-deg. section of line should be added as close to the diplexer as construction will permit. To make absolutely sure that uniformity exists up to the point where the 90-deg. section is added, identical elbows, reducers, expansion joints, and other fittings are used. Such procedure will ensure that any reflections occurring will result at the same electrical point in the transmission line.

The required transmission-line quarter-wavelength dimensions for use in television and constructed in accordance with Fig. 10.16, are given in Table 10.

TABLE 10

Channel	Frequency, mc.	Electrical quarter wavelength, in inches	Physical length	
			1⅝-in. line, in inches	3⅛-in. line, in inches
2	54–60	51¾	49⅞	48
3	60–66	46⅞	45¼	43½
4	66–72	42¾	41¼	39⅝
5	76–82	37⅜	36	34⅝
6	82–88	34¾	35⅜	32⅛
7	174–180	16⅝	15⅞	15⅛
8	180–186	16⅛	15¼	14⅝
9	186–192	15⅝	14⅞	14¼
10	192–198	15⅛	14⅜	13¾
11	198–204	14⅜	14	13⅜
12	204–210	14¼	13½	13
13	210–216	13⅞	13⅛	12⅝

The electrical length of a given transmission line is determined by dividing the physical length by the velocity of propagation. This information has been tabulated as follows:

Line size, in.	Impedance, ohms	Channel	Velocity of propagation, per cent
$1\frac{5}{8}$	51.5	2 to 6	96.3
$1\frac{5}{8}$	51.5	7 to 13	95.0
$3\frac{1}{8}$	51.5	2 to 6	92.6
$3\frac{1}{8}$	51.5	7 to 13	91.0

In order to obviate the possibility of moisture or foreign matter entering the transmission line through leaks at the joints, it is rather common practice to keep the line filled with dry air under pressure. An automatic dehydrator-compressor, which forces air through silica gel, is commonly used. The system includes a pressure switch-operated compressor which forces the air through the silica gel, thereby producing dry air which is forced into the line through a nipple and under pressure. By this method, the silica gel is reactivated automatically, the compressor motor operating only at times when the pressure within the line falls below a predetermined minimum. The use of a pressurized transmission line eliminates the possibility of flashover on peaks of transmitted power on black signal. Such flashovers are likely to occur if moisture is allowed to enter the line, thereby causing the dielectric separating conductors to break down. As an alternate to the method of pressurization described, oil-dried nitrogen gas can be introduced into the line from a pressurized cylinder of the gas. More gas is admitted by means of a valve as line pressure is reduced due to leakage. The pressure is usually maintained in the order of 5 to 15 lb. per sq. in.

The installation of the transmission line must be carried out with more care than would ordinarily be exercised in the construction of a line for AM or FM broadcasting service. The reason is that any mismatch in impedance, or impedance discontinuity, is apt to result in an echo in the transmitted picture, provided that the mismatch is located very far from the transmitter output. If the discontinuity is located near the transmitter output, distortion of the picture will result. The echo referred to is commonly termed a "ghost" and will appear as a second image slightly displaced to the right of the principal image.

The selection of a proper line for a particular installation will be principally a function of its power-handling capability. The rated power-handling capability is based on the *average* power to be transmitted and on a unity standing-wave ratio in the line. The average power imposed on the line will depend upon the picture content of the transmitted signal. When the picture is black, the greatest power will, of course, be transmitted. When this condition obtains, black-level voltage is 75 per cent of the peak voltage, the power being 50 per cent. The sync peaks are 100 per cent, thus resulting in the integrated average power being 60 per cent of the peak power. For the aural FM transmitter, average power is the same as that indicated as the transmitter output power rating.

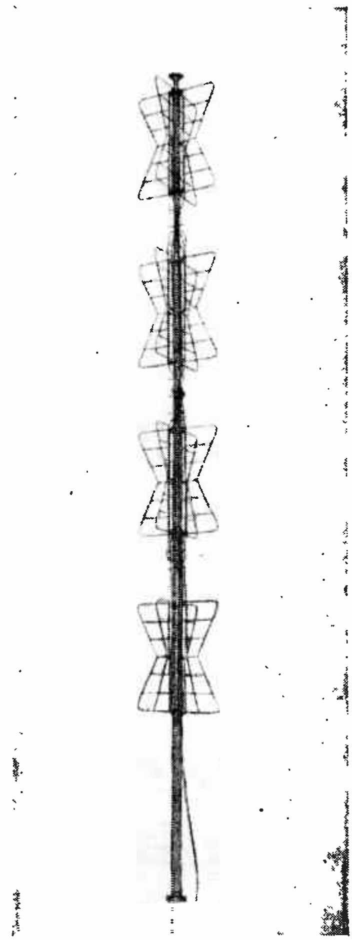


FIG. 10.17 The television super-turnstile antenna developed by the R.C.A. Engineering Products Department for use at 54–216 megacycles. It simultaneously radiates both the sound and picture signals of a television transmitter. The super-turnstile provides a gain of approximately four, depending upon the frequency used. Hence, when used in conjunction with a 5-kw. transmitter, the effective radiated power is about 20 kw., which is adequate for the coverage of a large city and its suburbs. (Courtesy of Radio Corporation of America.)

10.6 The Super-Turnstile Antenna. The turnstile antenna has long been a well-known radiating system. It has been made use of particularly in FM broadcasting installations for a number of years. The super-turnstile, or batwing, antenna now widely used in television broadcasting (see Fig. 10.17) is a special type of this turnstile antenna developed by R.C.A. It comprises a number of radiating elements appropriately mounted on a central steel pole. The wide-band characteristics required of a television antenna are brought about through proper shaping of the radiators. It is unnecessary to increase the diameter of the structural elements of the radiators. The wide-band transmission characteristics inherent in the design of the super-turnstile are a function of the shape of the over-all radiator and are not at all determined by the physical size of the arms making up the radiator. The result is that the wind resistance of the antenna has been kept at a low value. These antennas are designed to withstand a maximum wind velocity of 85 m.p.h. when coated with ½ in. of radial ice and a maximum wind velocity of 95 m.p.h. without ice.

The physical shape of the radiator allows advantage to be taken of the stiffness of structures that are formed by triangular construction. Because of the triangular construction involved, the shape of the antenna permits heavier than average mechanical loads such as would be imposed with heavy ice loading. The central pole of steel construction, upon which the various radiating structures are mounted, is grounded. It thus provides protection against lightning.

The geometry of the antenna is most interesting. Each individual section of the complete super-turnstile comprises a layer of four individual radiators, mounted at 90-deg. space phase about the central steel pole. Each section has a power gain of 1.2. The sections are mounted approximately one wavelength apart center to center and vertically up the supporting pole. Radio-frequency energy from the transmitter is fed to the sections by means of coaxial lines. The line is made to feed the center of each radiator, and thus only the center portion of the antenna is subjected to possible impedance change due to formation of ice on the structure. Calrod-type heating elements, electrically excited, are employed to melt sleet and ice as fast as it forms. Each element of the radiators is constructed of rigid seamless steel tubing and cold-rolled steel rods. The radiating elements and fittings are plated to prevent corrosion.

The horizontal pattern of the super-turnstile antenna is essentially circular and ordinarily will not deviate from a true circle by more than ± 0.05 db. The vertical pattern of the antenna is essentially constant throughout the band, the shape being proper to provide the requisite power gain. The input impedance is 51.5 ohms, so that an effective match can be had with standard rigid coaxial line. The voltage standing-wave ratio is 1.05 or better at the visual carrier frequency.

The wide-band characteristics of the batwing antenna are such that only three models of the antenna structure are required to cover the entire television band. A three-section antenna will cover the portion of the band extending from 54 to 66 mc., another three-section antenna covers the band from 66 to 88 mc., and a six-section antenna is used to cover that portion of the band extending from 174 to 216 mc.

The engineering data covering a single section of the low-band super-turnstile antennas, i.e., those operating in the region that includes channels 2 through 6, is supplied by R.C.A. in Table 11 (see also Fig. 10.18).

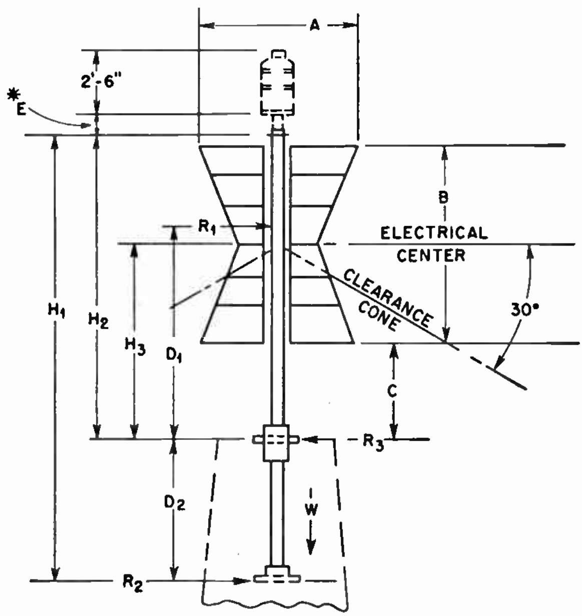


Fig. 10.18

The approximate engineering data for the complete super-turnstile antenna is given in Table 12 (see Fig. 10.19).

If the television broadcasting station also employs frequency modulation, it is entirely possible to use a combination antenna system, the super-turnstile TV antenna being supported by a pylon-type FM antenna. In such an arrangement, there is no resulting limitation in transmitter power in either FM or TV operation due to any proximity effect between the antennas. Three transmission lines are employed where antennas are stacked in this manner: two for the television antenna and one for frequency modulation. The two systems are arranged so that they are electrically independent.

10.7 The Television Diplexer Unit. The diplexer is a device employed at the transmitting station for the purpose of supplying both the visual and aural modulated carriers to the same super-turnstile television antenna without cross talk. The use of the diplexer greatly simplifies the installation problem and effects an economy, since only one antenna is required to take both the picture and sound carriers.

Electrically, the diplexer is a bridge circuit in which the four arms usually encountered in such networks are found. This circuit is shown in Fig. 10.20. The combination of a bridge circuit and a Balun unit is used to result in the inputs to the diplexer being single-ended. This arrangement is shown in the accompanying diagram, which also indicates that when the bridge circuit and the Balun are separated and represented

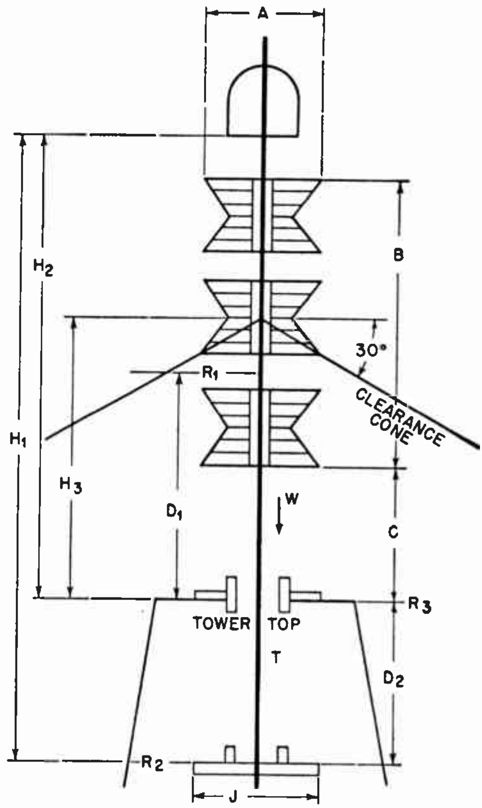
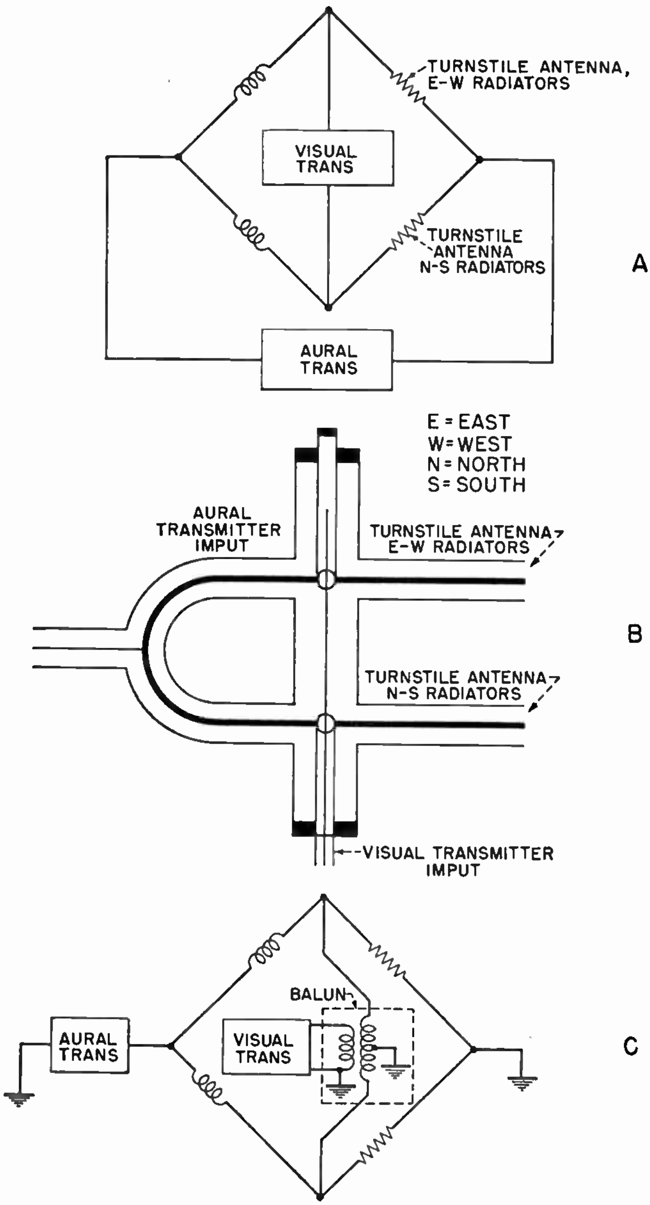


Fig. 10.19

by conventional lumped circuits, then the actual bridge becomes at once apparent.

The picture transmitter feeds the two equal impedance halves of a super-turnstile antenna in series and is shunted by two equivalent reactances in series. No visual signal can cross talk into the aural transmitter, since the sound transmitter is fed into the circuit across the midpoints of the antenna and reactances. In the same manner, the visual transmitter-modulated carrier feeds between two points of equivalent potential with respect to the aural transmitter. Thus, no visual signal


TURNSTILE ANTENNA,
E-W RADIATORS
VISUAL
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TURNSTILE
ANTENNA
N-S RADIATORS
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E = EAST
W = WEST
N = NORTH
S = SOUTH
AURAL
TRANSMITTER
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TURNSTILE ANTENNA
E-W RADIATORS
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TURNSTILE ANTENNA
N-S RADIATORS
VISUAL TRANSMITTER
IMPUT
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Fig. 10.20

TABLE 11

	Channels	
	2 and 3	4, 5, and 6
Frequency band	54–66 mc.	66–88 mc.
R.C.A. type No.	TF–1A	TF–1A
MI number	19015–2	19015–3
Weight (W)*	937 lb.	625 lb.
A ft.	8 ft. 11 in.	6 ft. 10½ in.
B ft.	10 ft. 7 in.	8 ft. 8 in.
C ft.	4 ft.	4 ft.
D_1 ft.	9 ft. 15 in.	8 ft. 5 in.
D_2 ft.	6 ft.	6 ft.
R_1†	463 lb.	353 lb.
R_2†	703 lb.	500 lb.
R_3†	1,166 lb.	853 lb.
H_1 ft.	21 ft.	19 ft.
H_2 ft.	15 ft.	13 ft.
H_3 ft.	9 ft. 3½ in.	8 ft. 4 in.
E	15 in.	12 in.
Diameter of central pole at guide flange	4½ in.	4 in.
Number of sections	1	1
Projected areas:		
With ½ in. radial ice	38 sq. ft.	27.9 sq. ft.
Without ice	24 sq. ft.	17.6 sq. ft.
Max. dimension of tower top‡	6 ft. × 6 ft.	5 ft. 5 in. × 5 ft. 5 in.

* *W* equals total weight, including pole, guide flange, pole socket, 300-mm. code beacon, pole steps, and hardware.

† Reactions R_1, R_2, and R_3 as indicated in the table are for estimating purposes only and are figured on the basis of 20 lb. per ft. of projected area without ice. All sections are rounds.

‡ Figures are for installation without railing at tower top.

Clearance Cone. In general, the antenna must be so elevated that surrounding objects within 50 to 70 ft. of the antenna are beneath a 120-deg. cone having the apex at the radiator center, but in no case higher than the tower top level.

(*Data, Courtesy Radio Corporation of America.*)

can enter the aural transmitter, and no aural signal can enter the visual transmitter.

For convenience, the conventional diplexer unit is enclosed in a suitable metal cabinet to exclude dust and dirt and to afford shielding, thereby also providing protection for the operating personnel so that they will not come in contact with high-voltage radio-frequency energy. The diplexer unit is almost always installed in the transmitter room and close to the transmitter power-output stage, in order to minimize the lengths of transmission lines connecting the two equipments.

10.8 Triplexing. The R.C.A. super-turnstile antenna may be used simultaneously for both television and FM broadcasting. When it is possible to employ such simultaneous operation, the process is termed

TABLE 12

	Channels		
	2 and 3	4, 5, and 6	7 to 13
R.C.A. MI No.	MI-19012-A	MI-19012-B	MI-19013
Weight*	3,800 lb.	2,650 lb.	2,300 lb.
A	8 ft. 11 in.	6 ft. 10½ in.	3 ft 10½ in.
B	44 ft. 7 in.	36 ft. 10 in.	33 ft. 2⅜ in.
C	2 ft. 8½ in.	1 ft. 10 in.	2 ft. 6⅝ in.
D_1	24 ft. 5 in.	18 ft.	18 ft.
D_2	12 ft.	10 ft.	10 ft.
R_1†	1,144 lb.	980 lb.	925 lb.
R_2†	2,330 lb.	1,746 lb.	1,711 lb.
R_3†	3,474 lb.	2,744 lb.	2,636 lb.
H_1	61 ft.	50 ft.	47 ft. 3 in.
H_2	49 ft.	40 ft.	37 ft. 3 in.
H_3 (Elec. center)	25 ft.	20 ft. 4 in.	19 ft. 1$\frac{13}{16}$ in.
Diameter of center pole at guide flanges	10¾ in.	8⅝ in.	8⅝ in.
Number of sections	3	3	6
Projected area with ½ in. radial ice	94.6 sq. ft.	71.8 sq. ft.	75.34 sq. ft.
Max. dimension of tower top‡	6 ft. × 6 ft.	5 ft. 5 in. × 5 ft. 5 in.	5 ft. 5 in. × 5 ft. 5 in.

* Weight equals total weight, including pole, guide flange, 300-mm. code beacon, pole steps, and miscellaneous hardware.

† Reactions R_1, R_2, and R_3, as shown in the table, are for estimating purposes only and are figured on the basis of 20 lb per sq. ft. of projected area without ice. All sections are rounds.

‡ Figures are for installation without railing on tower top. If the railing is to be used, the pole is extended as required.

(*Data, Courtesy Radio Corporation of America.*)

"triplexing." There is no loss in antenna gain when the super-turnstile is made use of both as a television transmitting antenna (for both aural and visual signals) and as an FM antenna. This arrangement effects a considerable economy in both installation and operation as well as reduces the maintenance problem.

Triplexing of the super-turnstile is only possible where the power outputs of the TV and FM transmitters are comparable. For instance, a 5,000-w. television transmitter can be triplexed with an FM transmitter with power output in the range 1 to 10 kw. and, under certain conditions, without interaction or cross talk. Triplexing may be employed where a super-turnstile is made use of for powers under 10 kw. for channels 4, 5, and 6. Ordinarily, FM transmitter output power of 3 kw. may be used on channels 2, 3, and 7 to 13, although each case must be studied. Both a diplexer and a triplexer are used when triplexing is desired.

In the installation of the triplexer unit (see Fig. 10.21), some special considerations are necessary. The triplexer unit is best situated near the diplexer unit, and transmission line runs must be kept as straight as possible. When triplexing is utilized, an additional quarter-wave phasing section must be placed in one of the coaxial lines connecting the

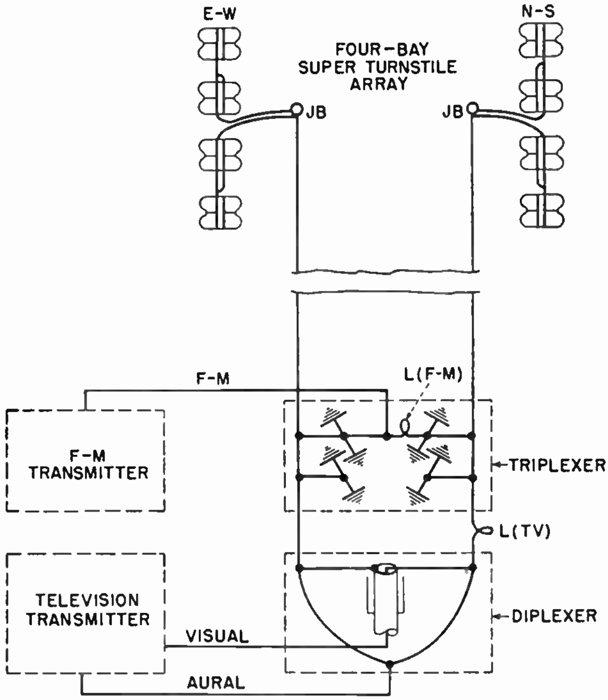


Fig. 10.21

diplexer and triplexer. Phasing is accomplished by making one of the two lines a quarter wavelength longer than the other. The two lines from the triplexer to the antenna must be of equivalent length, physically. It is only in diplexing that the quarter wave-line section is inserted in one transmission line interconnecting diplexer and antenna.

10.9 Vestigial Sideband Filter. The use of a vestigial filter at the output of the final power amplifier of the television transmitter (the picture transmitter) will assure that the undesired portion of the lower sideband will be suppressed in accordance with F.C.C. requirements. It has already been stated that the lower sideband must be attenuated at least 20 db. at a point 1.25 mc. below the visual carrier. The purpose, of course, is to prevent undue interference with the adjacent TV station which is operating just below the channel where the sideband filter is to be operated. Use of the filter also permits the use of high-level modulation.

The filter is electrically connected directly to the output of the visual transmitter output-power amplifier and absorbs the relatively small amount of lower sideband energy which falls outside the assigned television channel. The average amount of this energy is said to be about

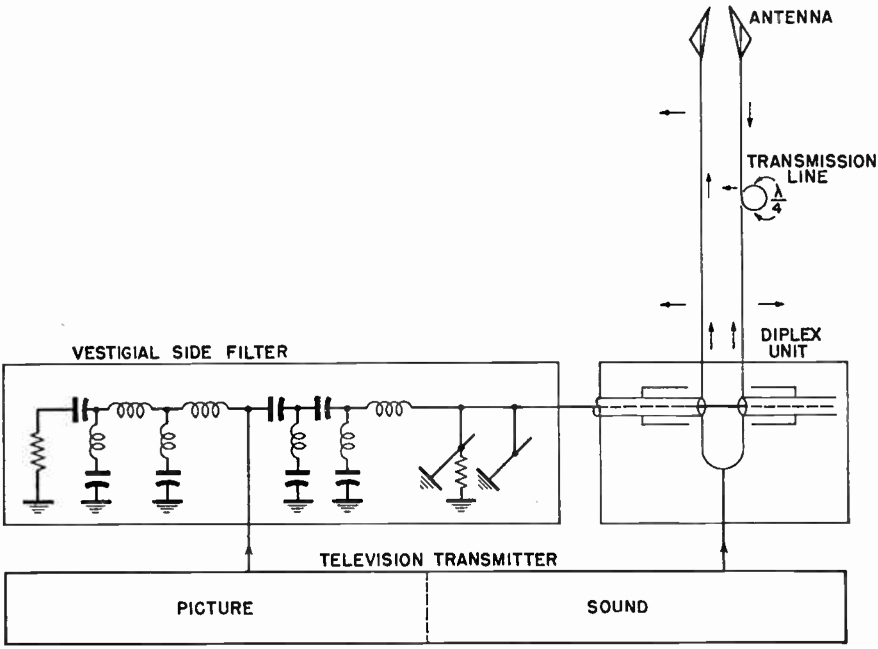


FIG. 10.22

75 w. maximum for a 5-kw. picture transmitter. The filter presents a constant input impedance throughout the entire double sideband.

The method by which the sideband filter is connected is shown in Fig. 10.22. The vestigial sideband filter is a combination of two M-derived filters made up of low-loss coaxial line sections. One of the filter sections constitutes a properly terminated low-pass line, effectively absorbing reflections of the lower sidebands. The second M-derived filter section develops the sloping characteristics for the lower end of the upper sideband. The signal then is admitted through a notching filter and is made resonant at a single frequency. Therefore, this filter absorbs energy at the frequency at which it is tuned or made resonant. Being adjusted for resonance at a point 1.25 mc. below the visual carrier, the filter provides a "notch" at the point along the channel where it is desired that the sideband be attenuated to the greatest extent; hence, the term "notching filter." The filter is made up of resonant coaxial lines, and the short line sections making up the network are enclosed in the metal cabinet that houses the complete vestigial sideband filter unit. The lines are folded within the metal cabinet to conserve space, and the entire unit occupies only 10 sq. ft. of floor space. Within this small area are located the three filters that make up the vestigial sideband unit, two M-derived sections (one low-pass and one high-pass section), and the notching filter, all three being constructed of coaxial line sections.

An advantage in making use of the vestigial sideband filter lies in the fact that it absolutely assures proper attenuation of the lower sideband by the amount desired, no reliance having to be placed upon proper tuning of the transmitter (as is the case when low-level band-pass stages have to be critically tuned to achieve the desired attenuation). In making possible high-level modulation in the transmitter, better over-all linearity in the picture channel is easily achieved.

10.10 The Dummy Antenna. The dummy, or phantom, antenna is employed for the purpose of dissipating the full peak power output of the transmitter without placing the carrier on the air, thereby obviating the possibility of creating undue or superfluous interference. The phantom antenna terminates the output of the transmitter in its proper terminal impedance for both sound and picture and facilitates measurement of the power output of the television transmitter. A 72-ohm line connects the output of the transmitter with the dummy load, the dummy antenna being in itself a high-attenuation coaxial line, the inner conductor of which is a water-cooled resistor. The power output of the transmitter is measured by the calorimeter method which makes use of two thermometers and a flowmeter.

The F.C.C., in its Standards of Good Engineering Practice Concerning TV Broadcast Stations, has prescribed the method by which average operating power may be measured. For the picture transmitter, the average power shall be measured while the transmitter is operating into a dummy load of substantially zero reactance and a resistance equivalent to the transmission-line surge impedance, and while transmitting a standard black picture. The peak power will be the power measured under this condition multiplied by 1.68. During the measurement, the direct plate voltage and current of the last radio stage and the peak output voltage or current is read for use in determining the mean power output.

The aural power output is determined by the indirect method. It is derived through taking the product of the plate voltage E_p and the plate current I_p of the last radio stage of the sound transmitter and multiplying it by an efficiency factor F. Stated as an equation, operating power is determined as follows:

$$\text{Operating power} = E_p \times I_p \times F$$

The efficiency factor F is established by the transmitter manufacturer for the particular type of transmitter.

Measurement of the power output of the visual transmitter is not so simple a matter. By means of the calorimeter method, the transmission

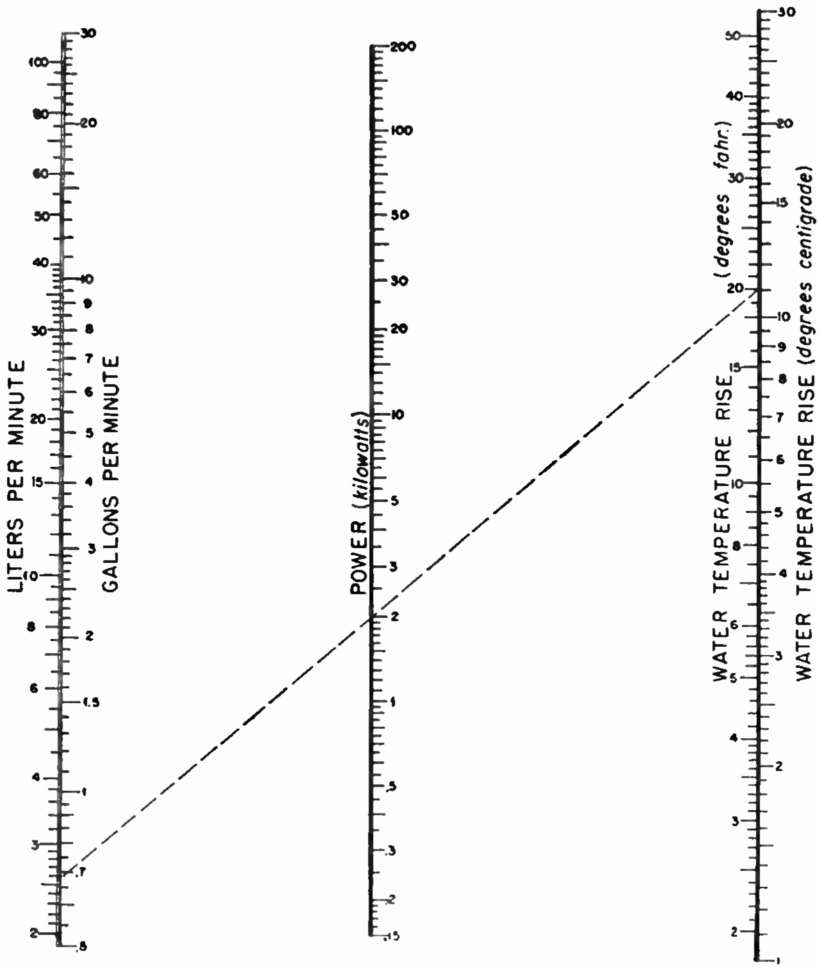


FIG. 10.23

line to the antenna is disconnected and is then terminated by a pure resistance equivalent to the characteristic impedance of the line. The dummy load thus provides a perfect resistive match (zero reactive). The resistor comprising the resistive load is coaxially installed within the transmission line as previously described, and water is passed over the resistance element, from which the temperature differential between input and output is determined. The rate of flow of the water is measured in volume per unit of time. The power dissipated in the resistive load (resulting in the temperature rise of the water between input and output) is then determined from the temperature differential, the rate of flow, and the specific heat of the water. The nomograph shown in Fig. 10.23 may be used where water is the coolant employed.

In using the R.C.A. dummy load, the transmitter water-cooling system is employed in determining power output or in dissipation of the full power output of the transmitter when it is not desired to put a signal on the air. Two 15-ft. water hoses carry the water between the transmitter and the dummy load. The flowmeter is provided with an interlock to shut off the transmitter if water fails to circulate. The transmission line is equipped with quick disconnect fittings which make it possible to place the load into operation on short notice. Terminated by the dummy load, the standing wave ratio on the 72-ohm line will be 0.85 or better.

BIBLIOGRAPHY

1. Conklin, J. W., and H. E. Gihring, "Television Transmitters Operating at High Powers and Ultra-High Frequencies," *R.C.A. Review*, July, 1937.
2. Goddard, D. R., "Observations on Sky-Wave Transmission on Frequencies above 40 Megacycles," *Proc. I.R.E.*, January, 1939.
3. Lindenblad, N. E., "Television Transmitting Antenna for Empire State Building," *R.C.A. Review*, April, 1939.
4. Fink, D. G., *Principles of Television Engineering*, McGraw-Hill Book Company, Inc., New York, 1940.
5. Kell, R. D., and G. L. Fredendall, "Selective Sideband Transmission in Television," *R.C.A. Review*, April, 1940.
6. Holtz, R. F., "Super Turnstile Antenna," *Communications*, April, 1946.
7. Kiver, M. S., *Television Simplified*, D. Van Nostrand Company, Inc., New York, 1946.
8. Fink, D. G., "Design Trends in Television Transmitters," *Electronics*, January, 1948.
9. Guy, R. F., "WNBW and WRC-FM," *Broadcast News*, March, 1948.
10. Kentner, C. D., "TT-5A Television Transmitter," *Broadcast News*, March, 1948.
11. Wolfe, L. E., "Triplexed Antenna at WNBW/WRC-FM," *Broadcast News*, March, 1948.
12. Hamilton, G. E., "TV Transmitter Design," *Communications*, May, July, and August, 1948.

REVIEW QUESTIONS

10–1. Describe (a) low-level modulation, (b) high-level modulation, and (c) mid-level modulation. What are the advantages and disadvantages of each as applied to the TV transmitter?

10–2. Why are two systems of modulation employed in the television transmitter? Describe each.

10–3. Explain d-c restoration as applied in TV transmitter operation.

10–4. (a) Describe fully a modern Super Turnstile Antenna. (b) What are its advantages for use in television?

10–5. Discuss the (a) diplexer; (b) triplexer; (c) dummy antenna. Where is each employed in the system and for what purpose?

10–6. Explain the use of a single sideband filter and its function in the system.

10–7. (a) What are the common types of coaxial lines employed in transmitting systems? (b) At what power levels is each type usually employed?

10–8. Describe the usual method of mounting coaxial transmission line in a typical transmitter installation.

10–9. What are the advantages and disadvantages of air-cooled vs. water-cooled tubes for the output power amplifier of a TV transmitter?

10–10. Describe the aural system of a typical television transmitter.

CHAPTER 11

TELEVISION BROADCASTING TECHNIQUES

11.1 Studio Operations. The technical operations that take place at the television studio are generally described as "studio operations." Within the scope of these activities are included operation of cameras, camera control equipment, lights, microphones, sound equipment, film-projection equipment, and teletranscription or kinescope recording apparatus. All of these functions are normally under the direction of the station chief engineer, with the assistance of such supervisory personnel as a chief operating engineer, supervising engineer, technical director, or other staff technical personnel. In the line or operating organization are video operators and engineers, audio engineers or operators, lighting technicians, microphone-boom operators, cameramen, maintenance technicians, and projectionists. In the well-established television broadcasting station all these people work together in a closely knit engineering organization, the engineering group functioning to execute all the many operating activities necessary to provide a steady and well-organized flow of program material as outlined and scheduled by the program staff. The equipment in use at the television studio is now fairly well established and standardized.

Ordinarily, a dual- or triple-image Orthicon camera chain will be employed at the studio. The operation of a dual camera chain will require at least two experienced television cameramen; one to man camera No. 1 and one to man camera No. 2. The cameraman is charged with the responsibility of keeping his camera properly focused both optically and electrically. In addition, there are a number of auxiliary controls associated with the camera that he must continually adjust in maintaining a picture of acceptable quality. He must move the camera about the studio floor in order to take up the most appropriate position for televising a particular scene or sequence of scenes. Instructions are relayed to him from the control room by means of an interconnecting telephone communicating system, and he wears headphones for the purpose of receiving necessary instructions as to camera movement and positioning. In some installations a breast telephone set, similar to that worn by telephone switchboard operators, is employed for communicating purposes. This apparatus is connected to a line which arrives via the camera cable interconnecting the control room and studio camera. A plug and jack arrangement allows connection of the breast set directly at the camera.

In a great many installations, the intercommunicating system comprises a high-impedance microphone at the studio camera control position. It feeds an audio amplifier, the output of which is provided with an appropriate distribution and impedance-matching system for the purpose of supplying a number of headsets worn by key personnel who work on the studio floor. All important operating personnel on the studio floor must wear these headsets during normal operations. The sets are connected with the control room by means of suitable cables. Of late, a radio-frequency intercommunicating system employing high-frequency radio waves has been used for this purpose. The apparatus is similar to that employed in transceiver operation and has the advantage of eliminating necessary interconnecting wires and cables.

The television cameraman must be prepared to dolly his camera about the studio floor, moving it from one advantageous position to another as he is directed to do so by the technical director, production assistant, or other supervisory personnel in the control room. He must be ready at all times to pan, tilt, dolly in or out on a scene, or execute other required camera movements as the construction and sequence of the studio production requires. An electronic view finder, which is essentially a small television picture monitor, enables him to see the televised scene exactly as it should appear on the screen of a receiver in the home. This view finder, or camera monitor, is made physically a part of the camera itself. Through its use the cameraman is able to obtain the best possible picture under existing conditions of lighting. He must exercise great care that no direct light enters the optical lens system of the camera. Direct light falling upon the photosensitized target or mosaic of the camera's electron tube for image pickup is liable to burn the target, sometimes seriously damaging the camera tube. For this reason, a lens cover is kept over each lens face except when it is actually being used during studio operations. A typical scene depicting studio operations is shown in Fig. 11.1.

The television cameraman must have considerable knowledge of his camera if he is to obtain maximum utility. A thorough understanding of the technical operation of the camera, its circuits, tubes, and associated apparatus, may often help reduce the time that the camera is actually out of operation as a result of technical failure. With a proper knowledge of its operation, he may effect normal repairs or replace tubes during the televising of a show. Such repairs or adjustments are always made at a time when another camera is actually "shooting" the scene, his camera being taken out of operation for the moment. With a sound knowledge of the basic underlying principles of television, the cameraman may diagnose trouble and provide remedial measures whenever necessary. He must know something of photography, light, lenses, and optics if he is to become proficient in this field.

A directional-type microphone is used for sound pickup purposes in the studio. This type of microphone is chosen so as to exclude extraneous noise pickup. The cardioid-shaped area over which such a microphone will gather sound results in the elimination of unwanted noises originating

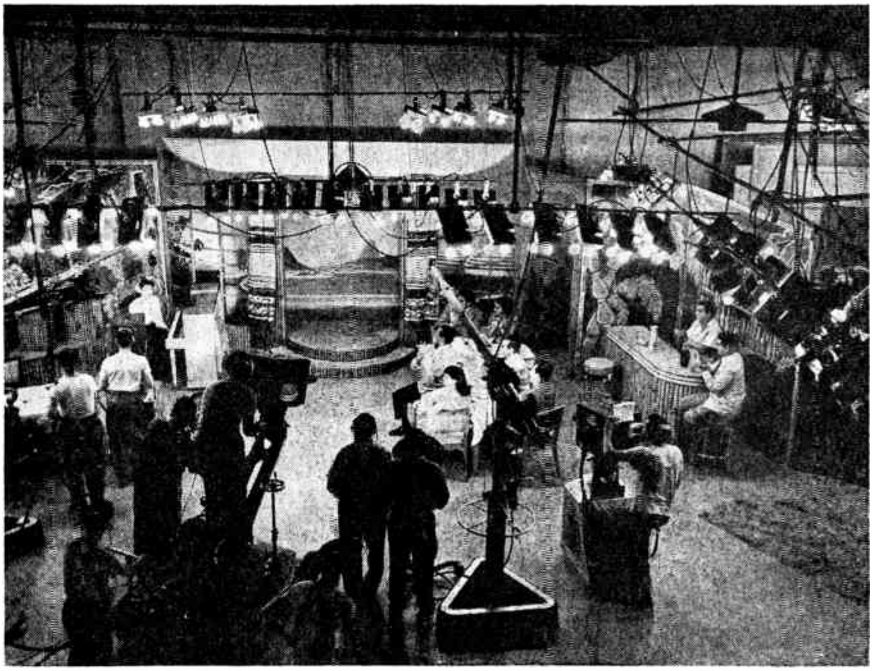


FIG. 11.1 A triple Image Orthicon studio camera chain in operation at Studio A, the John Wannamaker Studios of the Du Mont Television Network, New York City. (Courtesy of Allen B. Du Mont Labs., Inc.)

from parts of the studio not directly a part of the scene being televised. The use of an omnidirectional microphone would result in the transmission of noise due to the movement of other cameras and the handling of stage scenery and properties, as well as extraneous noise provided by members of the cast or the studio audience. The directional-type microphone is suspended from the end of a boom such as is ordinarily used in the motion-picture studio. Provision is made for orienting the microphone, to allow its angle of greatest pickup or directivity to lie toward the desired point of sound pickup on the studio stage or floor. The boom is also arranged so that its horizontal member may be moved in the vertical plane, so as to alter the elevation of the microphone as required. This arrangement is necessary in order to accommodate persons of varying stature and height, and to ensure keeping the microphone itself "out of the picture." The horizontal member of the boom is ordinarily so operated in the vertical plane as to keep the microphone just above the scene being televised and out of camera range. Other techniques to achieve this result include the placement of microphones in concealed positions about the stage wherever possible, for example, in lamps, plants, furniture, or other stage properties. Whenever possible, microphones are suspended over the stage, located among the footlights, or in the wings. Arrangements have been used whereby the microphones have been moved about over the stage by means of a trolley and system of steel cables to control movement. The microphone boom, however, has proved the most practical expedient, and television microphone techniques follow the motion-picture industry in this respect. Low-impedance microphones are used almost exclusively for studio and stage sound pickup because of the relatively low noise level associated with the operation of such types. Careful shielding of interconnecting cables is required.

The microphone-boom operator wears headphones in the television studio, moving his boom in or out, up or down, or sidewise as he is directed by the technical director or studio assistant in the control room. In a great many installations, a high-impedance microphone is bridged across the technical director's microphone line in the control room to provide a microphone for the audio operator seated at the sound console. This microphone is equipped with a base-mounted switch which permits the instrument to be parallel-connected with that of the technical director or production assistant at will. Thus, the operator at the sound console in the control room may upon occasion break in to convey instructions to the microphone-boom operator. This arrangement is highly desirable, since the operator of the sound console is more intimately concerned with the problems incident to proper sound pickup, the technical director or production assistant operating from a separate portion of the control room and being more concerned with video problems.

The audio control operator or engineer ordinarily presides at a standard broadcast sound console, which is operated in much the same manner as it would function in standard AM or FM practice. A copy of the script covering the show being televised is usually provided the operator so that he may follow the continuity of the production and anticipate microphone movement. His script is marked up to indicate the proper time and place for introduction of any special sound effects, and so on. He must be provided with a suitable picture monitor, or he must be seated in such a manner that he may view the monitoring screens used by other members of the control-room staff. This condition is important in ensuring that sight and sound will be properly coordinated as the show progresses in accordance with the script.

Ordinarily, both 33⅓- and 78-r.p.m. transcription turntables are provided at the audio operating position, and they are conveniently placed to give the operator access to them while comfortably seated. In addition, telephone facilities are made available with either the master control room or the transmitter so as to provide a means of coordinating matters pertaining to sound. A similar telephone facility interconnects the video console with the master control room or transmitter, and occasionally the complete telephone system is so arranged that the program office is also connected so as to expedite last-minute program changes or instructions.

If a dual-image Orthicon camera chain is installed in the particular studio, it is customary that two video engineers preside at the video console in the control room. Before them are ordinarily located three picture monitors with screens of convenient size, two of these monitors having their inputs so connected that they bridge across the outputs of the two video intermediate amplifiers in the system, the third monitor input being bridged across the output of the video line amplifier. Thus, it is possible for the video engineers to see the pictures resulting from operation of both cameras before mixing (at the outputs of the intermediate video amplifiers), as well as the final output subsequent to modulation of the transmitter (or at a point in the over-all system after the line amplifier). Line and frame monitors are provided as well, so that the electronic information in the picture (at both line and frame frequencies) may be continuously monitored. In a typical installation, one video operator at the control console or control position normally adjusts the controls of both camera control units (one for each camera) as required. The second video engineer effects the mixing and camera switching, as well as coordinating activities by means of the telephone system interconnecting studio control room with the master control room and transmitter. When Iconoscope cameras are used in the studio, the operating problem is of greater consequence, since shading becomes a paramount problem. Here, both engineers at the console or operating position must "shade" each picture as described elsewhere in the text, other activities assuming secondary importance. Fortunately, such cameras are no longer in widespread use in the United States.

At some television stations, a production assistant (program-staff member) handles the actual switching and mixing of the picture information at the line amplifier, thereby relieving the hard-pressed video engineers of this task, the philosophy being that the program staff is more capable of providing a smooth flow of integrated scenes of high pictorial quality because of duties requiring lesser responsibility. Surely, the video engineer is more absorbed in producing a picture of high technical quality from the engineering standpoint. Whatever the arrangement, the director of the show issues directions to the people on the studio floor, either through a production assistant or a technical director. These instructions are relayed to the operating personnel in the studio by means of the intercommunicating and telephone facilities already described. The technical director speaks into a convenient microphone,

FIG. 11.2 A view of the studio control room at Station WABD, New York City. (Courtesy of Allen B. Du Mont Labs., Inc.)

and his voice is amplified and carried to the headphones worn by the cameramen and other personnel on the studio floor. A view of a studio control room during the televising of a typical show is illustrated in Fig. 11.2.

Lighting is usually arranged prior to the time that actual shooting of a scene begins. The lights for a particular stage or set are switched on upon instructions from the director, usually just prior to the shooting of a particular scene or sequence. Since several stages are ordinarily used in televising a production, this limits the amount of temperature rise in the studio, the result of the operation of the many required lighting fixtures. It has been found most convenient to operate these lights from the studio floor, a lighting technician presiding at a suitable switchboard or lighting console where the switching of the lights is accomplished.

During the course of a studio production, the entire technical organization must function as a closely coordinated group. The director of the show, who is located at an advantageous position in the control room, has over-all charge of the production. His function, in following the prepared script, is to choose appropriate shots, all of which may be so coordinated as to blend into an acceptable pictorial production of high quality. His instructions are relayed, as described, through the production assistant or other staff member to cameramen, the lighting technician, microphone-boom operators, and other personnel actively engaged in the technical operations which take place within the confines of the studio proper. The director calls for camera No. 1 or camera No. 2, and so on, as the shots are selected, the engineer or other staff member seated before the line amplifier or switcher affecting the required switching, fading, and mixing operations. Lap dissolves, fades, superimpositions, and other transitions from one scene to another are all accomplished electronically in the modern television system, mechanical or electrical relays being eliminated for obvious reasons. The audio control operator maintains the proper level, microphone balance, and so on, to ensure the proper quality of the sound accompanying the picture, and to ensure proper modulation of the aural transmitter. Video levels are set and corrected by the engineers seated at the video console, subsequent over-all supervision being provided by members of the master control-room staff or by the transmitter engineer prior to the point in the system where modulation of the radio-frequency carrier is accomplished. Audio levels are also further monitored and corrected at the master control room and at the transmitter location.

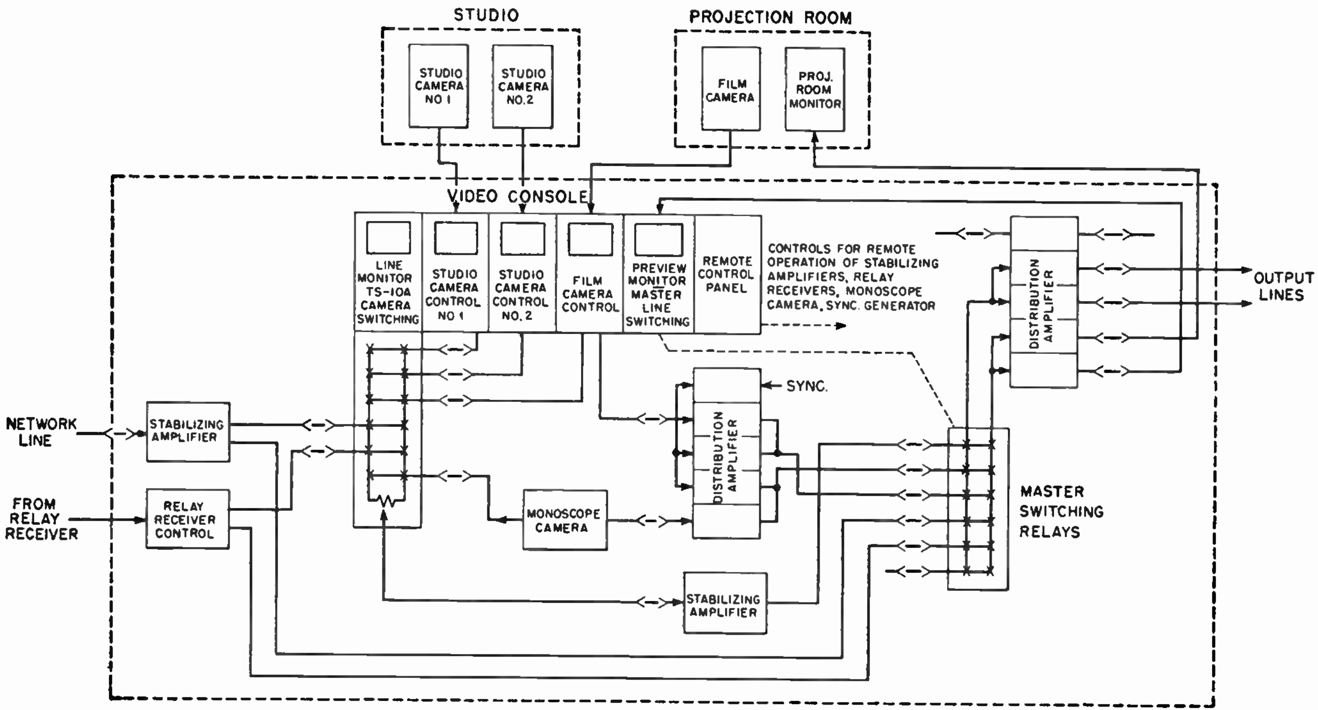
A corps of studio maintenance technicians are required to keep the technical equipment in such condition as to ensure a high state of perfection insofar as picture quality and continuity of operation of the technical equipment is concerned. The provision of a workshop adjacent to the studio area facilitates the proper servicing of the studio equipment, and it should be well equipped with appropriate tools, spare parts, test equipment, and other items required for adequate maintenance of the equipment. Where the studio operations are extensive, as in the operation of a large metropolitan television station or network, maintenance activities are carried out after the program schedule for the day has been completed and when normally scheduled programs and rehearsals do not interfere. It is most important that intricate electrical equipment such as is employed in television broadcasting be continually serviced to ensure continuous operation, as well as to prevent breakdowns before they actually occur. A well-organized maintenance program will also reduce depreciation of the equipment, which represents a sizeable investment which must be adequately protected.

Figure 11.3 illustrates the typical layout of equipment for a modern studio, projection room, and master control room. It may be seen that two Image Orthicon cameras are operated in the single studio, the outputs of these cameras feeding into studio camera control units No. 1 and No. 2. These latter items of equipment are located in the studio control room. Picture monitors associated with these control units permit the video engineers to see the scene being televised and permit the director and other personnel properly to instruct the cameramen as to camera movement and operation.

A line monitor enables the control-room personnel to view the picture present at the output of the line amplifier after camera switching has been accomplished. It will be noted that a film camera is situated in the projection room and receives the image from the film projector. A projection-room picture monitor is also provided for convenience of the projectionist. The signal to this monitor may take the form of a composite television signal, taken from the output of the line amplifier through the picture-distribution amplifier. He can thus take a cue from a program sequence preceding the instant when he is called upon to *roll* the film or introduce film as a portion of the integrated program. The picture monitor also enables the projectionist to see the result of adjustments that he may have to make to the projector or associated camera during intervals when film supplies a portion of the program. It will be seen that the output of the film camera is fed to a film camera control unit in the master control room.

Network programs may also be fed to the master control room through a stabilizing amplifier. This amplifier permits the dressing up of the incoming composite signal before introduction to the camera switching unit. Through its use the synchronizing signal may be expanded by the proper amount to compensate for any compression that may have occurred in program transmission through the coaxial-cable facility employed in network broadcasting. It has other functions as well, although all serve to dress up the incoming composite signal so that it is proper for transmission through the master control room to the television transmitter.

A relay receiver is a part of the complete array of equipment usually found at the modern television station. Its purpose is to receive signals from remote points in the field. A microwave television relay usually connects the remote point with the studio proper. The control unit for the relay receiver is situated in the master control room for operating convenience. The composite television signal present at the output of the relay-receiver control unit is fed into the camera switching unit, so



COMBINED STUDIO FILM AND MASTER CONTROL ROOM

FIG. 11.3

that it may become a part of the carefully integrated television program.

A monoscope camera is also provided at master control for the purpose of providing a test pattern signal that may either be introduced into the camera switching unit or routed through a video distribution amplifier to desired points about the station. The monoscope signal is usually employed for equipment-test purposes. In some installations, a flying-spot scanner is also useful in developing a test-pattern signal for transmission. Its use precludes the necessity of operating a complete camera chain when it is desired only to put a test pattern on the air. A considerable economy is effected in station operations, since a full camera crew is not required.

The output of the camera switching unit and line amplifier is fed, by means of another stabilizing amplifier, to a video-distribution amplifier. From that point it may be distributed to any number of desired points. The sync signal, from the synchronizing generator and shaping unit, is usually introduced into the system at the line amplifier. The picture-line amplifier standard output signal is shown in Fig. 11.4. The integrated signal that comprises the complete composite television signal may be passed through a further distribution amplifier to the television transmitter and to other desired points outside the studio.

The block schematic of the essential audio system employed at the modern television studio is shown in Fig. 11.5. The layout of equipment is almost identical with that used at both AM and FM stations, and the various units of equipment are arranged in much the same manner as they would be for use in any type of broadcasting operation. For this reason, the complete system will not be described in detail. However, it will be noted that sound pickup may be effectively handled from a number of program sources, including an announce booth, studio, projection room, and remote lines. The output signal from the audio console may be fed to a master control room or directly to the transmitter. Provision is also made for a director's announce system, which includes cueing speakers located in the announce booth, studio, and projection room. Of course, adequate audio-monitoring facilities are also shown, and monitoring speakers enable the control-room staff effectively to follow the program aurally.

11.2 The Master Control Room. In large television installations, the master control room exists between the studio and the transmitter, if we are to consider the entire technical operation as a series of links making up a chain of integrated and associated operations, all of which result in the transmission of a picture together with its accompanying sound. The master control room is usually the location where the synchronizing generators for the station are located and where video control equipment is made available for the mixing and switching of various incoming

PICTURE LINE AMPLIFIER STANDARD OUTPUT

SYNCHRONIZING SIGNAL AMPLITUDE α SHALL BE HELD CONSTANT WITHIN ±4% DURING ANY TRANSMISSION.

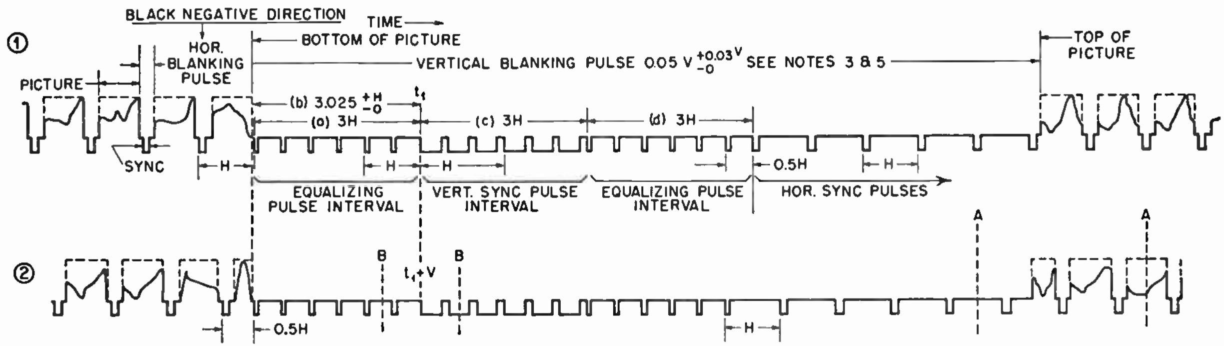
α MAY HAVE ANY VALUE BETWEEN 0.375 AND 0.625 VOLTS.

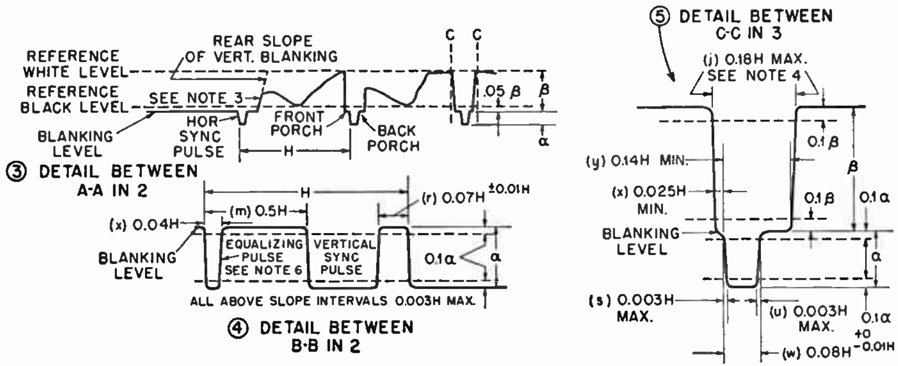
THE RATIO $\frac{\alpha}{\alpha+\beta}$ SHALL BE 0.25

DRAWINGS NOT TO SCALE.

RMA SUB-COMMITTEE ON STUDIO FACILITIES
APPROVED JAN. 22, 1946
REVISED OCT. 9, 1949

Fig. 11.4





1. H = TIME FROM START OF ONE LINE TO START OF NEXT LINE
2. V = TIME FROM START OF ONE FIELD TO START OF NEXT FIELD
3. LEADING AND TRAILING EDGES OF VERTICAL BLANKING SHOULD BE COMPLETE IN LESS THAN 0.1 H.
4. LEADING AND TRAILING SLOPES OF HORIZONTAL BLANKING MUST BE STEEP ENOUGH TO PRESERVE MIN. & MAX. VALUES OF (x + y) AND (j) UNDER ALL CONDITIONS OF PICTURE CONTENT
5. ALL TOLERANCES AND LIMITS SHOWN IN THIS DRAWING APPLY FOR LONG TIME VARIATIONS ONLY AND NOT FOR SUCCESSIVE CYCLES.
6. EQUALIZING PULSE AREA SHALL BE BETWEEN 0.45 AND 0.5 OF THE AREA OF A HORIZONTAL SYNC PULSE
7. ALL SLOPE INTERVALS TO BE MEASURED BETWEEN 0.1 AND 0.9 AMPLITUDE REFERENCE LINES
8. THE OVERSHOOT ON BLANKING SIGNAL MUST NOT EXCEED 0.02 β AT THE BEGINNING OF THE FRONT PORCH AND MUST NOT EXCEED 0.05 β AT THE END OF THE BACK PORCH. THE OVERSHOOT ON SYNCHRONIZING SIGNALS MUST NOT EXCEED 0.05 α

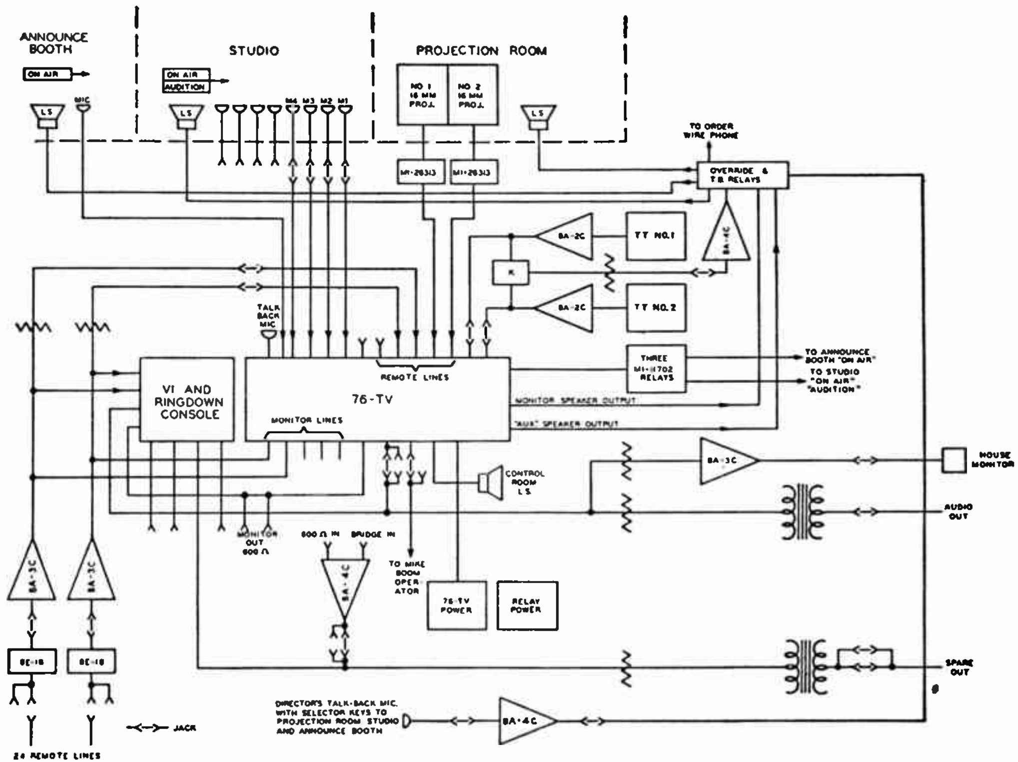

ANNOUNCE BOOTH
STUDIO
PROJECTION ROOM
ON AIR
AUDITION
LS
MIC
M4 M3 M2 M1
TO ORDER WIRE PHONE
OVERRIDE & T.B. RELAYS
BA-2C
TT NO. 1
TT NO. 2
BA-4C
TALK BACK MIC
VI AND RINGDOWN CONSOLE
76-TV
REMOTE LINES
MONITOR LINES
THREE MI-11702 RELAYS
TO ANNOUNCE BOOTH "ON AIR"
TO STUDIO "ON AIR" "AUDITION"
MONITOR SPEAKER OUTPUT
"AUX" SPEAKER OUTPUT
BA-3C
HOUSE MONITOR
CONTROL ROOM L.S.
AUDIO OUT
MONITOR OUT 600 Ω
600 Ω IN
BRIDGE IN
TO MIKE BOOM OPERATOR
76-TV POWER
RELAY POWER
SPARE OUT
JACK
24 REMOTE LINES ON JACKS
DIRECTOR'S TALK-BACK MIC. WITH SELECTOR KEYS TO PROJECTION ROOM STUDIO AND ANNOUNCE BOOTH
BA-4C

FIG. 11.5

sources of program intended for transmission. The master control room is usually located in the same building which houses the studios of the station. In common practice, the film pickup facilities are located either in the master control room or adjacent thereto, since this facilitates the coordination of film-scanning activities with studio-developed portions of the scheduled programs for the particular operating period. Such video techniques as shading (particularly as applied to the operation of film chains), the superimposition of pictures from two or more program sources, the supervision of remote operations, the acceptance of incoming remote programs, network operations and signal switching, are all a part of the activities taking place in the master control room.

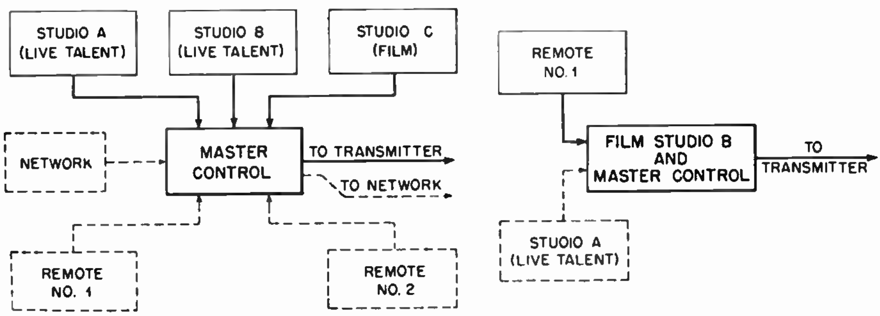


FIG. 11.6

The facilities required in the master control room of a typical television broadcasting station are shown in Fig. 11.6. The actual physical arrangement of some of the master control equipment at Station WTTG, Washington, as planned by M. Burleson and the author, is shown in Fig. 11.7. In the block diagram shown, three individual studios feed program material into the master control room, two of which provide live talent pickup and one providing film scanning. Two sources of remote programs are shown in dotted lines, and these also feed into the master control room. These outside pickups of sports or other field activities may reach the master control room by means of microwave relay, coaxial cable, or balanced telephone lines. The most convenient means of linking the master control room with these remote points will depend upon the facilities available and convenient for the particular pickup. It is also shown in the block diagram that network programs are accepted at the master control room. One or more sources of network programs may be switched or mixed before transmission to the station transmitter or other network. Programs may be accepted from networks at the master control room, or they may be fed to other stations or networks and to their associated stations.

The master control room is the central point of control for program material, as many as six program sources being accepted in the system shown and the selected program information being furnished to as many outside points as required. With the complexity of television programming increasing all the time, it is highly desirable that appropriate facilities be made available to handle any program demand which management might impose. This arrangement necessitates the installation of con-

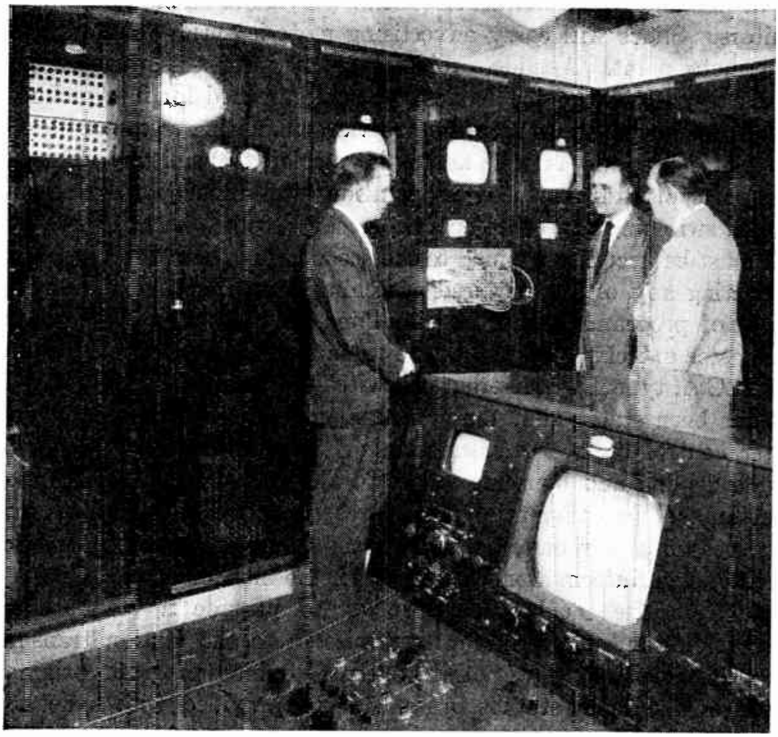


FIG. 11.7 The master control room at Station WTTG, Washington, D.C. (Courtesy of Du Mont Television Network.)

siderable equipment, together with such auxiliary or spare equipment as will ensure continuity of operation. The result is a vast array of highly complex apparatus, usually under the supervision of three or more highly trained video and audio engineers.

A hypothetical example of a typical master-control operation may be found by referring to Fig. 11.6. A live-talent program may be emanating from studio A, while it is necessary to provide portions of the program from studio C as a film presentation. A rehearsal may be occurring in studio B, which is being fed to a client's room or teletheater where a prospective client of the station is previewing the show. The program following that originating in studio A is to come from a remote pickup point outside the studio by means of a microwave relay. The remote program must be set up in advance; that is, the remote-program picture information must be previewed by the master control-room staff to ascertain if the signal is proper for high-quality transmission. To accomplish this, the master control engineers will observe the picture on a suitable screen, the line and frame information, i.e., the picture information at line and frame frequencies, being previewed on suitable waveform monitors. Slides will carry advertising material prior to the switch to the remote point. A slide projector is used for this purpose and is associated with one of the Iconoscope cameras used for film pickup. It will also be necessary to feed the program emanating from studio A to a network of stations as well as to the station transmitter. This short review of typical master-control operations will impart some idea of how complex switching and other operations can become. All of these operations must be accurately timed to the second, and there must be no delay in effecting any of the required switching from the various points and sources of program pickup. A simplified diagram of a camera control and master switching system is shown in Fig. 11.8. The close-up view of an R.C.A. type TS–10A program-switching panel is shown in Fig. 11.9.

It has been stated that the synchronizing generator is located in the master control room. One function of the master control room is to provide driving and blanking pulses to all local studios. This involves correction of the differential delay occasioned by the supplied studios being located at a remote point from the common master control room. Synchronizing information is added to the noncomposite signals accepted from the local studios, so as to provide a standard composite television waveform for transmission to the station transmitter or to a television network of other stations. Remote programs originating outside of the main studios ordinarily are provided with sync at the pickup point, a synchronizing generator being a part of the portable field chain. Such programs are ordinarily switched directly through the master control room, it being unnecessary to add the synchronizing signal. Another function of the master control room is to handle the phasing of synchronizing-generator pulses, so as to ensure proper operation, for example, of the film pickup equipment.

With reference to remote network programs, the vertical synchronizing information from these points outside the studio must be properly and adequately related in phase and frequency to that of the local master control-room synchronizing generator. This facilitates switching from local-program pickup point to remote pickup point or from remote to local pickup point, with no deleterious effects upon receivers in the field. Without such phasing, the pictures at receivers are apt to roll vertically owing to loss of vertical sync when switching is being accomplished. It is sometimes necessary to supply synchronizing signals from the master control room to individual studios. The output of the synchronizing generator is fed through an equipment termed a "sync-distribution amplifier." It comprises a number of cathode-follower, or isolation, stages, the outputs of which are terminated in suitable video jacks at a patch

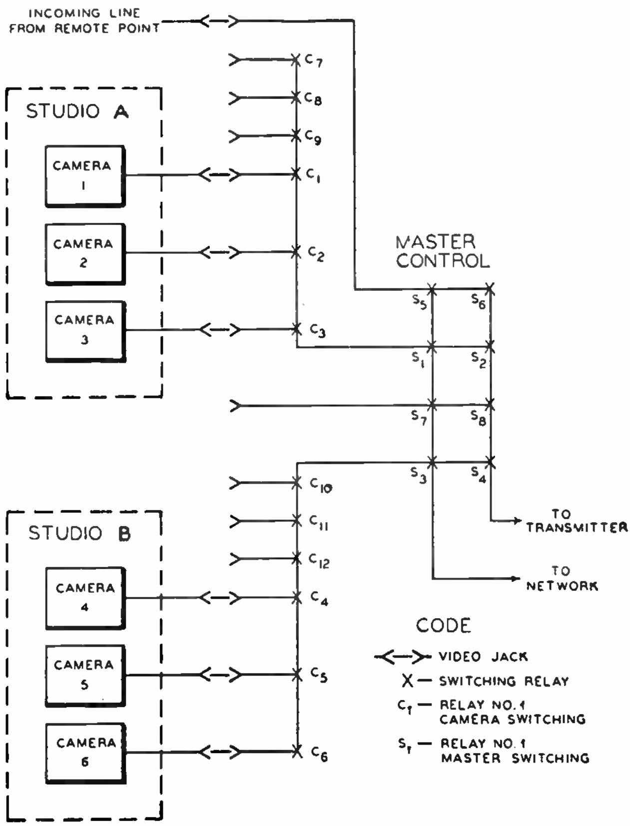


FIG. 11.8

panel. Synchronizing information may then be patched to any desired point throughout the plant and transmitted by means of coaxial cables.

In addition to the development of a composite picture signal in conformance with accepted standards and the distribution of synchronizing information and blanking and driving signals to other studios, adequate facilities must be made available in the master control room for the distribution of a composite picture signal to teletheaters, to control rooms (particularly for cueing purposes), to clients' rooms, and to other desired points about the television station. A picture distribution amplifier, comprising a number of cathode followers as well as a suitable patch panel at which the follower outputs are terminated, accomplishes this result. In large television stations or in networking, it may be necessary to employ a considerable number of sync-distribution and picture-distribution amplifiers, together with an array of video patch panels and cords, in order to provide flexible operation and to handle the work load imposed.

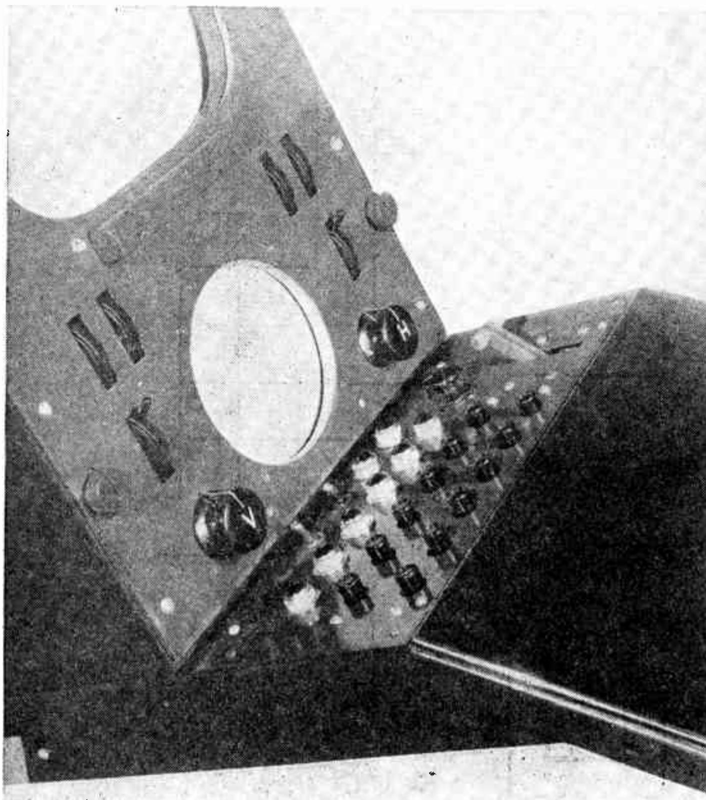


FIG. 11.9 Close-up view of R.C.A. TS-10A switching panel. (Courtesy of Radio Corporation of America.)

Suitable facilities for picture monitoring must be provided so that the transmitter or network, or both, can be given the required program at the proper level at the correct time. If the master control room is that of a television network, the outgoing program is fed to the local telephone company exchange or plant, from which point it is distributed by suitable wire line, coaxial cable, or microwave relay facilities. The block schematic of a typical equipment layout for studio, film projection, and master control operations is shown in Fig. 11.10.

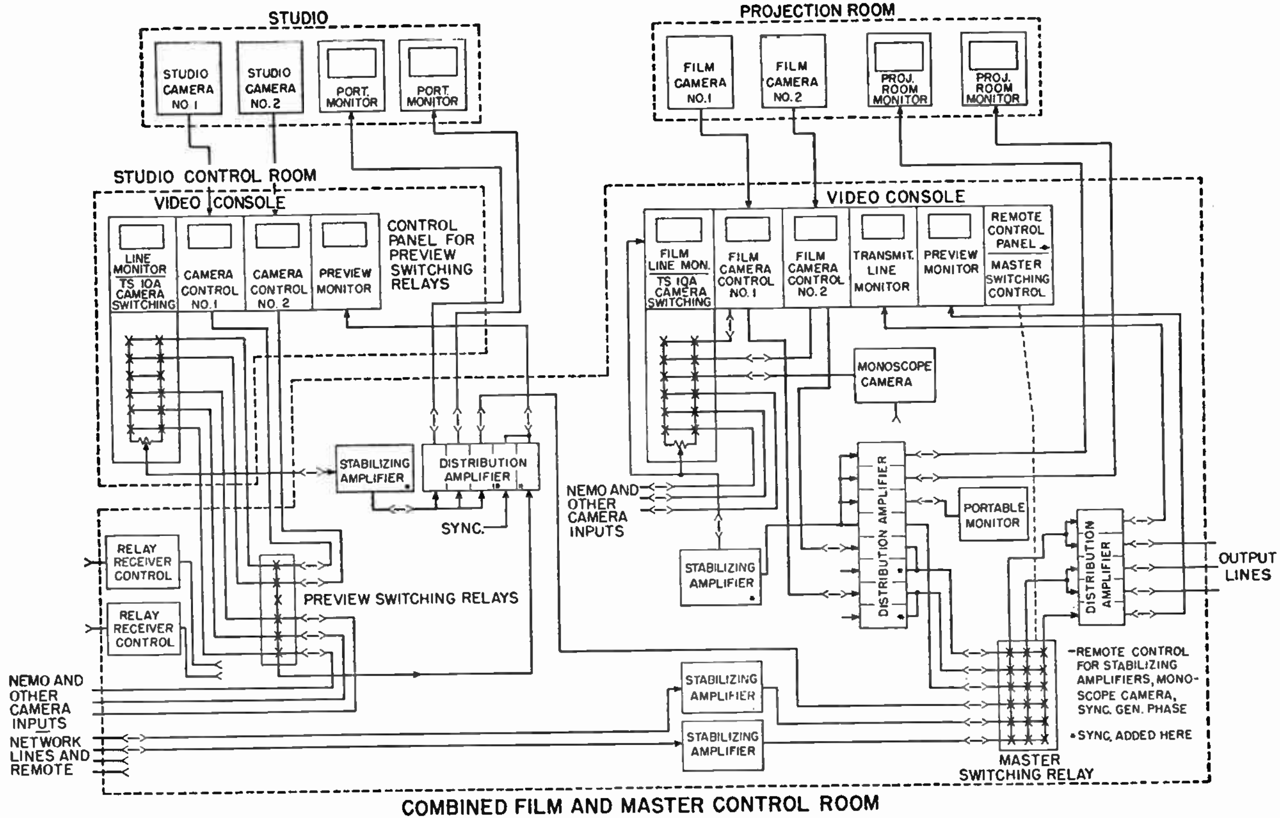

STUDIO
STUDIO CAMERA NO. 1
STUDIO CAMERA NO. 2
PORT. MONITOR
PORT. MONITOR
STUDIO CONTROL ROOM
VIDEO CONSOLE
LINE MONITOR
TS 10A CAMERA SWITCHING
CAMERA CONTROL NO. 1
CAMERA CONTROL NO. 2
PREVIEW MONITOR
CONTROL PANEL FOR PREVIEW SWITCHING RELAYS
STABILIZING AMPLIFIER
DISTRIBUTION AMPLIFIER
SYNC.
RELAY RECEIVER CONTROL
RELAY RECEIVER CONTROL
PREVIEW SWITCHING RELAYS
NEMO AND OTHER CAMERA INPUTS
NETWORK LINES AND REMOTE
PROJECTION ROOM
FILM CAMERA NO. 1
FILM CAMERA NO. 2
PROJ. ROOM MONITOR
PROJ. ROOM MONITOR
VIDEO CONSOLE
FILM LINE MON.
TS 10A CAMERA SWITCHING
FILM CAMERA CONTROL NO. 1
FILM CAMERA CONTROL NO. 2
TRANSMIT. LINE MONITOR
PREVIEW MONITOR
REMOTE CONTROL PANEL
MASTER SWITCHING CONTROL
MONOSCOPE CAMERA
NEMO AND OTHER CAMERA INPUTS
STABILIZING AMPLIFIER
DISTRIBUTION AMPLIFIER
PORTABLE MONITOR
DISTRIBUTION AMPLIFIER
OUTPUT LINES
STABILIZING AMPLIFIER
STABILIZING AMPLIFIER
-REMOTE CONTROL FOR STABILIZING AMPLIFIERS, MONOSCOPE CAMERA, SYNC. GEN. PHASE
•SYNC. ADDED HERE
MASTER SWITCHING RELAY
COMBINED FILM AND MASTER CONTROL ROOM

Fig. 11.10

Audio-frequency signals must also be dispatched through the master control room. In common practice, a standard audio console such as is used in AM or FM broadcasting is made available for this purpose. Auxiliary audio bridging amplifiers, monitoring amplifiers, monitoring speakers, patch panels, cords, and switching facilities are included, depending upon the problems to be handled and the work load to be imposed. Both 33⅓- and 78-r.p.m. record turntables are made available for the playing of records and transcriptions. Facilities are provided for recording sound if such procedures are necessary for legal purposes, or for the purpose of maintaining records of the programs being transmitted. Audio monitoring and terminal facilities must be made available as required, and several commercial-type line equalizers are an indispensable adjunct to complete facilities.

With reference to the picture signals handled in the master control room, line-to-line clamping techniques are employed so that extraneous signals may be eliminated from the television signal. The conventional stabilizing amplifier is employed for this purpose. These stabilizing amplifiers also allow stretching of the synchronizing signal to compensate for any reduction in its amplitude due to compression at any point in the system. Such compression is particularly likely to occur where program transmission is by means of currently operated coaxial-cable facilities.

A typical network master control setup is shown in the block diagram in Fig. 11.11. Twelve sources of program may be accommodated with this arrangement, six from local studios and six from other network or remote points outside the studios. Four of the six local studios may be selected for immediate use. Two of these go to a bridging amplifier in the "On the Air" rack of equipment, while two go to the video bridging amplifier in the rack supporting picture-preview equipment (see Fig. 11.12). The standard Du Mont video bridging amplifier provides two inputs and four multiple-output connections to provide flexible operation. After passing through the bridging amplifier, four lines exist for each of the four selected video channels. These outputs are also present and terminated at the OAR (on the air) patch panel, and at the PVR (preview) patch panel. A four-channel line amplifier is located at the OAR rack and another at the PVR rack of equipment. All switching and mixing at the inputs to these line amplifiers is accomplished electronically without the use of mechanical or electrical relays at a master control switching and mixing desk. It will be seen that any desired number of lines may be fed by this master control arrangement. A most flexible layout of equipment thus provides any control switching, mixing, monitoring, or patching desired in network operations. Suitable telephone facilities are made available for intercommunication with associated studios,

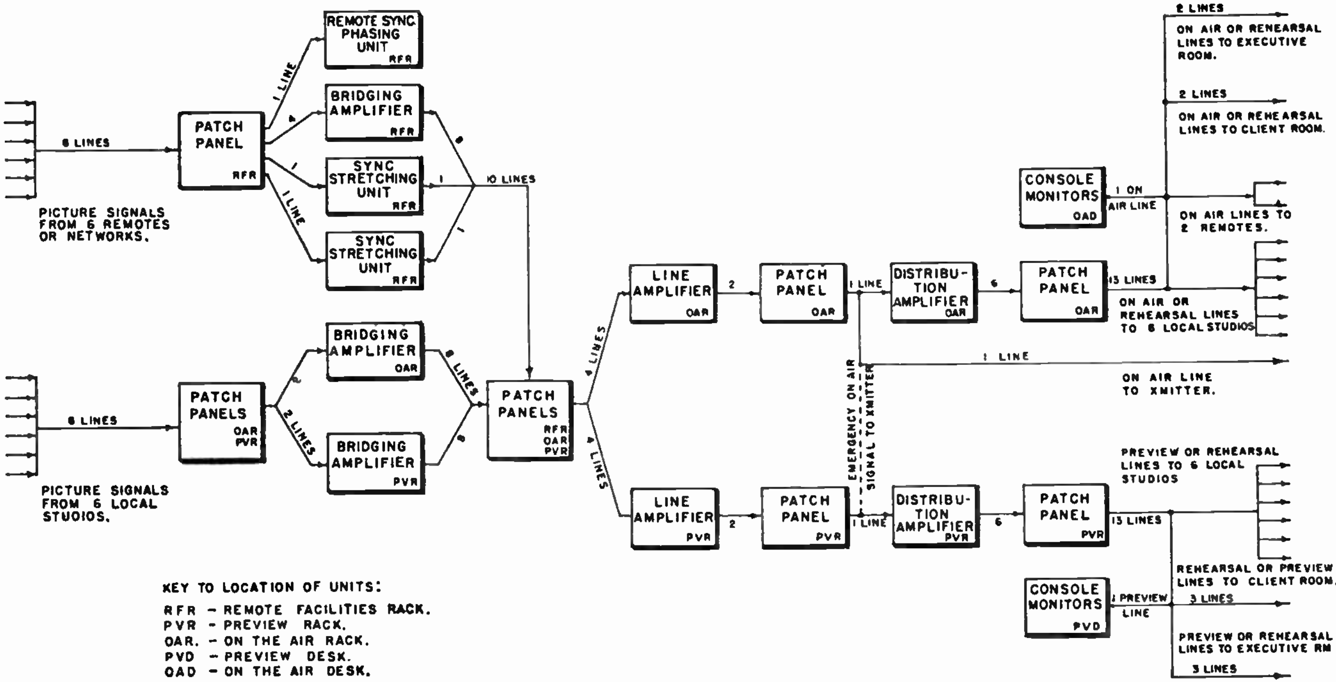

6 LINES
PICTURE SIGNALS FROM 6 REMOTES OR NETWORKS.
PATCH PANEL RFR
1 LINE
REMOTE SYNC PHASING UNIT RFR
BRIDGING AMPLIFIER RFR
SYNC STRETCHING UNIT RFR
SYNC STRETCHING UNIT RFR
1 LINE
10 LINES
6 LINES
PICTURE SIGNALS FROM 6 LOCAL STUDIOS.
PATCH PANELS OAR PVR
BRIDGING AMPLIFIER OAR
BRIDGING AMPLIFIER PVR
2 LINES
6 LINES
PATCH PANELS RFR OAR PVR
4 LINES
4 LINES
LINE AMPLIFIER OAR
PATCH PANEL OAR
1 LINE
DISTRIBU-TION AMPLIFIER OAR
PATCH PANEL OAR
LINE AMPLIFIER PVR
PATCH PANEL PVR
1 LINE
DISTRIBU-TION AMPLIFIER PVR
PATCH PANEL PVR
EMERGENCY ON AIR SIGNAL TO XMITTER
CONSOLE MONITORS OAD
1 ON AIR LINE
13 LINES
2 LINES
ON AIR OR REHEARSAL LINES TO EXECUTIVE ROOM.
2 LINES
ON AIR OR REHEARSAL LINES TO CLIENT ROOM.
ON AIR LINES TO 2 REMOTES.
ON AIR OR REHEARSAL LINES TO 6 LOCAL STUDIOS
1 LINE
ON AIR LINE TO XMITTER.
PREVIEW OR REHEARSAL LINES TO 6 LOCAL STUDIOS
13 LINES
REHEARSAL OR PREVIEW LINES TO CLIENT ROOM.
CONSOLE MONITORS PVD
1 PREVIEW LINE
3 LINES
PREVIEW OR REHEARSAL LINES TO EXECUTIVE RM
3 LINES
KEY TO LOCATION OF UNITS:
RFR - REMOTE FACILITIES RACK.
PVR - PREVIEW RACK.
OAR. - ON THE AIR RACK.
PVD - PREVIEW DESK.
OAD - ON THE AIR DESK.

FIG. 11.11

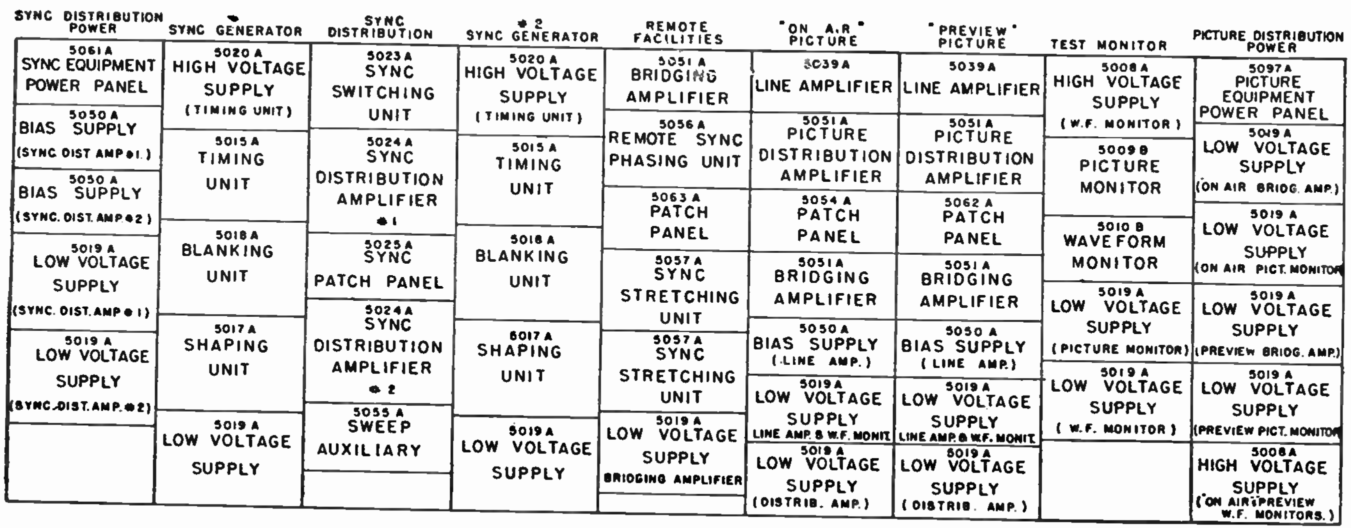

SYNC DISTRIBUTION POWER
5061 A SYNC EQUIPMENT POWER PANEL
5050 A BIAS SUPPLY (SYNC DIST AMP #1)
5050 A BIAS SUPPLY (SYNC. DIST. AMP. #2)
5019 A LOW VOLTAGE SUPPLY (SYNC. DIST. AMP. #1)
5019 A LOW VOLTAGE SUPPLY (SYNC. DIST. AMP. #2)
SYNC GENERATOR
5020 A HIGH VOLTAGE SUPPLY (TIMING UNIT)
5015 A TIMING UNIT
5018 A BLANKING UNIT
5017 A SHAPING UNIT
5019 A LOW VOLTAGE SUPPLY
SYNC DISTRIBUTION
5023 A SYNC SWITCHING UNIT
5024 A SYNC DISTRIBUTION AMPLIFIER #1
5025 A SYNC PATCH PANEL
5024 A SYNC DISTRIBUTION AMPLIFIER #2
5055 A SWEEP AUXILIARY
#2 SYNC GENERATOR
5020 A HIGH VOLTAGE SUPPLY (TIMING UNIT)
5015 A TIMING UNIT
5018 A BLANKING UNIT
6017 A SHAPING UNIT
5019 A LOW VOLTAGE SUPPLY
REMOTE FACILITIES
5051 A BRIDGING AMPLIFIER
5056 A REMOTE SYNC PHASING UNIT
5063 A PATCH PANEL
5057 A SYNC STRETCHING UNIT
5057 A SYNC STRETCHING UNIT
5019 A LOW VOLTAGE SUPPLY BRIDGING AMPLIFIER
"ON AIR" PICTURE
5039 A LINE AMPLIFIER
5051 A PICTURE DISTRIBUTION AMPLIFIER
5054 A PATCH PANEL
5051 A BRIDGING AMPLIFIER
5050 A BIAS SUPPLY (LINE AMP.)
5019 A LOW VOLTAGE SUPPLY LINE AMP. & W.F. MONIT.
5019 A LOW VOLTAGE SUPPLY (DISTRIB. AMP.)
"PREVIEW" PICTURE
5039 A LINE AMPLIFIER
5051 A PICTURE DISTRIBUTION AMPLIFIER
5062 A PATCH PANEL
5051 A BRIDGING AMPLIFIER
5050 A BIAS SUPPLY (LINE AMP.)
5019 A LOW VOLTAGE SUPPLY LINE AMP. & W.F. MONIT.
5019 A LOW VOLTAGE SUPPLY (DISTRIB. AMP.)
TEST MONITOR
5008 A HIGH VOLTAGE SUPPLY (W.F. MONITOR)
5009 B PICTURE MONITOR
5010 B WAVE FORM MONITOR
5019 A LOW VOLTAGE SUPPLY (PICTURE MONITOR)
5019 A LOW VOLTAGE SUPPLY (W.F. MONITOR)
PICTURE DISTRIBUTION POWER
5097 A PICTURE EQUIPMENT POWER PANEL
5019 A LOW VOLTAGE SUPPLY (ON AIR BRIDG. AMP.)
5019 A LOW VOLTAGE SUPPLY (ON AIR PICT. MONITOR)
5019 A LOW VOLTAGE SUPPLY (PREVIEW BRIDG. AMP.)
5019 A LOW VOLTAGE SUPPLY (PREVIEW PICT. MONITOR)
5008 A HIGH VOLTAGE SUPPLY (ON AIR & PREVIEW W.F. MONITORS.)

FIG. 11.12

the transmitter, and the offices of the affiliated or associated telephone company to which network programs are dispatched. It is the usual practice to employ a telephone-line facility panel for this purpose, which is provided with the necessary jacks for terminating incoming and outgoing lines, as well as including annunciators and signal lights to indicate traffic.

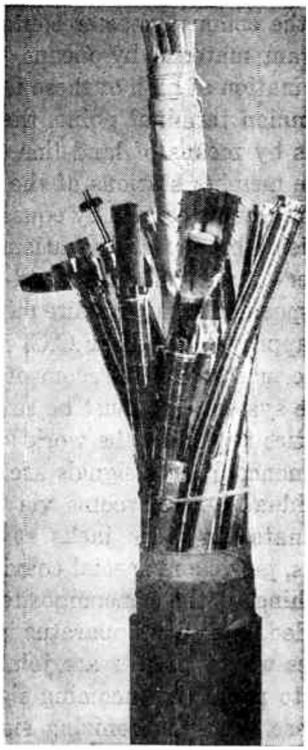


FIG. 11.13 Cut-away section of coaxial cable. Actually, there are eight individual coaxial cables in the assembly, each capable of carrying a television program from city to city. At the center are telephone cables for the purpose of carrying hundreds of long-distance conversations simultaneously. (Courtesy of American Telephone and Telegraph Co.)

11.3 The Television Network. In television-network operations, programs are distributed from a key station to member or affiliated stations by means of microwave-relay or coaxial-cable facilities. A cut-away section of coaxial cable is shown in Fig. 11.13. The common carrier, which supplies the wire, coaxial cable, or microwave-relay facilities interconnecting the various cities and the stations comprising the network, supplies the facilities available which exist at the present time. Some cities are connected solely by microwave relay, and some are connected by coaxial cable. In a few instances, both types of facilities exist between cities. In general, it is believed that the microwave radio-relay facilities are more effective for television networking than are coaxial lines or cables, principally because the bandwidth of the relay system is greater.* The increased bandwidth of the microwave radio relay permits the transmission of greater picture detail, the upper frequencies and harmonics determining the amount of fine line detail which exists in the television image. The radio relay also presents a more direct transmission medium from point to point, fewer repeaters being in service. This materially reduces the scope of the engineering problems involved.

The individual studios at the key station of a television network feed into the common master control room, the output of which provides the program material by means of coaxial cable, balanced wire line, or a combination of both of these facilities, to the local telephone office. From a common terminal point, the common carrier routes the network programs by means of land-line coaxial cable or microwave-relay facilities to the member stations of the particular network. The aural portion of the program is carried by equalized telephone lines overland to the various television broadcasting stations that make up the network. The common carrier charges toll on its land-line coaxial-cable and radio-relay facilities at a specified rate per route mile per interval of time. The rates are fixed and approved by the F.C.C. in the United States.

The master control room of the television network is the nerve center of the system. It must be suitably equipped with both video and audio facilities to handle the work load imposed. In a typical network operation, noncomposite signals are fed into the master control room from the individual control rooms via coaxial cables, the incoming cables being terminated in video jacks at suitable patch panels. The use of patch panels, jacks, and special coaxial patch cords permit flexible patching and switching of the noncomposite signals before synchronizing information is added, and such apparatus is designed to minimize impedance discontinuities where circuits are joined or connected. It often becomes necessary to route the incoming signals through a sync stretcher in order to increase the synchronizing signal amplitude that has been compressed in transmission via coaxial cable. This is particularly true of signals that have originated at remote points outside the studio and are composite signals, the synchronizing signal having already been included at the remote point. The use of stabilizing amplifiers permits compensation for compression of the amplitude of the synchronizing signal, as well as permitting the removal of extraneous noise through the use of line-to-line clamping techniques. Such clamping is almost always effected during the back-porch interval of the signal waveform, since this results in much more effective clamping. Clamping on sync tips is not to be encouraged, because any compression of the sync tends to defeat the purpose of clamping. Such techniques have been discussed elsewhere in the text,

* Bell Telephone Laboratories are developing a carrier system for use with coaxial cable which will increase the available bandwidth up to approximately 8.0 mc.

as have the specific master control operations. They will not be discussed here.

In networking by means of microwave relay, signals are passed from hilltop to hilltop along routes that are carefully chosen to take advantage of the existing terrain. Sites for video relay repeater stations are chosen

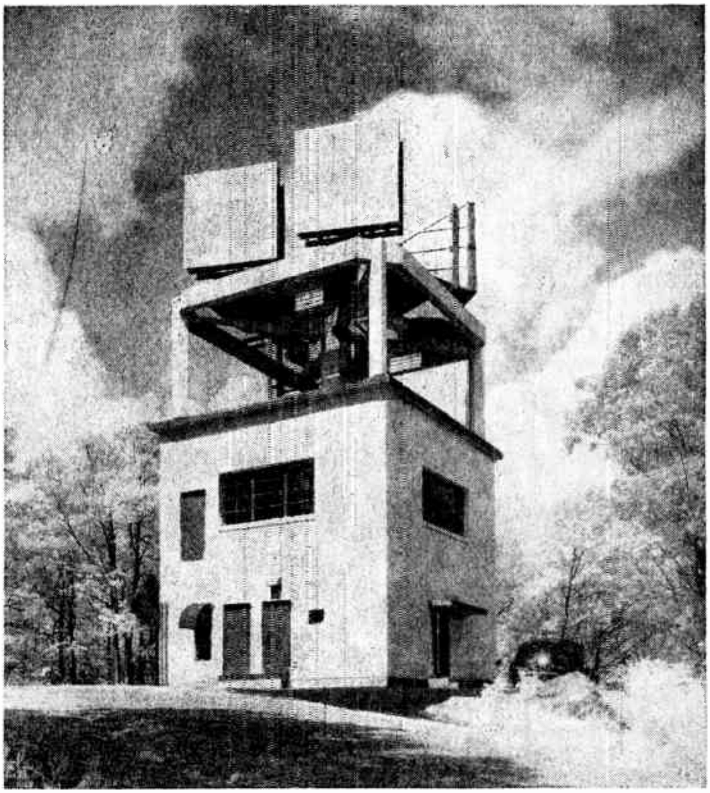


FIG. 11.14 Bell System radio-relay tower at Jackie Jones Mountain in New York state, part of New York–Boston radio-relay system. (Courtesy of American Telephone and Telegraph Co.)

because of the *elevation* present at the intended location, the *geographical relation* of the site to other sites along a specified route, the *presence of power and telephone facilities,* and the *accessibility* of the site from road or highway under conditions of inclement weather. Because of the necessary elevation, most of the relay repeater stations are located in remote mountainous regions. For this reason, the latter factor is of greater importance in the selection of possible sites along a desired route. It is also important from the standpoint of transportation of materials to the site for construction purposes. In the selection of sites along an intended route, suitable locations are first established on a topographical map indicating the elevation of the terrain in feet above mean sea level. After the locations are established on this topographical map, the actual locations must be visited to determine their suitability. If found suitable from a preliminary study, each location is surveyed and the plots staked out.

Since television broadcasting stations, members of the network, have transmitting locations that are elevated sites, it is often found possible to make use of one or more of these in network relaying, the signal being passed from one transmitting station to another, with suitable repeater stations constructed wherever necessary. By the same token, it is sometimes more desirable for a television broadcasting station to accept network programs at the transmitter rather than at the studio location. This is particularly true where microwave relays are made use of.

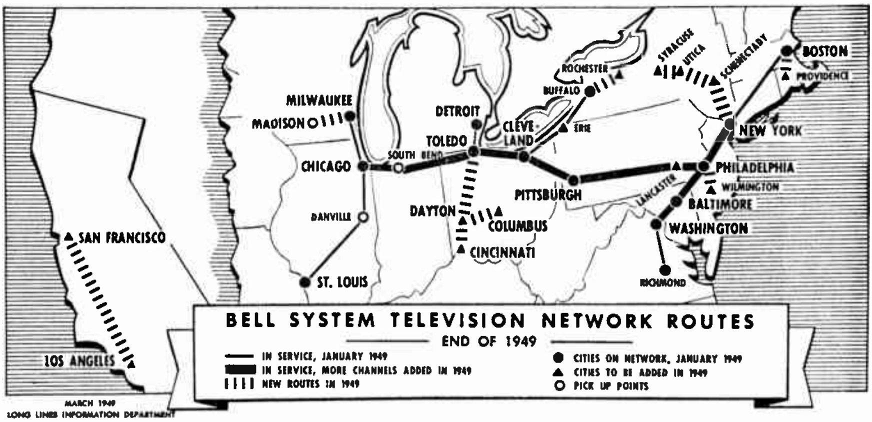


FIG. 11.15

A typical microwave-relay station is shown in Fig. 11.14. It is one of several repeater stations along the route connecting New York City and Boston. The existing and proposed coaxial-cable and microwave-relay facilities provided by American Telephone and Telegraph Company as of the latter part of 1949 are shown in Fig. 11.15. Additional routes will be made available when the construction of stations creates a demand for more extended facilities. As has been stated before, the aural portion of the television program is carried by existing land-line facilities of the common carrier. This portion of the program is thus handled in all respects as are the programs in standard AM broadcasting. The equipment layout at a typical microwave-relay station is shown in Fig. 11.16.

The frequencies utilized in the radio relaying of television programs are

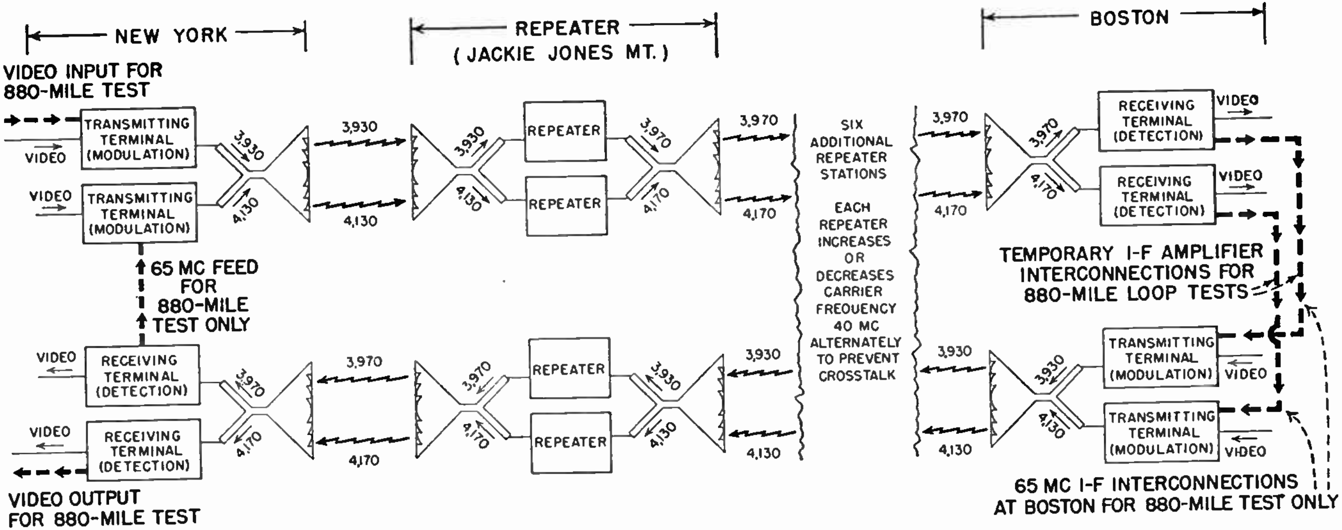

NEW YORK
REPEATER
(JACKIE JONES MT.)
BOSTON
VIDEO INPUT FOR
880-MILE TEST
TRANSMITTING TERMINAL (MODULATION)
VIDEO
TRANSMITTING TERMINAL (MODULATION)
VIDEO
65 MC FEED FOR 880-MILE TEST ONLY
RECEIVING TERMINAL (DETECTION)
VIDEO
RECEIVING TERMINAL (DETECTION)
VIDEO
VIDEO OUTPUT
FOR 880-MILE TEST
3,930
4,130
3,970
4,170
REPEATER
REPEATER
REPEATER
REPEATER
SIX ADDITIONAL REPEATER STATIONS
EACH REPEATER INCREASES OR DECREASES CARRIER FREQUENCY 40 MC ALTERNATELY TO PREVENT CROSSTALK
RECEIVING TERMINAL (DETECTION)
VIDEO
RECEIVING TERMINAL (DETECTION)
VIDEO
TEMPORARY I-F AMPLIFIER
INTERCONNECTIONS FOR
880-MILE LOOP TESTS
TRANSMITTING TERMINAL (MODULATION)
VIDEO
TRANSMITTING TERMINAL (MODULATION)
VIDEO
65 MC I-F INTERCONNECTIONS
AT BOSTON FOR 880-MILE TEST ONLY

FIG. 11.16

necessarily in the microwave region. The tentative television radio-relay channel assignments are given in Table 13.

TABLE 13

Below 300 mc. per sec.		Above 300 mc. per sec.		Total	
Channels	Bandwidth, mc.	Channels	Bandwidth, mc.	Band, mc. per sec.	Total, mc.
7	26	10	65	5,650–7,050	832
5	27	5	66	10,500–13,000	465
3	24	3	63	1,295–1,425	261
16	26	25	65	5,650–7,050	2,036
5	27	20	66	10,500–13,000	1,505

Television relay systems include studio-to-transmitter systems, portable-mobile television relays, intercity relays, and intracity relays. Whatever the classification, a television relay system may be generally defined as a system of two or more stations for transmitting television relay signals from point to point, using radio waves in free space as a medium, the transmission not being intended for direct reception by the general public. On this basis, licenses are issued by the F.C.C. in the United States. Transmission is generally in the microwave region because it is free from interference to other existing services, and because the allocation situation is such that it is easier for the licensing authority to allocate adequate facilities in this portion of the frequency spectrum. Of paramount importance is the fact that signals in this region are quasi optical and more easily directed from point to point about the country.

The various television relay systems in current use are as follows: A *studio-to-transmitter relay system* is one intended for the transmission of relay signals from a fixed source, such as a studio, to a television broadcast transmitter. A *portable-mobile relay system* is designed and constructed for the purpose of transmitting television relay signals from a portable or mobile program source to a fixed control room, master control room, or to a television broadcast transmitter. The *intercity relay system* is intended primarily for the transmission of television relay signals by fixed stations from one service area to another. These are the systems employed in television network broadcasting (see Figs. 11.17, 11.18, and 11.19). The *intracity relay* is intended for the transmission of television relay signals from point to point within a city, though not for any of the purposes already described.

In order to get the relay signal from point to point in even the most elementary relay system, two stations are required—one for transmitting and one for receiving. This elementary combination is multiplied many times in network broadcasting. The *transmitting station* has been termed a "sending terminal station" and includes the specific assembly of apparatus for receiving a television relay input signal and then radiating

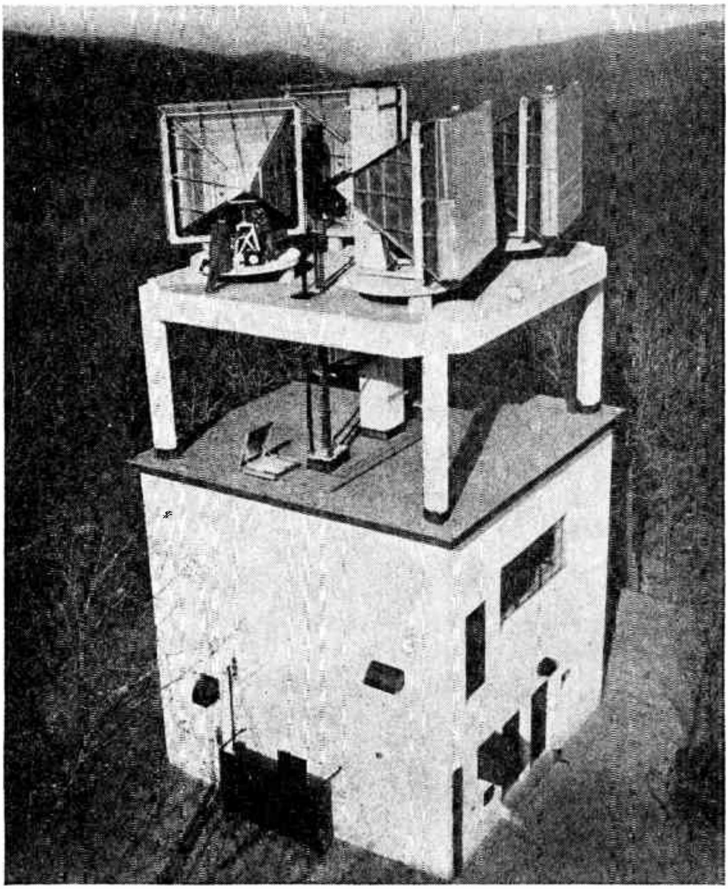
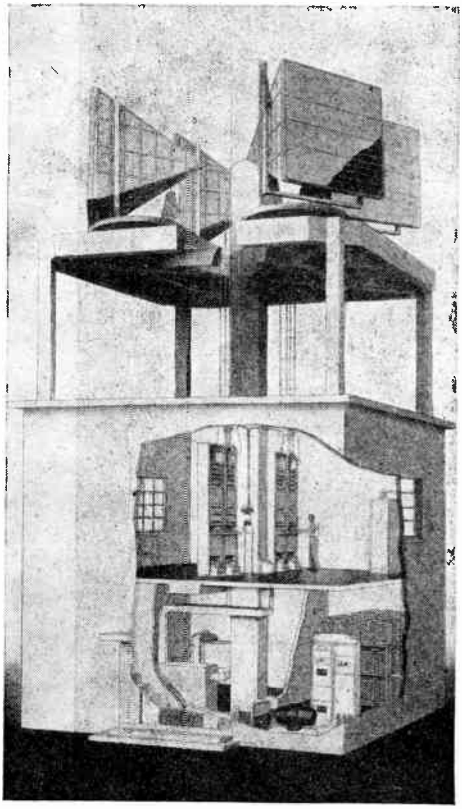


FIG. 11.17 Radio-relay station on Jackie Jones Mountain in New York state, one of seven such mountain-top structures comprising the Bell System's New York–Boston microwave radio-relay system. Two of the four shielded-lens antennas face the New York City terminal atop the Long Lines Building at 32 Avenue of the Americas, while the other two are directed at the next repeater station at Birch Hill, N.Y., 35 miles to the northeast of Jackie Jones. This type of antenna system permits the concentration of super-high-frequency radio waves into a very narrow beam of about 2 deg. These waves carry television network programs originating at either New York or Boston, or telephone messages between those points. (Courtesy of American Telephone and Telegraph Co.)

a television relay signal. A *receiving terminal station* includes the apparatus that accepts or receives a television relay signal and then delivers a standard television relay output signal. In network operations, there has been classified a special type of relay station termed a *sending-receiving terminal station.* This definition applies where both a sending terminal station and a receiving terminal station are present. An intermediate relay station, situated at some mid-point between the sending



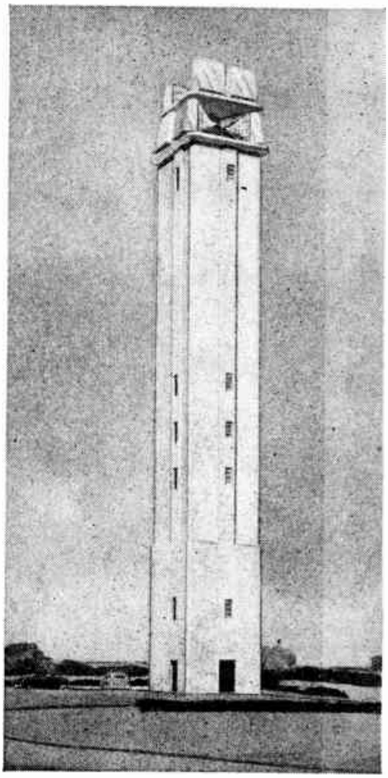


FIG. 11.18 Cut-way view of the typical radio-relay station on the New York–Boston route, featuring the metal-lens antenna, power supply, and other components of the station. (Courtesy of American Telephone and Telegraph Co.)

FIG. 11.19 Architect's drawing of the new type of radio-relay building being erected by the American Telephone and Telegraph Company's Long Lines Department on the New York–Chicago route. These structures will range in height from 60 ft. in mountainous country to 205 ft. on the flat land near Chicago. (Courtesy of American Telephone and Telegraph Co.)

terminal station and the receiving terminal station, is classified as a *repeater station* (see Fig. 11.20).

The licensing authority has provided relay channels of specific band-width to accommodate those television stations requiring the facilities, and sufficient relay facilities have been allocated to each city to allow for the optimum local relay facilities. Special channels have been assigned for the purpose of network relaying between cities across the nation.

A relay channel has been defined as the band of frequencies used in the transmission of a single television relay signal and normally includes both the frequency band necessary for the transmission of intelligence and adequate guard bands above and below the channel to prevent interference.

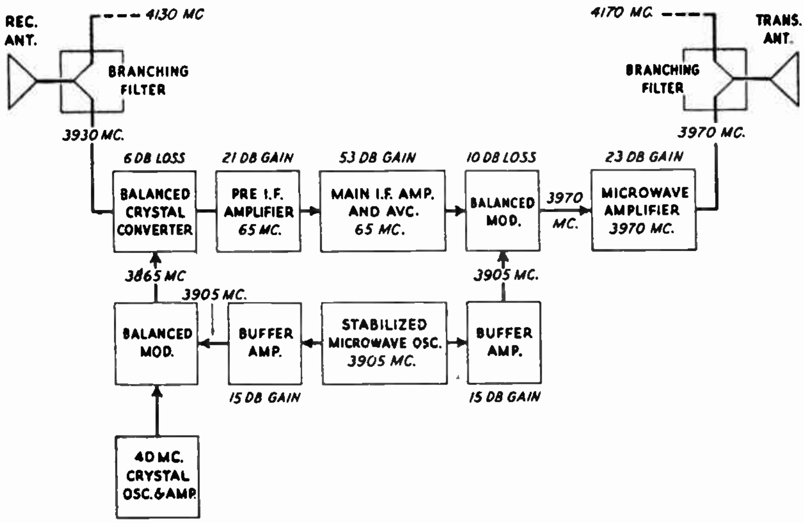


FIG. 11.20

11.4 Over-All Relay Performance Characteristics. In order to ensure uniform performance of television relays, certain electrical standards have been adopted by the various manufacturers of such equipment. These standards result in the production of commercial equipment that can be used in many cities and at interconnecting points with but little variation in electrical operating characteristics.

The input impedance of a television relay is made variable over a range of 75 ohms $\pm$ 10 per cent, the input impedance being held constant within $\pm$ 5 per cent over a frequency range of 0 to 4.5 mc. and over a range of d-c input level of 0 to 15 v. The impedance is connected for single-ended operation. If an audio signal is transmitted by the relay, the standard input impedance for the sound is fixed at 600/150 ohms, both impedances being made use of in standard practice. The output or load impedance of the television relay has been standardized at the same values as are specified for the input impedances.

The picture signal output of the relay system has been established as a minimum of 1.5 v. and a maximum of 2.5 v. peak to peak when the signal contains reference white. The audio frequency output level of the relay has been standardized as 18 dbm., when the relay is feeding lines of the telephone company, and 10 dbm. ± 2 db., when the relay is directly driving or feeding a radio transmitter.

The standard polarity of the picture signal at the input or output terminals of the relay shall be black negative. The network or other relay system must not appreciably discriminate either as to amplitude or as to phase shift against any frequency in the band extending from 60 c.p.s. to 4.5 mc. for the picture signal. With reference to the audio signal, the frequency response should be such that the energy throughout the band transmitted must not deviate by more than 1 db. from a flat characteristic required between 50 and 15,000 c.p.s.

In order to ensure proper transmission of the composite picture signal by a network relay system, certain standards have been adopted as to the transfer characteristic to be achieved. The transfer characteristic of a relay system is that function which when multiplied by an input magnitude will give the resulting output magnitude. The transfer characteristic of a television relay system should be essentially constant between the limits set by carrier-reference black level and carrier-reference white level. If the transfer characteristic is not constant in the region of carrier black level to peak of sync, it must be possible by correction in other parts of the system to satisfy the over-all system requirements.

In determining whether the transfer characteristic of a television relay system satisfies these requirements, a method of measurement has been specified. A signal generator having an output impedance corresponding to the standard source impedance shall be connected to the relay receiver input. The signal generator is then modulated with a standard composite picture signal in which the picture voltage between horizontal synchronizing pulses varies essentially linearly between reference black and reference white levels. The signal generator has been adjusted for modulation equivalent to the rated modulation of the transmitter with which the relay receiver is designed to operate and for levels in accordance with those already specified. The relay receiver output is terminated in a standard load impedance and connected to an oscillograph having amplitude-frequency and phase-frequency characteristics equivalent to those of a standard waveform monitor. The waveform is then examined with respect to linearity of rise of the picture signal and compression of the sync pulses to determine the constancy of the transfer characteristic.

In network operations, repeater stations are used throughout the system. A repeater has been defined as a specific assembly of apparatus which accepts a television relay signal at its input terminals, amplifies the signal, and delivers a television relay signal at its output terminals, without reducing the signal to video and audio frequencies at standard impedance, level, and polarity. It is evident that the repeater station is quite different from a send-receiving terminal station which is also used in network practice and operations.

If a picture monitor is included as a part of the television relay apparatus, there are certain recommended standards that apply. For example, the connections for a terminating monitor should provide a signal of black negative polarity with an amplitude of 0.5 to 2.5 v. peak to peak across a resistive impedance of 75 ohms when delivering a standard composite signal containing reference white. We refer to the receiver monitor.

A bridging monitor should provide a recommended signal of black negative polarity with an amplitude of 0.5 to 2.5 v. peak to peak and should be capable of working into an impedance whose resistive component is not less than 10,000 ohms. The reactive component is represented by a shunt capacitance not greater than 40 $\mu\mu$f. when delivering a standard composite picture signal containing reference white. It is convenient to provide for monitoring the radio-frequency output of the relay receiver. This may be accomplished through use of a built-in demodulator. Radio-frequency terminals may also be provided for an external demodulator.

The carrier-frequency stability of a repeater in a network or other radio relay system in television is specified as $\pm$ 0.01 per cent if operation is below 300 mc. For operation above 300 mc., the frequency stability should be $\pm$ 0.02 per cent. The frequency of the carrier of a radio relay operating below 300 mc. can be measured through extracting a sample of the unmodulated carrier and heterodyning the sampled radio-frequency energy by means of an accurately calibrated precision oscillator. Some means must be provided for determining the frequency of the resulting beat. When operation is above 300 mc., a suitable temperature- and humidity-compensated cavity wavemeter is recommended. A horn may be employed to collect sufficient energy from the parabolic reflector or other radiator in order to accomplish the measurement. The usual microwave techniques are employed for this purpose and will not be covered here.

11.5 Teletranscriptions. In television broadcasting, the maximum economies are realized through network affiliation, the program material originating at the principal studio of the network being widely distributed to a great number of stations. Unfortunately, the microwave-relay and coaxial-cable facilities necessary to interconnect all stations now in operation have not yet been made available by the common carrier. The solution to the problem of unavailability of networking facilities has been found in teletranscriptions.* These recordings are also termed "kinescope recordings" by some networks, but they are essentially the same as teletranscriptions and are produced for one and the same purpose.

Teletranscription recording is a unique process. Each network records the programs originating in its studios, and the resulting teletranscription of both picture and sound on 16-mm. motion-picture film is rushed by air express to the various network affiliates who are unable to obtain service over the existing coaxial-cable and radio-relay facilities. In some instances it has been found more economical to employ teletranscriptions of network programs even though regular coaxial-cable and microwave-relay facilities are available. This difference is due to the excessive tolls which accumulate when a considerable air-line distance separates the network principal station from the affiliate desiring service. Also, the program may be aired at the most convenient time so as not to interfere with already existing program schedules.

For the continuous recording of television programs on motion-picture film, special techniques are required. The double system of recording is advantageous, two recording channels, one for picture and one for sound, being made use of. A special picture-recording camera is shown in Fig. 11.21. It is used in conjunction with special high-quality 16-mm. film-recording equipment to produce a record of both the picture and sound originating at the network studios. In one system, the picture camera and the sound recorder are both equipped with 1,200-ft. film magazines, resulting in 35 min. of recording time per magazine of film. High-quality picture monitors equipped with cathode-ray tubes having especially developed screen phosphors are used in reproducing the image to be photographed. The picture monitors are driven by a signal from the main program bus, usually from the master control room at the network studios. It is common practice to take the signal from master control through a video bridging or distribution amplifier, although a high-quality off-the-air receiver is often found useful in recording pictures directly off the air either from the transmitted signal of the network key station or from other stations.

Before the composite picture signal is fed to the picture monitor for teletranscribing directly from the screen of the cathode-ray tube, it is passed through a sync stretcher or stabilizing amplifier in order to ensure excellent quality. By means of the sync stretcher, compression of the synchronizing signal, which might have occurred in the system prior to recording, is corrected for, the amplitude of the synchronizing signal being expanded to its original peak voltage value. In the usual recording

* Goldsmith, T. T., Jr., and Harry Milholland, "Television Transcription by Motion Picture Film," *J. Soc. Motion Picture Engrs.*, August, 1948.

Goldsmith, T. T., Jr., and Harry Milholland, "Television Transcriptions," *Electronics*, October, 1948.

system, arrangements are made for instantaneous switching of signal input from line or off the air.

To ensure a high-quality image at the picture monitor, it is necessary that the image be made perfectly stable. Fluctuations in picture size, picture brilliance, positioning, or linearity, cannot be tolerated. To achieve this, a well-regulated power supply must be associated with the monitor. The special fluorescent-screen material of the picture tube is of very fine grain, and the second anode potential of the tube is made sufficiently high to result in the spot size of the tube being reduced to the minimum. This results in the optimum resolution being obtained.

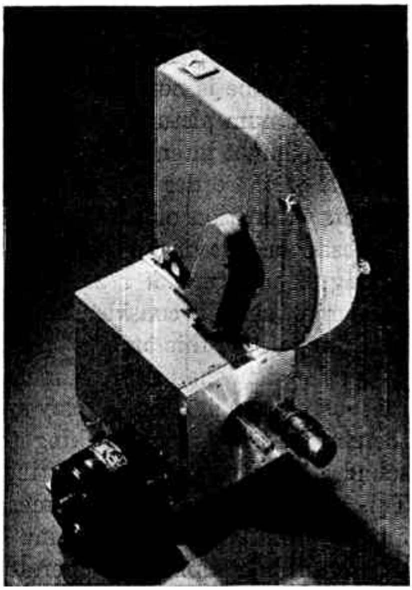


FIG. 11.21 Kodak television recording camera. (Courtesy of Eastman Kodak Co.)

Picture linearity is of paramount importance, no geometric distortion being tolerated. If two picture monitors are used in a typical setup, arrangements are made for instantaneously switching them, thus providing instantaneous recording for an hour or more when required. Both monitors must therefore have identical linearity characteristics in both the horizontal and vertical directions. A standard test pattern is useful in adjusting both monitors to perfect linearity before the recording of a program is attempted.

In producing teletranscriptions of acceptable commercial quality, gamma control is essential. Thus, the gray scale in the electronic picture may be made to match the gamma characteristics of the film being used. This results in optimum control of the contrast. To ensure high quality, a positive picture is used at the monitor screen, although a negative picture may be used, thereby reducing the processing time. In providing the negative picture at the screen of the monitor picture tube, it is common practice to drop out one stage of video amplification at some point in the system. This action reverses the picture polarity, changing the final picture from positive to negative. In making use of a negative picture, a reversed blanking signal must be used in order to eliminate the return traces which otherwise would show up in the print.

To reduce optical distortion to the absolute minimum, a picture tube 12 in. in diameter is used in one system, the picture being held to a rectangular area of 6 by 8 in. (48 sq. in.). This area is held at the center or relatively flat portion of the tube face. Second-anode potential for such a tube is normally held at 25,000 v., direct current and results in the optimum picture.

The highlight intensity available from currently available cathode-ray tubes is in the order of approximately 150 ft.-lamberts. This intensity permits utilization of a relatively slow positive film stock for recording purposes, one having a Weston rating of approximately 1, the camera having an aperture of f/2. The use of such slow film results in great economies, since a considerable quantity of raw film stock is consumed in making use of this process on a network basis.

In operation, the picture camera and sound recorder are started simultaneously through use of a relay system. Synchronous motors drive both, thereby effectively interlocking the separate recordings of picture and sound. Ten seconds after starting, both films are fogged by bloop lights. This action provides an easy means for time registration in making the final composite print containing both picture and sound. If the tele-transcription equipment is operated from the same 60-c.p.s. source of a-c power as is the transmitter through which the program is to be broadcast, both will operate synchronously. However, if such is not the case, there will develop a tendency for lap dissolve portions of the recorded image to creep up and down at a rate equivalent to the difference frequency between the 60-c.p.s. supply driving the transmitter and that driving the camera. Critical adjustment of shutter angles will eliminate any banding. Banding consists of horizontal bands of over- or underexposed portions of the image, the result of uneven matching of the odd and even television fields making up each frame.

It is at once apparent that the 30-frame-per-second television image must be converted to the film frequency of 24 frames per second, so that projection of the 16-mm. film by means of a standard motion-picture projector at the station using the recording may be obtained. A 72-deg. closed shutter is employed at the camera in one system, together with a 42-deg. pull-down. The pull-down is 50 deg. in another system. However, pull-down occurs while the shutter is closed. The camera eliminates

6 frames per second of the 30-frame television image during the camera pull-down time, resulting in recording at the standard 16-mm. sound speed of 24 frames per second. The camera shown in Fig. 11.21 was developed by Eastman Kodak Co. in cooperation with Du Mont and N.B.C. Figure 11.22 provides a comparison between the exposure and pull-down timing of a conventional motion-picture camera and a special camera used by N.B.C. to accommodate the television field rate. It will be noted that the exposure in the special camera occurs between television pull-down intervals that occur twice in every five fields.

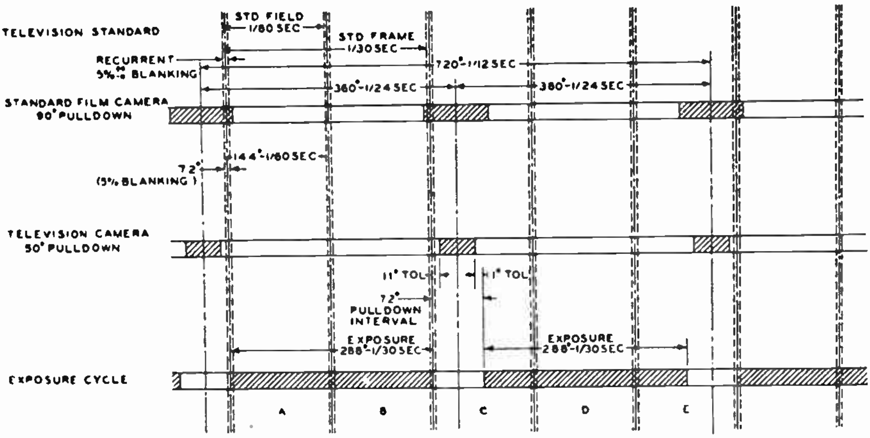


FIG. 11.22

In terms of the television time, the exposure time of the camera must be accurate to less than one half of a scanning line, or to one part in 31,500. If the camera is not adjusted to expose exactly the proper number of picture lines per television frame, banding will take place on the exposed film. Exposure is controlled by either of two types of shutters, *mechanical,* as related to the camera, or *electronic,* as related to the television system. See Fig. 11.23. It indicates the relation between shutter operation and the TV field and frame frequency in teletranscribing.

The shutter drive of the Eastman camera is isolated from the main camera drive. A 3,600-r.p.m. synchronous motor drives it at the required 1,440 r.p.m. by means of a set of precision gears. A second motor, operating synchronously with the shutter-drive motor, drives the film transport and the intermittent mechanism. Figure 11.24 illustrates important time intervals in teletranscribing television images.

In electronic control of exposure time, exposure of the film is controlled through biasing the picture-tube image on and off by means of a special blanking signal. By this means, the need for a moving camera shutter is eliminated. The electronic exposure-control circuit is started by a contact on the camera operating in proper phase relationship with the film transport, which closes after the pull-down is complete. The contact closes when the film has been transported and registered. Then the ex-

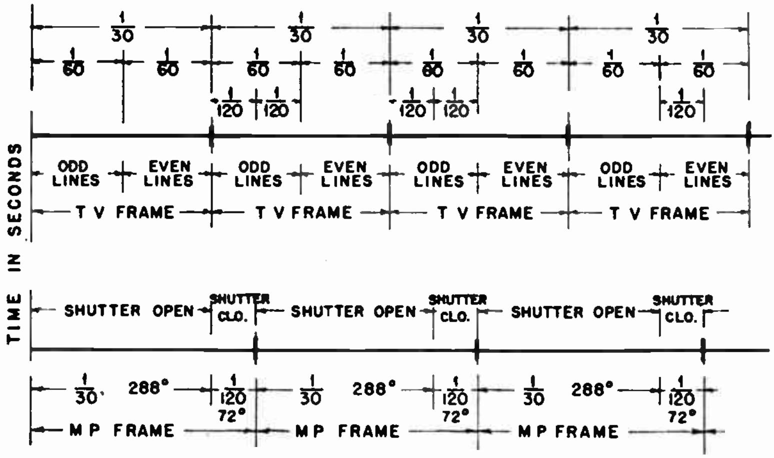


Fig. 11.23

posure-control circuit operates to remove the cutoff bias from the picture tube. This cutoff allows the picture to appear on the screen of the cathode-ray tube and results in exposure of the film. The control circuit is actuated by the horizontal driving pulses and counts 526 lines or to the

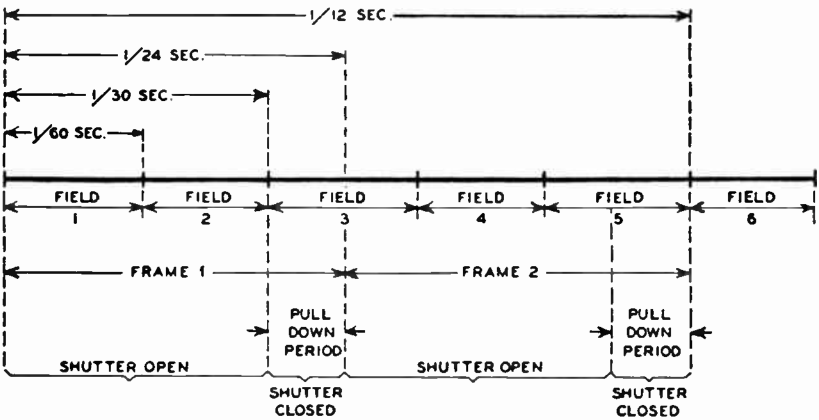


Fig. 11.24

end of the 525-line frame, then returns the picture-tube bias to cutoff, thereby removing the picture image and concluding the exposure. This electronic system of exposure does not require any synchronization between the camera and the television signals. The incoming video signal supplies the necessary keying, so that the position of the blanking of the picture tube can change in phasing. The exposure will always be correct, however, since exposure is timed by the television signal itself.

Picture brightness is important in teletranscription recording. Since there is a direct relationship between the light output of the picture tube and beam current, a microammeter is used for the purpose of ascertaining the value of beam current during recording. Inasmuch as the exposure is fixed, the highlight brightness of the picture is varied by means of the video gain control at the picture monitor.

In the R.C.A. system, a special 5-in. flat face aluminized screen projection type cathode-ray tube is associated with the picture monitor from which the images are to be photographed. The type 5WP11 cathode-ray tube employed has a short-persistence blue-phosphor screen of high actinic value, this resulting in the use of high-resolution low-cost positive film stock.

After both picture and sound are combined on a single film, as many prints as are required can be made. They are then rushed to television stations that use the teletranscription service of the network. Figure 11.25 indicates the relation between the motion-picture projection frame rate and the television frame rate.

11.6 The Video-Distribution Amplifier. Video amplifiers are used in a great many applications other than those found in the television receiver or the studio camera chain. One such application is in the arrangement of a video distribution system, a system in which a number of video program amplifier channels are provided. The purpose of the video distribution amplifier is to distribute the composite picture signal to a great many remote points where it may be desired to view or monitor the visual program material. It may be desired, for instance, to supply the composite picture signal from the studio or master control room to several points about the television station—to offices, clients' rooms, announce booths, or to viewing monitors in reception or talent rooms. It may be desired to supply a common television program to a number of rooms in a hotel, or to various viewing monitors in a club or other public place. Another frequent application of the multichannel video-distribution amplifier is in the factory testing of television receivers, where it may be desired to distribute a composite video signal to a number of test benches or test positions. Often, a test pattern is distributed in this manner, so that receivers may be adjusted for optimum operation before delivery for packing and shipping. Almost always, a multichannel video-distribution amplifier, or several of them, make up part of the complement of equipment in the master control room of the television station, thereby making it possible to transmit the final composite picture signal back to individual control rooms for cueing purposes.

The circuit of one channel of a commercially available video-distribution amplifier is shown in the accompanying circuit diagram (see Fig.

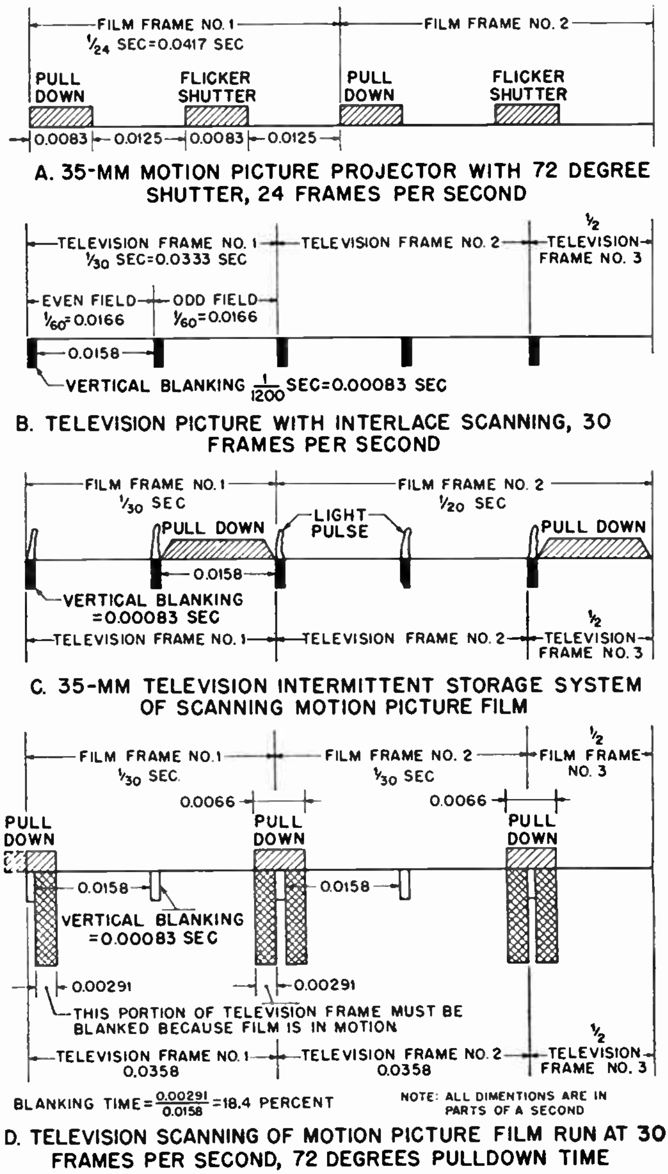


FIG. 11.25

11.26). Usually, a number of identical program channels are supplied on a common chassis, five or six being the number normally supplied in commercial equipment. A very carefully regulated power supply furnishes d-c potential to the unit and in most cases is located on a separate chassis to minimize hum pickup and to reduce the noise level at the amplifier.

Examining the amplifier diagram, it will be seen that two stages are provided at each channel, an input and an output stage. The first stage makes use of a type 6AC7 vacuum tube in a conventional shunt-compensated video-amplifier circuit. The input circuit to the amplifier channel is at high impedance, so that it may be bridged across any 75-ohm coaxial line supplying the picture signal and with negligible effect upon the line so bridged. All the several input channels of one distribution amplifier or the input circuits of several video distribution

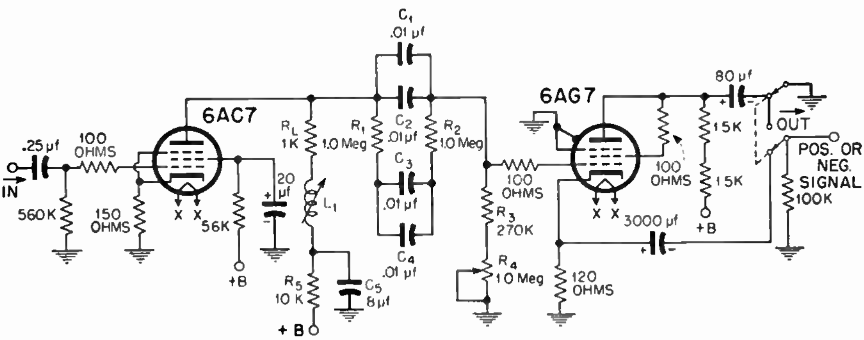


FIG. 11.26

amplifiers may be effectively bridged across one common video program source. This bridging is usually accomplished in the master control room of the television station by bringing all the input and output circuits of the video-distribution amplifier to a video patch panel. Thus, any desired combination of input and output connections may be made by means of video patch cords. The result is great flexibility in handling any desired combination of patches.

In examining the circuit diagram in Fig. 11.26, it may be seen that the plate-load resistor of the input tube is made 1,000 ohms, a low value, producing excellent frequency response. The circuit shown results in a response which is down only 3 db. at 11 mc. from the reference of 0 db. at 1,000 c.p.s. A unique coupling network between the input and output stages is provided, and it comprises R_1, R_2, R_3, and R_4, together with C_1, C_2, C_3, and C_4. The potentiometer R_4, in series with the grid return of the 6AG7 output vacuum tube, provides a low-frequency compensation adjustment. It will be evident that the output may be connected by means of a suitable switch to deliver either positively or negatively polarized signals into a 75-ohm coaxial line. This particular amplifier is the product of the Tel-Instrument Co., Inc.

11.7 Obtaining Optimum Quality from Orthicon Tubes. In order to obtain optimum picture quality from Orthicon-type camera chains used in television broadcasting, it is necessary to have some knowledge of the circuits involved. This information can be best obtained through diligent study of the manuals supplied by the manufacturer of the equipment. A thorough knowledge of the chain is necessary so that the various controls associated with the chain may be intelligently adjusted. To obtain the best quality picture, these controls must be adjusted in an orderly manner, step by step, and in the proper sequence. Haphazard adjustments by trial-and-error methods will result in nonuniform picture quality from one operating assignment to another. It is important that a consistently uniform picture of high quality be produced.

It is accepted practice, once the chain has been energized, to align the scanning beam carefully at the Orthicon tube. A rotating yoke, which surrounds the electron gun of the Image Orthicon tube, provides a means for adjusting or aligning the scanning beam. In one camera chain, a crossfield in the region of the tube gun is developed through passing current from the focus-field regulated power supply through the windings of the rotatable yoke. An alignment potentiometer provides the necessary control of the magnitude of the produced crossfield, its direction being capable of adjustment through the physical arrangement of the yoke's positioning with respect to the Orthicon tube. These means provide electrical correction for any mechanical misalignment of the electron gun of the Orthicon tube. The result is that the radial component of the beam is made to coincide properly with reference to the scanning axis of the tube. This is the first step in the adjustment procedure.

A test to determine whether or not the scanning beam is set for optimum alignment may be made through adjustment of the Orthicon focus control. If the reproduced television image, as viewed on a suitable picture monitor, rotates as the focus voltage is made to vary, proper alignment is not obtained. The dynode or multiplier spots, which appear prominently when no illumination is present on the photocathode of the tube, may be viewed for a more critical adjustment of the scanning beam alignment. With optimum adjustment of the beam, the dynode spots will not rotate or move about. Instead, they will be observed to go in and out of focus as the setting of the Orthicon focus control is adjusted, the position of the spots remaining fixed.

The alignment potentiometer should be held at minimum, or very close to minimum, when the alignment of the scanning beam is attempted. This is suggested since Image Orthicon tubes normally possess such well-designed gun structures that very little alignment current is required.

The optimum performance of Image Orthicon cameras will be obtained when a fixed value of 75 ma. of focus field current is employed. This magnitude results in a magnetic field of 75 gausses in the center of the focus coil and is the recommended amplitude. The best performance cannot be obtained through varying the focus field current, since it serves best when adjusted to the absolute value of 75 ma., to result in the proper magnitude of crossfield at the gun.

Improper adjustment or variation of the focus-field current results in misalignment of the beam, improper image focus voltage, and misalignment of the scanning beam. A properly set focus field automatically results in proper Orthicon focus voltage and image focus voltage. These values should be approximately 180 v. for Orthicon focus and approximately 450 v. for image focus.

It is assumed that the Image Orthicon decelerator grid voltage G_5 will be so adjusted that the corner focus of the picture is proper and that a flat field is obtained. The multiplier-focus voltage must also be set so as to provide the maximum output signal consistent with a flat field. Also, the image accelerator potential G_6 should be adjusted for the minimum S distortion, which usually obtains when set at about 80 per cent of the image-focus voltage. When the electric fields between the photocathode and target are nonuniform, the charge image suffers an angular displacement demonstrating radial nonuniformity. This is termed "S distortion" and results in the straight horizontal lines in the picture appearing sinusoidal.

It is very important that lighting or scene illumination be proper to produce the best possible picture under optimum camera adjustment. With an f/2.8 lens in operation at the turret, the minimum scene illumination where the type 2P23 Orthicon tube is employed is 15 to 25 ft.-c. for daylight, 15 to 20 ft.-c. where tungsten light is employed, and 25 to 35 ft.-c. where fluorescent lighting is used.

A somewhat different light requirement is desired when the type 5655 studio-type Image Orthicon tube is used in the camera. Here, 150 to 200 ft.-c. of incandescent or tungsten light is recommended as the minimum, and 100 to 150 ft.-c. of fluorescent light is considered to be the minimum. This tube is not intended for outdoor use; hence, no data are available on daylight minimum requirements.

The type C–73150 Orthicon tube requires 4 to 8 ft.-c. minimum when employed under daylight conditions, 5 to 10 ft.-c. when used under studio conditions where tungsten or incandescent lighting is employed. Fluorescent lighting will place the minimum lighting requirement at 4 to 8 ft.-c. For the type 5769 Orthicon tube, approximately 20 to 30 ft.-c. of daylight illumination is considered to be the minimum, 30 to 40 ft.-c. of tungsten lighting being minimum and 20 to 30 ft.-c.

of fluorescent lighting being the required minimum for indoor stage or studio illumination. When the lens is stepped down smaller than f/2.8 to obtain greater depth of focus, the number of required foot-candles of illumination will increase with the square of the ratios of the f numbers.

It is said that for optimum tonal rendering of the skin and for best reproduction of the gray scale, an Image Orthicon tube should be so operated that the highlights imaged on the photocathode of the tube result in the signal output developing slightly above the knee of the signal-output curve for the illumination used. The knee has been defined as "the point where the signal due to the highlights in the picture begins to show appreciable reduction as the lens opening is decreased in size."

When Image Orthicon cameras are used outdoors, the best lens opening is that in which the highlights of the most poorly lighted portions of the television scene result in camera output just above the knee. With this optimum adjustment, all other degrees of illumination can be satisfactorily handled without a change in the lens-stop adjustment. In other words, the camera lens should be set for the darkest portion of the scene. This practice has become the common and accepted one of well-versed studio engineers and makes it possible to pan the camera about without serious degradation of the television picture.

With reference to Image Orthicon beam current, it is common practice to operate with just sufficient beam current to hold down or to discharge the highest highlight in the television scene. The best signal-to-noise ratio will be obtained when the beam current is low. The use of excessive beam current can only result in an unsatisfactory signal-to-noise ratio and a poor picture, as well as greatly reduced tube life.

The target voltage should be maintained within the range of −3 to +3 v., direct current, if optimum results are to be had. If the target voltage is made more negative than shown, an operating point will be reached where cutoff voltage at the target will obtain, and no picture will be seen. The usual operating voltage at the target is maintained at 2 to 2.5 v. more positive than the cutoff voltage, the beam being adjusted to discharge the highest highlights encountered with the operating conditions as prescribed. A high-resistance voltmeter can be used to set the target voltage, since it is connected between the center arm of the control potentiometer and ground. It is suggested that this operating potential be initially adjusted as proposed. Proper setting of the target voltage is very important if the proper transfer characteristic of gray-scale rendition is to be obtained. This can be demonstrated if the target is operated at a point a fraction of a volt beyond cutoff. Under this condition, the results will be most unsatisfactory, blacks and grays being compressed, so that no detail will be noted in parts of the scene under low light level. The more positive the target potential is made, the greater the required beam current for discharge of the highlights. The upper limit which may be utilized is determined by the ability to obtain a well-focused beam and good resolution of highlight details.

The target setting may be made slightly less positive than the upper limit in order to provide for some range in illumination. It is considered improper to attempt to hold down the highlights through operating with a more negative target potential, when the more desirable practice would be to stop-down the iris of the camera lens.

It is usually considered worth while to employ a lens shade under all conditions of lighting, since the shade will prevent stray light from falling upon the photocathode of the pickup tube. The Image Orthicon is susceptible to stray light insofar as gray-scale rendition is concerned, and flesh tones are very greatly improved through use of the shade. This is particularly true where stray light conditions prevail.

It is important that the Image Orthicon tube should not be operated under conditions where scanning has failed. Nor is it good practice to underscan the target. As with the Iconoscope camera pickup tube, the camera lens should not be focused on a stationary bright image for any considerable length of time. Image Orthicon tubes which develop ion spots should be retired from service. It is important that the Image Orthicon tube should not be placed in operation for pickup purposes until it has reached normal operating temperature. The normal operating temperature of the target of the 5769 and 2P23 tubes is 35°C.; and that of the 5655 tube is 45°C. When the tubes are operated below normal temperatures, a "sticking" picture, of polarity opposite to that of the original, will remain when the camera is panned about. Loss of resolution occurs when the tube is operated at too high a temperature.

After 200 to 300 hr. of operation, an Image Orthicon tube should be removed from service for 3 to 4 weeks. This will result in the tube regaining much of its original sensitivity as well as much of its resolution. Tubes must be handled carefully when being removed or installed in the television camera. Care must be taken to store the tube in a carton or box that provides ample room for storage, and sufficient cushioning material must be used to guard against fracture of the glass envelope as a result of rough or improper handling. It is well to construct a tube-storage cabinet in mobile units used for purposes of field program pickup, since tubes receive considerable vibration under these conditions of operation, and spares should be well protected. A record should be kept on tube life and any operating vagaries.

11.8 Maintenance of Television Broadcast Equipment. In no field of radio engineering is the problem of equipment maintenance more important than in television broadcasting. At the present state of the art there are likely to occur a great many minor cases of trouble throughout the operating day. Although most operating difficulties will not individually result in time off the air, collectively they can result in degradation of picture quality. Each trouble must be promptly cleared. If troubles are allowed to accumulate, the total effect of the many minor irregularities will unquestionably lead to complete equipment failure in time. Preventative maintenance will obviate the possibility that these small irregularities may lead to a serious and possibly expensive shutdown. The maintenance technician at the television broadcasting station must day by day seek out and eliminate all possible sources of trouble which give evidence of resulting in equipment failure and time off the air.

A constant source of trouble is small-tube failure. As a matter of fact, tube failures are by far the most frequent source of trouble. This is particularly true of tubes employed in camera chains, picture monitors, synchronizing generators, and voltage-regulated power supplies. Tubes of the popular miniature type are the prime offenders, and they must be frequently replaced because of microphonic tendencies, an effect not to be tolerated particularly in camera operation. It is good policy to test all tubes operating in video amplifiers at least once weekly in a good dynamic mutual-conductance type of tube tester. Tube testers of the emission type are not to be depended upon for obvious reasons. The operation of voltage-regulated power supplies must be regularly checked to determine if voltage regulator and passing tubes are functioning properly. The most rapid means of effecting such a test is through varying the voltage range potentiometer associated with the power supply, meanwhile sampling the output of the device by means of a high-resistance d-c voltmeter. A serious departure from the normal range through which the supply regulates will ordinarily indicate the presence of poor or inoperative tubes in the regulator portion of the power supply. Ordinarily, the output impedance of such a supply is very low, usually in the order of an ohm or less. Should the impedance be reduced for any reason, motor-boating at video amplifiers in the system is apt to occur. Any indication of motor-boating in a video amplifier should immediately lead to suspicion of the associated voltage-regulated power supply. The difficulty must be isolated and corrected.

The location of noisy or microphonic tubes can be quickly determined through gently tapping the envelope of the tube with the eraser end of a lead pencil, meanwhile observing the raster of a picture monitor associated with the equipment under test. The presence of microphonics can be quickly detected through observation of the raster in this manner. The tubes are then replaced in a particular socket until no further microphonics are apparent. Microphonics at tubes in a video amplifier can also be located by shouting loudly at the amplifier while standing in its immediate vicinity. The presence of microphonics will be indicated through observation of the raster of an associated picture monitor. Microphonic noise is particularly troublesome if present in the video preamplifier of a television camera. The high gain of the preamplifier and the low signal-to-noise ratio at the input to the system operate to make such effects more pronounced and troublesome. Therefore, whenever microphonics are noticeable at the system output, the first part of the system to investigate is the camera preamplifier. If microphonics are found not to occur in the preamplifier of the camera, intermediate video amplifiers are next checked; and finally the line amplifier, which drives the transmitter or master control equipment, should be checked.

Low-frequency noise in the picture is often the result of operating vacuum tubes in the system with "leaky" cathodes. This refers to leakage at the cathode sleeve of the tube and may be corrected only through replacement of the tube. Low-frequency noise can also be the result of improper filtering at one of the voltage-regulated power supplies or of the presence of a defective tube in one of the regulator circuits. This condition is particularly true of VR types, which are commonly used in such devices.

Hum bars in the picture generally indicate poor or inadequate filtering at one or more of the power supplies, voltage-regulated power supplies not in proper regulation, vacuum tubes evidencing severe cathode leakage, or improper, faulty, or poorly made ground connections. The frequency of the current owing to the hum may be a clue as to the source of the hum. In observing the hum bars present at some convenient picture monitor associated with the camera chain, i.e., the number of wide horizontal black or white bars (depending upon the polarity of the picture signal at the point of inspection), it will be noted that two hum bars will appear if 120-c.p.s. hum is present, and three hum bars will indicate the presence of 180-c.p.s. hum, and so on. If two hum bars are present, any single-phase 60-c.p.s. full-wave rectifier associated with the system should come under suspicion, since the hum frequency present in the output of such a supply will be 120 c.p.s. Improvement of the filtering, replacement of the rectifier tube, or the location and correction of other possible causes within the supply will usually correct the difficulty.

A common source of failure is the electrolytic capacitors. These components dry out after long use, the result being outright rupture or puncture of the dielectric or severe leakage. If such capacitors are not securely grounded, or if their aluminum cases are not in perfect contact with the supporting chassis, they can generate hum bars. When aged dry electrolytic capacitors are operated in camera-equipment power supplies, dielectric leakage is likely to result in bullets shooting horizontally across the reproduced image. These bullets, or bullet-shaped patterns of interference, may be in either the positive or the negative polarity when viewed on the monitor screen, i.e., either black or white in appearance. It is important that electrolytic capacitors be replaced before they have sufficiently aged to dry out and produce electrical interference. They are replaced on regular schedule after one year's service in the equipment of one organization, thereby providing for elimination of any old units before they have an opportunity to result in operating difficulties. Since the organization which has established this policy is a large one and is well recognized for its widely accepted engineering policies, it would seem a wise procedure to follow.

Electrolytic capacitors are also likely to cause trouble if allowed to show excessive temperature rise. Such components should only be operated in a well-ventilated chassis, where ambient gradient is not severe. This is particularly true of capacitors associated with critical saw-generating circuits and deflection amplifiers. In some parts of such circuits, capacitance is critical, and any severe variation in the value of capacitance will result in nonlinear scanning. The capacitance of an electrolytic capacitor has been shown to vary with temperature change. It is unfortunate that the heavy values of capacitance needed in some circuits can be obtained only in small packages through use of the electrolytic type of capacitor. Whenever possible, it is wise to use components utilizing paper, oil, or mica dielectric.

If solenoid-operated relays are employed in camera switching or in master control-room equipment, it is extremely important that contacts be kept scrupulously clean. Dirty contacts are likely to interfere with picture quality to a marked degree, and relay contacts are more likely to cause trouble when used in TV systems than would the same contacts if employed in passing audio frequencies. It is easy to keep contacts sufficiently clean through the careful application of carbon tetrachloride to the contacts each day, wiping the residue off with thin linen tape, the tape being pulled between the contacts. Proper adjustment of relay contacts is also important, so that they cleanly make and break when operated. Of course, all-electronic switching and mixing systems are to be preferred over those employing solenoid-type relays, because of the obvious elimination of relay-maintenance problems. Whatever the mixing or switching system used, it must be so maintained that no interference with picture quality occurs when switching from one camera to another or from one part of the system to another.

The synchronizing generator, which supplies the complete television system with standard R.M.A. driving, blanking, and synchronizing signals, must be maintained in a state of optimum operation. It is this unit upon which the entire system depends for properly timed and shaped pulses and waveforms. Ordinarily, tubes are never replaced in the sockets of a synchronizing generator unless one definitely indicates trouble. The reason is that small vacuum tubes are inherently nonuniform as to operating characteristics, and it may be that a replacement tube will have slightly different characteristics from the original, with the result that the generator may evidence trouble after a tube replacement. This is particularly true of tubes used in some timing circuits and in frequency-divider circuits which lack proper stability. It is good practice, however, to check all tubes in the synchronizing generator at least once weekly and through use of a good dynamic mutual-conductance tube tester. Failures can thus be anticipated before they occur in a great many instances, tubes being replaced when suspected of impending failure. Care must be exercised in testing tubes in the synchronizing generator to replace tubes in the same sockets from which they have been removed, provided that they are found to be operative. It is useful to make a record each week of the tube-tester readings as related to operation in a particular unit of equipment. A study of these records from time to time will enable the engineer or maintenance technician to anticipate failures before they occur.

Rosin joints and poorly soldered connections may result in trouble. Badly or poorly soldered connections are particularly annoying when they occur in mobile-operated equipment. The constant vibration and shock to which field equipment is subjected, results in the solder at the joint being fractured. It is good practice to relegate periodically all types of field equipment to the work bench for inspection and test. Here, each soldered connection should be checked by firmly pulling on wires and other leads by means of a pair of needle-nosed pliers, making certain that all connections are tight and electrically capable of passing the required current at the point of connection. Sometimes an inspection of the insulation on leads at the point of connection will indicate poorly soldered joints, the temperature rise due to the high-resistance connection resulting in the insulation becoming charred or burned.

Suspicious soldered joints can be "sweated" through application of a hot soldering iron, and new solder is applied wherever necessary. While the remote equipment is on the workbench, it may also be checked for any mechanical damage due to shock, nuts and machine screws being tightened, and a general inspection of the unit being conducted in an attempt to uncover sources of possible failure.

Of much importance in the maintenance of studio equipment is the constant effort to avoid geometric distortion of the transmitted picture. Linearization of the horizontal and vertical saw-toothed scanning waveforms will assure proper linearity of the picture, and it is necessary to ascertain daily that the saws at both the horizontal and vertical scanning frequencies are perfectly linear. The linearity of the upward slopes of both saws must be such as to result in negligible "pulling" or "packing" of the picture.

In determining whether the horizontal and vertical saw-toothed waveforms possess proper linearity, it is best to employ a good cathode-ray oscillograph, the vertical amplifier frequency response of which is suitable for passing the horizontal and vertical saws without appreciable frequency distortion. The vertical amplifier input of the oscillograph operating at high impedance is connected across the circuit at the point where it is desired to observe the saw-toothed waveshape.

With the oscillograph Y amplitude, Y attenuation, X amplitude, X attenuation and centering controls so adjusted as to obtain a proper display on the screen of the cathode-ray tube, the sweep range, vernier, and sync controls of the oscillograph are adjusted until a suitable reproduction of the saw-toothed waveform to be inspected is reproduced for observation. It is then possible to make circuit adjustments of R and C in the portions of the circuit developing and amplifying the saw-toothed waveforms and until linearization of the waveforms is achieved.

In checking the presence of geometric distortion in a studio camera chain, it is helpful to employ a test pattern mounted on an easel. The test pattern is suitably illuminated, the camera being trained upon it in such a manner that no error due to camera position (with reference to the principal axis of the optical lens system as related to the center of the test pattern) results in distortion of the reproduced image as viewed at the output of the line amplifier. If a film chain is employed, and is checked for geometric distortion, a test-pattern slide may be used. It can be scanned by means of a slide projector. Test patterns are also available on both 16- and 35-mm. film for projection by means of the station's film-projection equipment.

Whatever the source of the test pattern, it can be checked for possible distortion by reproducing it through the camera chain and observing the reproduced image at a suitable picture monitor connected at the line amplifier output. With the test pattern reproduced as the display on the cathode-ray tube screen of the monitor, measurements are made with a translucent scale to determine whether the distance between the outer edges and its center is precisely the same throughout 360 deg. Any difference in the measured separation of the test-pattern center and the outside edges of the outer circle will indicate the presence of geometric distortion. The use of a bar-and-dot generator, which injects suitable markers across the reproduced test pattern, will be helpful in determining just what quadrant or portion of the test pattern evidences distortion. The Du Mont type TA–107–A synchronizing generator provides linearity test signals at 900 c.p.s. (which produce 15 horizontal marker bars across the raster) and 157.5 kc. (which produces 10 vertical marker bars across the raster). These signals may be injected or mixed with the blanking by means of a switch, thereby providing a means of checking the scanning linearity of the television equipment. With these test bars superimposed upon the test pattern and the display viewed at the screen of a picture monitor, it becomes relatively simple to ascertain to what degree any geometric distortion of the test pattern exists. It may then be corrected circuit-wise, while observing the screen of the picture monitor. The correction usually involves changing the values of circuit components in the particular portion of the system where nonlinearity of scanning has developed.

In the studio, it is important that extraneous noise be kept to the absolute minimum. This dictates that the wheels of camera dollies, microphone booms, and other mobile equipment be kept well lubricated. This maintenance work should be scheduled at least once weekly. If studio lights are controlled by means of cords, the pulleys over which the cords operate must be kept thoroughly oiled and lubricated. The mechanical parts of studio cameras, such as optical focusing control mechanisms, must also be kept well lubricated, for the slightest extraneous noise occurring in the studio may well mar an otherwise perfect program. The same advice holds true for pan and tilt-top mechanisms which provide movement of the camera in either the vertical or horizontal plane. All moving parts must be kept well lubricated.

In the well-organized television broadcasting station, the chief engineer usually sets up a daily and a weekly routine maintenance schedule, assigning specific duties each day or week to regular staff maintenance technicians on a strictly routine basis. A maintenance report form must be filled out at the end of each operating day, wherein the maintenance technician to whom the work has been assigned, certifies that he has satisfactorily completed the assigned work. Any work previously assigned by the chief engineer and not completed by the close of the day's operations is carried over and charged against the engineer's maintenance assignment for the following day. Thus, all necessary routine maintenance is definitely carried out in an orderly and business-like manner. Such preventative maintenance can do much toward eliminating loss of valuable time off the air.

The maintenance and care of camera lenses are discussed in Chap. 1 in considerable detail, and for that reason are not repeated here. Other detailed studio maintenance will occur to the station chief engineer, some dictated by the type of equipment in use, and he will want to include it in the maintenance schedule of the particular station concerned.

The institution of a routine maintenance program at the television transmitter is of the greatest importance and will accomplish much toward reducing time off the air. Of primary importance is the care of transmitting tubes. It has been found convenient to carry a 3- by 5-in. card file divided into three sections: tubes in spare stock, tubes in the transmitter and actually in operation, and records of tubes that have been discarded. When tubes are received from the supplier, they are first tested in the transmitter in the sockets for which they are intended. Such testing is usually conducted when the station is not operating on regular schedule, preferably after midnight when there is no possibility of creating undue interference with other stations or services. Of course, operation into a phantom or dummy antenna is much to be preferred.

After a new tube is tested, the following types of information are entered in the file:

1. The date the tube was received
2. The condition of the packing and the result of preliminary inspection of the tube
3. Date when the tube was tested in the transmitter
4. The result of the test, together with any appropriate comments as to its behavior under operating conditions.

Additional entry space is provided on the card for:

5. The date the tube was placed in active service
6. The socket in which it is to be operated
7. The date the tube was removed from service
8. The reason for the removal of the tube from service
9. The disposition made of the tube after final removal from the transmitter.

On the reverse side of the card, space is provided for a month-by-month record of the number of hours that the tube has been in operation. This information is extremely important in determining whether a particular type of tube is giving satisfactory operation in the transmitter under a given set of operating conditions. Often, the tube-life record will indicate that some other type of tube will prove more acceptable for a particular application. Then, either a substitution may be made or a report sent to the transmitter manufacturer of the life record obtained with the tube. A guarantee is usually extended by the tube manufacturer covering all types of transmitting tubes in use at the television broadcasting station. The usual practice is to guarantee transmitting tubes for 1,000 hr. of operation. A rebate is made to the station on defective tubes covering the difference between full value of the tube and the actual value of the tube to the station based on failure before 1,000 hr. Thus, if a particular transmitting tube fails at 500 hr. and through no fault of the station, a 50 per cent rebate is allowed upon return of the unsatisfactory tube so it may be tested and inspected by the manufacturer to substantiate the station's claim.

The routine maintenance schedule at the television transmitter must include regular removal of accumulated dust from within the equipment. If dust is allowed to accumulate, high-voltage flashovers and ensuing equipment failure are liable to occur, particularly in circuits carrying high-potential d-c or radio-frequency energy. The dust can be removed by means of a hand bellows, or it may be wiped off with a soft cloth if sufficient care is exercised and all high-voltage equipment is rendered inoperative before being dusted. In this regard, high-voltage capacitors should be momentarily short-circuited at their terminals before being cleaned, even though bleeder resistors are generally believed to provide protection. Dust must also be removed from all accessory equipment operated at the transmitter, with particular attention to regulated high-voltage power supplies associated with such equipment.

It is important that all relays used in operation of the transmitter be regularly cleaned, contacts burnished with a burnishing tool, and the whole mechanism adjusted for proper operation. Failure to do this will result in improper operation of control circuits, when it is desired to start or stop the transmitter quickly. It is highly desirable to check and inspect regularly all overload, underload, and other protective relays to make certain that they are functioning properly. Such procedure should be made a part of routine transmitter maintenance.

The condition of high-voltage capacitors in the transmitting equipment can be ascertained through feeling them with the palm of the hand after a long period of operation of the transmitter. Any excessive temperature rise will indicate dielectric leakage and impending failure of the dielectric material. In such cases the high-voltage capacitors or components of this type which pass heavy radio-frequency currents should be immediately replaced before they result in failure of the transmitter and consequent loss of time off the air.

If water-cooled tubes are employed, the water-cooling system of the transmitter must be regularly inspected for possible accumulation of scale due to excessive carbonates and sulphates in the water. The specific resistivity of any distilled water should be greater than 20,000 ohms per cu. cm. Care must be particularly exercised that all nipples and hose or ceramic tubing connections are kept clean and free of scale or sludge. It is also most important that all air blowers providing forced air on tube seals be kept in proper operating condition. All electric motor bearings must be well and regularly oiled and lubricated. It is a good idea to suspend a small strip of cloth in the air stream of all air blowers providing cooling of tube seals, so as to provide an indication of blower operation. These blowers are usually mounted inside the transmitter frame, which is provided with glass doors or windows in front. It is difficult to check properly on the operation of the blowers during periods of regular operation unless some means of this kind is provided.

Disconnect switches and interlocks should be regularly inspected to determine whether they result in interruption of the high voltage when transmitter access doors and windows are opened. High voltages are present within the transmitter, as well as dangerous radio-frequency potentials, and every means must be provided to ensure the maximum protection to the operating personnel. Rubber gloves and gauntlets should be worn when any work is attempted where dangerous high potentials are present, and rubber blankets should be thrown across transmitter sills and doors when it is necessary to reach inside for parts of the transmitter needing service under operating conditions. It must be remembered that rubber gloves and blankets will not afford protection against radio-frequency voltage, and it is the established practice to make the transmitter high-voltage circuits inoperative when work is attempted on circuits where radio-frequency energy is present.

11.9 The Cathode-Ray Oscillograph in Television Broadcasting. A wide-band cathode-ray oscillograph is essential in properly conducting tests of the picture and synchronizing circuits of a television system. The cathode-ray oscillograph employed for this purpose must have adequate gain to display properly the minimum potentials normally encountered in the system, and the sweep or deflection circuits of the instrument should be capable of displaying in precise detail any portion of any wave or pulse occurring in the system. The phase and amplitude response of the oscillograph chosen for television systems testing must possess both phase and amplitude response characteristics which will not result in appreciable distortion of any wave or pulse being analyzed.

The oscillograph should be capable of faithfully reproducing square waves, and within the tolerance specified by I.R.E.* The general performance of an oscillograph used for test purposes in television should be such that limitations on amplitude as well as phase characteristics should be created by the video and radio generating equipment under test, rather than by the test oscillograph. The rise time of the test instrument should not exceed 0.05 μsec., exhibiting no visible overshoots when driven by a high-frequency critically damped square wave with a rise in time not in excess of 0.01 μsec.

The maximum amplitude difference of any two frequencies between 30 and 5,000,000 c.p.s. should not exceed 0.5 db. There should occur no sudden changes in the response characteristics.

* *Standards on Television, 1948*, The Institute of Radio Engineers, New York, 1948, p. 16, Fig. 13.

Servosweep circuits, which provide operation with repetition rates of 30 to 20,000 c.p.s. and with sweep lengths of 10 to 1,000 μsec., have proved useful. An adjustable control permitting delay of the start of the sweep is a desirable feature. It is helpful if the oscillograph incorporates trace-timing facilities to make possible the measurement of time of occurrence of any wave or fraction thereof to be observed. The input impedance of such an oscillograph should comprise a parallel equivalent resistance of not less than 100,000 ohms shunted by an effective capacitance of not more than 10 μμf. The input terminals of the instrument should be at the end of a probe cable at least three feet in length.

The amplifier gain should be such as to provide a 1-in. deflection from a 0.1-v. peak-to-peak signal at the probe input terminals. The gain control, or attenuator, should provide ample range so that a 100-v. input signal may be maintained below the overload level of the amplifiers. It is not essential to make the gain control continuously variable, provided that incremental steps are present which are not greater than 3 : 1 or 10 db. It is essential that some calibrating device be provided within the oscillograph, or as an accessory, so that quick calibrations may be had. If the calibration circuit is of the substitution type, it should permit measurement of the instantaneous portion of any part of an electrical wave or impulse to be observed.

Several commercial types of oscillograph have been developed which easily meet the requirements set forth for television measuring purposes. The Du Mont type 280 cathode-ray oscillograph is particularly useful as a precision instrument that may be used at the television studio or transmitter. It also has wide application in the research laboratory or in television manufacturing. It has a frequency range of 10 c.p.s. to 10 mc. and provides sweep speeds as great as 0.25 μsec. per in. The time duration of any part of the standard television signal, for instance, may be measured on the 0.25 μsec. per in. sweep with an accuracy of ±0.01 μsec. Time intervals in excess of 5 μsec. may be read directly from a calibrated dial to an accuracy of ±0.1 μsec. The accelerating potential of the cathode-ray tube may be readily adjusted between 7,000 and 12000 v., and writing rates are possible up to 63 in. per μsec. This instrument makes possible the precise measurement of the time duration of the various component waveforms of the standard television signal, so as to determine whether they conform with the Standards of Good Engineering Practice concerning TV Stations, of the F.C.C.

The Du Mont type 248–A oscillograph may be used in the measurement of television signals and where the accuracy of an instrument such as the type 280 is not required. Type 248–A possesses a useful frequency range of 20 c.p.s. to 5 mc. and has been especially developed for the investigation of electrical pulses containing high-frequency components of a recurrent or transient type. The unit incorporates high-frequency recurrent sweeps, driven sweeps of short duration, and timing markers, as well as a well-designed signal-delay network. A writing rate of approximately 69 in. per μsec. has been achieved. While not possessing the bandwidth of the type 280 oscillograph, it is nevertheless portable and possesses great utility as a general-purpose instrument.

Ordinarily, several oscillographs of different operating specifications are desirable in television operations. A low-priced general-service instrument is useful for rapid testing and troubleshooting where time is an important consideration. An instrument of medium accuracy and easily portable should be available for routine testing, especially where the instrument must be moved about frequently. Then, there is a genuine need for an instrument of very great accuracy to enable the staff to investigate waveforms and pulses such as those making up the standard television signal. Thus, at least three oscillographs are normally included in the test-equipment complement of a television broadcast station. The identical selection of oscillographic equipment is desirable for the research laboratory, or in manufacturing.

11.10 The Monoscope Tube. For testing purposes in laboratories, in the final testing of television receivers in manufacturing, and sometimes as a picture-signal source for the purpose of driving studio equipment or the television transmitter, a static-signal image-generating tube is sometimes made use of. In its various forms this tube has been termed a "monoscope," a "phasmajector," and a "monotron." Such tubes are physically similar to the Iconoscope in that they have much the same shape, but they are quite different electrically. Unlike the Iconoscope and Orthicon, which depend essentially upon variations in secondary electron emission at the point where the scanning beam impinges on the target, these tubes depend upon the variation in secondary emission at the static image target to develop the picture signal.

The Monoscope has been described by C. E. Burnett of R.C.A.* The target of the tube is a sheet of flat aluminum approximately 0.004 in. thick. The image to be reproduced is stamped on this aluminum plate with ordinary printer's ink, a halftone engraving or line engraving usually being used in the printing process. When the temperature of the tube is increased during the manufacturing process, the ink is reduced to pure carbon. It is said that the ratio of secondary electrons for the carbon is about three electrons per incident electron, the ratio for the aluminum being 7 to 1. As the scanning beam travels over the surface of the target, greater electron emission obtains from the aluminum surface as compared with the carbon surface. Owing to the difference in

* *R.C.A. Review*, April, 1938.

the two ratios, there is a variation in secondary emission, and the resulting electrons are collected by the collector ring and developed across a load resistor at the output circuit. Usually, this resistor has a relatively high value of approximately 10,000 ohms. Since high efficiency obtains with this type of tube, about 3 to 4 mv. are developed across this resistor. It must be remembered that the variations in secondary electrons developed at the printed signal plate as it is scanned by the electron beam of the tube results in the television image. The detail achieved in using the monoscope tube is limited principally by the beam diameter. Thus, the definition capabilities of the tube are relatively high.

A popular application of the monoscope is in providing a source of test-pattern signal, the station test pattern being printed directly on the aluminum target plate by the method indicated above. It is necessary to employ a standard television synchronizing generator with signal-shaping unit to provide the requisite driving signals for the monoscope. Two accompanying photographs illustrate the R.C.A. type TK–1A Monoscope Camera system as it is mounted in a convenient metal cabinet for station or factory installation (see Figs. 11.27 and 11.28). Ordinarily, the output of the unit is distributed to a number of test positions in the factory, so that test patterns may be utilized simultaneously at a number of work benches or test locations. A video distribution amplifier, comprising a number of video amplifying channels, distributes the picture signal by coaxial cable to the various locations. The test pattern produced by a typical Monoscope camera chain is shown in Fig. 11.29.

11.11 The Monochrome Scanner. The monochrome or flying-spot scanner has recently come into widespread use, particularly since this equipment permits the scanning of test patterns, still photographs, commercials, and other nonanimated subjects without requiring a complete camera chain to be placed in operation for the purpose. This effects an operating economy. All subject matter to be scanned, however, must be made up on glass transparencies. The Du Mont type TA–150–A Monochrome Scanner will scan 2- by 2-in. glass slides, which are identical with slides usually employed in the television station's slide projector.

A monochrome, or flying-spot, scanner consists essentially of a *special flying-spot cathode-ray tube*, together with its power supplies, deflection yoke, and scanning circuits; a *system to project the raster* on the subject to be scanned (the subject is ordinarily a glass-slide transparency, motion-picture film, or opaque object); a *multiplier-type phototube* to pick up the information reflected by the subject being scanned; and a *compensated video amplifier.*

Essentially, the operation of the monochrome scanner is relatively simple. A short-persistence 10-in. cathode-ray tube in the Du Mont equipment produces a light beam that is focused by means of a projection lens onto the transparency to be scanned. A capacitor lens focuses the

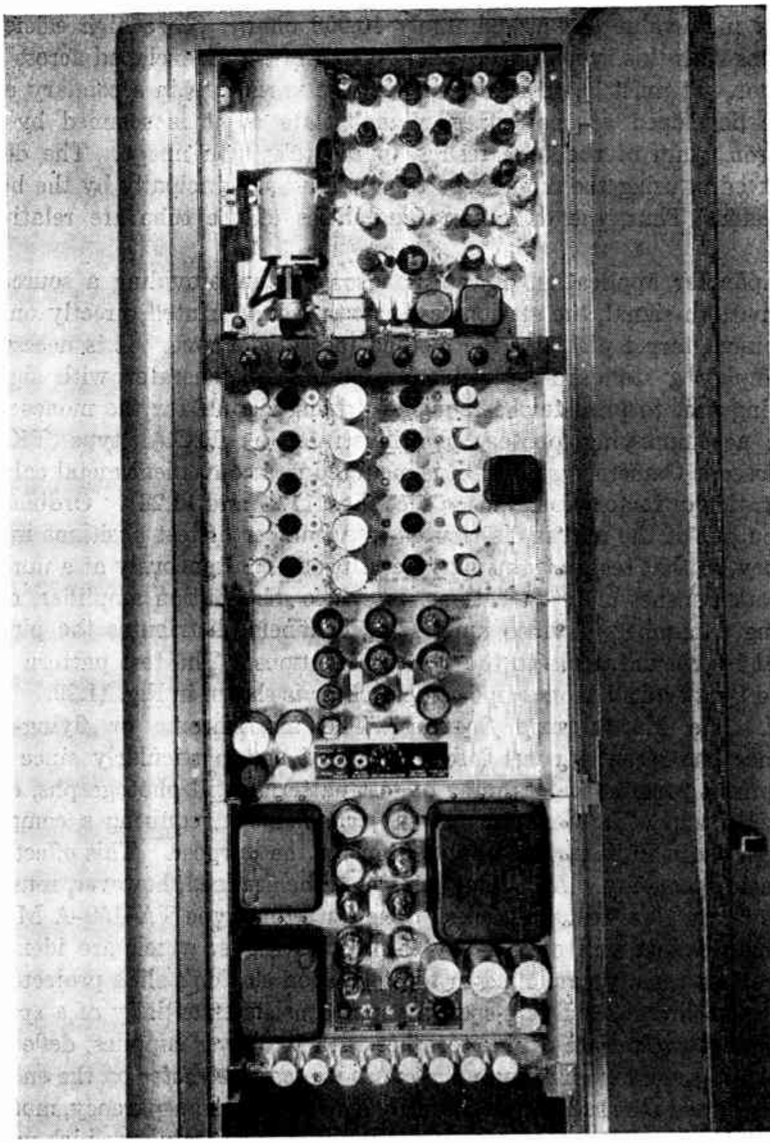


Fig. 11.27 Television test unit for broadcast stations and production lines. (Courtesy of Radio Corporation of America.)

light beam after it has penetrated the glass slide, projecting it onto the cathode surface of an electron-multiplier type of photoelectric tube.

The signal voltage produced at the photoelectric-cell output is amplified and mixed with blanking and synchronizing pulses. The resulting waveform constitutes a standard R.M.A. television signal.

The cathode-ray tube employed in the Du Mont scanner is a Du Mont type K1037–P15 10-in. tube of the short-persistence type and constitutes

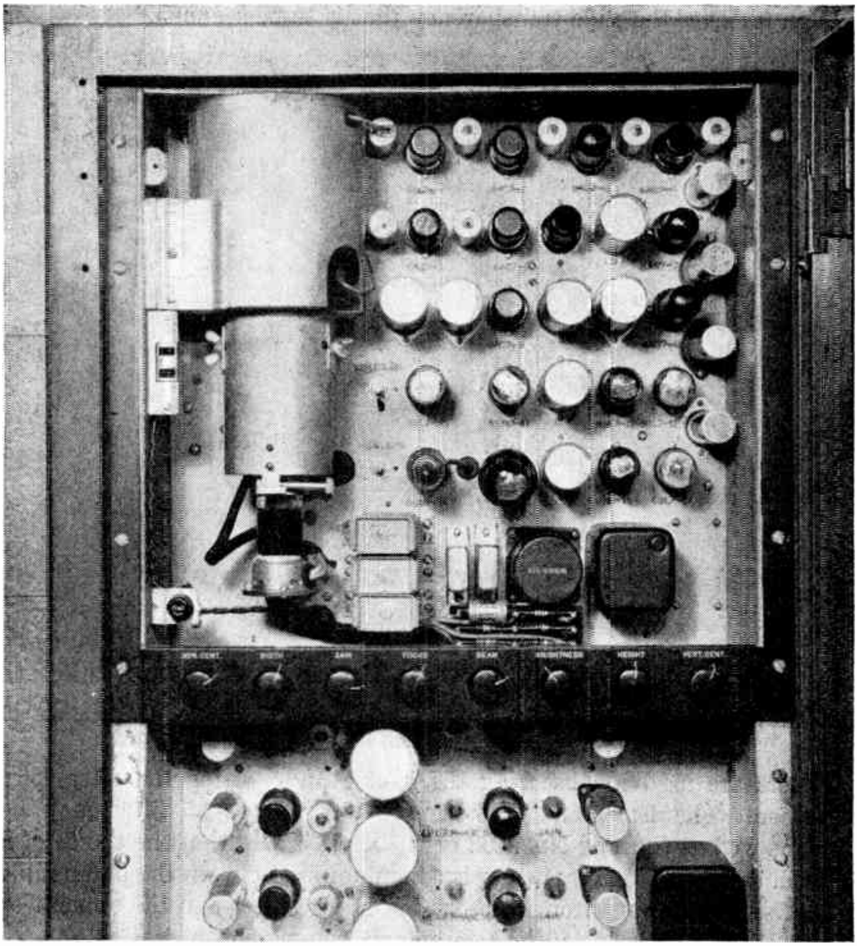


FIG. 11.28 R.C.A. Monoscope camera aids quality testing of television equipment. (Courtesy of Radio Corporation of America.)

the flying spot of light. In the R.C.A. scanner, an R.C.A. type 5WP15 5-in. cathode-ray tube is employed. The type 15 phosphor used in the manufacture of both tubes has a spectral-emission characteristic with peaks in the blue-green and near-ultraviolet light regions. A unique characteristic of tubes used in these scanners is the fact that the ultraviolet radiation has a persistence shorter than that which obtains in the visible region. By utilizing the ultraviolet radiation it is possible to reduce "trailing" in the reproduced picture.

The lens often employed in these devices is an enlarger-type objective lens. It is designed for low magnification and is corrected to handle ultraviolet radiation. The diameter of the objective lens must be large enough to cover the slide transparency that is to be scanned.

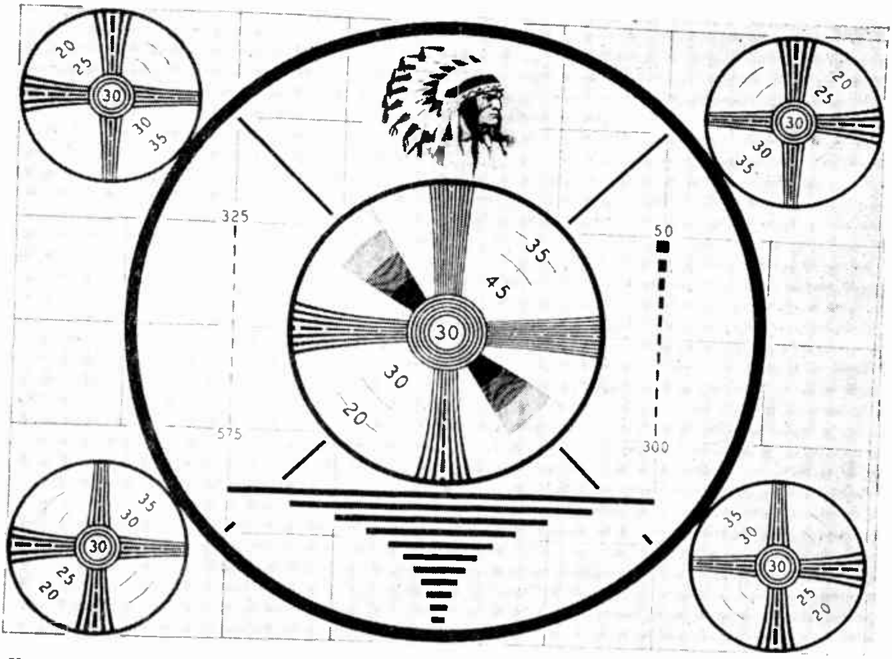


FIG. 11.29 Monoscope-tube test pattern. (Courtesy of Radio Corporation of America.)

Filters are used in absorbing the visible and passing the ultraviolet radiation. The Eastman Wratten No. 18A, 34, or 35 filter may be used, as well as Corning No. 9863 or 5670. It is said that the choice of a filter in designing such a scanner is a compromise between the permissible loss of signal output through absorption by the filter and the amount or extent of trailing that can be tolerated in commercial operation.

There exists a lag in the build-up and decay of output from the screen of a tube used in monochrome scanning, and the effect is similar to the aperture effect. The reproduced picture presents an appearance similar to that which would obtain were a deficiency in high frequencies present. It is therefore necessary to emphasize the high frequencies at the video amplifier following the photoelectric tube, through equalization. Less equalization is required with the P15 phosphor at the cathode-ray tube screen. The video amplifier following the scanner is usually made to have response out to 10 mc., and resolution of better than 700 lines is achieved.

In operation of the scanner, standard horizontal and vertical driving pulses are derived from an associated synchronizing generator. These pulses are clipped at pulse amplifiers in the unit developed by Du Mont, after which the differentiated leading edges of the clipped pulses are employed to produce the saw-toothed waveforms at line and field frequencies necessary for scanning. A horizontal and vertical deflection amplifier follows each of the respective saw generators, a type 6AS7–G damping tube being employed in the horizontal deflection circuit to ensure good linearity. Dual sections of a type 12AT7 vacuum tube clip and amplify standard blanking signals for elimination of the scanning spot of light during retrace intervals. A pulse rectifier applies a positive potential to a sweep-failure protection tube. The result is that the plate current of this tube operates a relay, the contacts of which serve to close the cathode circuit of the cathode-ray tube when both H and V deflection potentials across the secondaries of the two output deflection transformers are normal.

The plate current of a pentode-connected type 6AG7 vacuum tube flows through the focus coil associated with the cathode-ray tube. Thus, any slight variation in focus-coil resistance with changes in ambient temperature will produce no defocusing. Negative feedback applied to the cathode circuit results in stabilization of the tube characteristics, so that the type 6AG7 tube may be replaced without any readjustment of focusing. The potential admitted to the grid of the focus stabilizer is obtained from both regulated and unregulated direct current, and by such means that variations in line voltage, which can produce a change in the high secondary-anode potential for the cathode-ray tube incorporated in the device, produce a small change in the focus-coil current, which is just sufficient to maintain focus over a line voltage range of ± 10 per cent.

To provide some indication as to how the monochrome scanner functions, a block diagram of the device is shown in Fig. 11.30. The picture signal from the type 1P21 phototube, in being admitted through the five-stage video amplifier, is high-frequency compensated by means of a suitable equalizer system. Two networks are used to provide compensation for the phosphor of the cathode-ray tube employed in the Du Mont scanner. The networks are so designed that they correct for effective spot size and for the effects produced by phosphor excitation and decay intervals of approximately ten times the period of the picture element desired. Either positive or negative slides may be used because of a polarity inverter which is included in the circuit. Polarity selection is obtained by removing the desired signal from the output of the cathode or plate of a unity gain amplifier in the device.

A gamma corrector is included, to ensure that the output signal due to scanning is essentially proportional to the logarithm of the subject brightness. A type 6BA6 remote cutoff tube is used for this purpose. The plate of the gamma corrector tube (6BA6) is operated in shunt with the plate of a blanking amplifier, in order to provide emphasis of the blanking component, the signal being transferred by means of a series clipper to provide adjustment of the amplitude of blanking to the proper

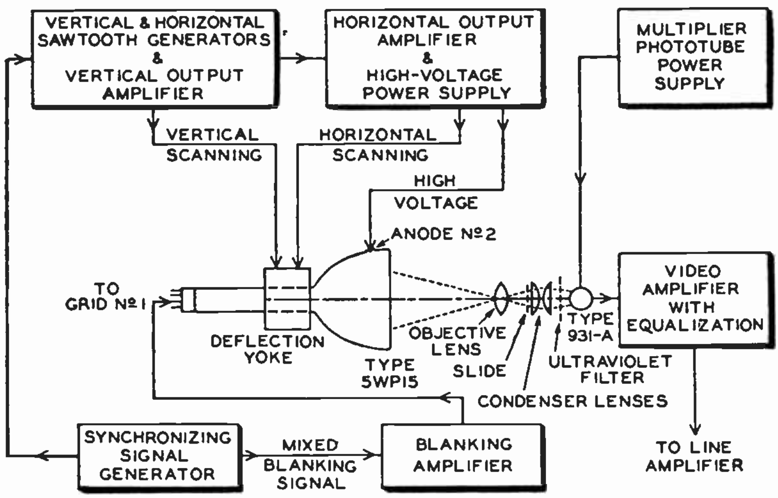


FIG. 11.30

level. The control grid of the type 6BA6 vacuum tube is clamped, its plate being directly coupled to the blanking clipper, since the input signal of the gamma corrector contains an excellent black reference during the blanking interval of the cathode-ray flying spot.

A unique feature of the Du Mont monochrome scanner is its automatic slide changer. It consists essentially of a reciprocating plunger which raises the lower slide in a stack to the proper position for scanning. After slides are scanned, they are relegated to a hopper for removal by hand. A slide magazine, in which the slides are stacked, will hold approximately twenty-five 2- by 2-in. glass slides of average thickness. Slides may be automatically changed in 0.2 sec.

The picture output signal may be varied in amplitude through adjustment of the voltage applied to the dynode stages of the phototube. The video gain control, as well as the pedestal control, are located on the front panel of the scanner for convenience. It is possible to feed two composite television signals from the output of the scanner, synchronizing information being introduced into the scanner by means of mixing in a common plate load. The automatic slide change mechanism may be remotely operated from the control desk in a master control room, or other convenient operating point.

The use of the monochrome scanner is particularly advantageous at the transmitter, where it is often necessary to transmit a test pattern over an extended period of time while adjustments are being made at the transmitting equipment. Through the use of this device, such test periods can be conducted with only members of the transmitter staff present, no additional personnel being required. Operation of a single camera chain for the same purpose would require the use of at least two qualified engineers to operate the chain.

11.12 The Film-Projection Room. The film-projection room of the typical television station is usually located in an area adjacent to the master control room. Such an arrangement has proved to be the most convenient from many points of view, a most important advantage being that of effecting close coordination between the master control-room engineering staff and the film projectionist. Such coordination is important since it is necessary to cut film in and out of studio presentations, the film supplying a portion of the studio presentation in a great many instances, and with split-second timing. It is also necessary occasionally to include information which has been made up into slide transparencies, and the projectionist must often introduce "spot" advertising, "stand-by" slides, or a test pattern or other station identification as a visual "curtain" between programs or portions of a studio production.

A typical film projection room is shown in Fig. 11.31, depicting the arrangement of some of the equipment at Station WGN-TV, Chicago. The location of the projection room, with relation to the master control room at Station WCAU-TV, Philadelphia, is shown in Fig. 11.32. In the usual arrangement, motion pictures or slides are projected through ports in the wall that separates the master control room and projection room, the projected program material being imaged on the targets of pickup tubes in TV cameras in the master control room, these cameras being arranged to face the open port holes. In many typical installations, the camera or cameras move along the wall and floor of the master control room on a railway. This makes it possible for one TV camera to receive the images of more than one film or slide projector, the camera being moved back and forth along the railway and being stopped before any desired projector. The TV cameras may also be located in the projection room proper, as in the WCAU-TV installation.

In the arrangement of equipment at Station WCAU-TV, it will be seen that the projection room is almost centrally located in the area allocated to the master control, film-projection, and developing rooms and the announce booth and workshop. Thus, films and still pictures of local news and sports events may be rapidly processed and televised, both still- and motion-picture developing rooms are made available, together with film cutting and rewind rooms—certainly an ideal arrangement.

The film-projection room of a large television station or network is usually equipped with dual 16- and 35-mm. motion-picture projectors

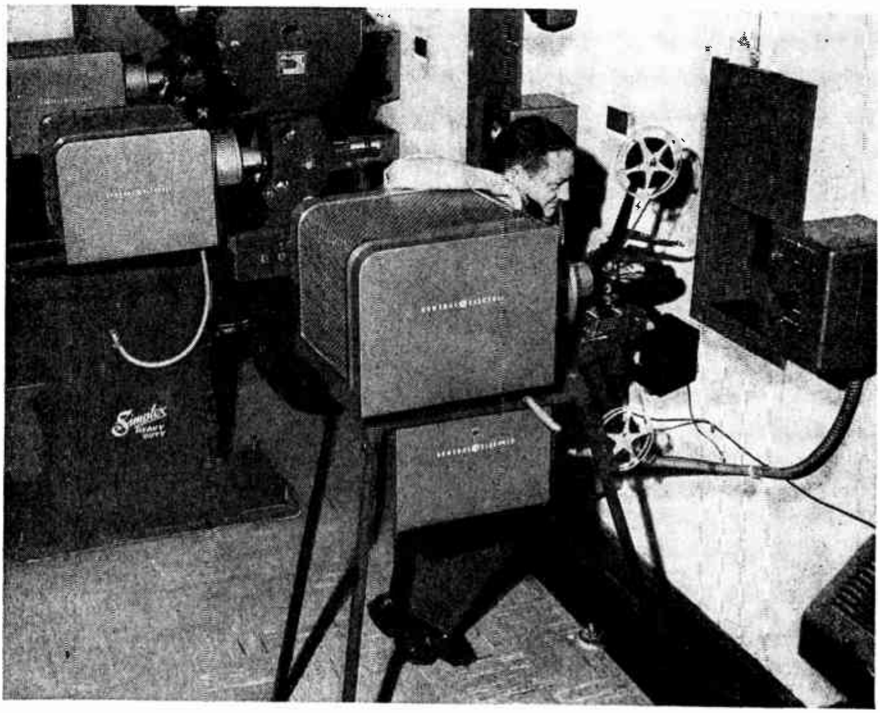


FIG. 11.31 The film-projection room of Station WGN-TV in Chicago. In the background are two 35-mm. projectors and in the foreground a 16-mm. projector. In this booth, movies or slides are projected through portholes to film cameras on the opposite side of the wall. A slide projector is shown at the lower right-hand corner. (Courtesy of General Electric Company.)

which have either been especially designed and developed or modified for use in television. The modification of standard film projectors for TV use has already been discussed (in Chap. 9), several commercial types of television motion-picture projection equipment being described. Because of the economy in the use of 16-mm. motion-picture film, smaller stations are usually equipped with only single or dual 16-mm. TV film projectors, a television camera for translating the projected picture into the television signal, a rack-mounted picture monitor, and, in many instances, a film multiplexer and slide projector.

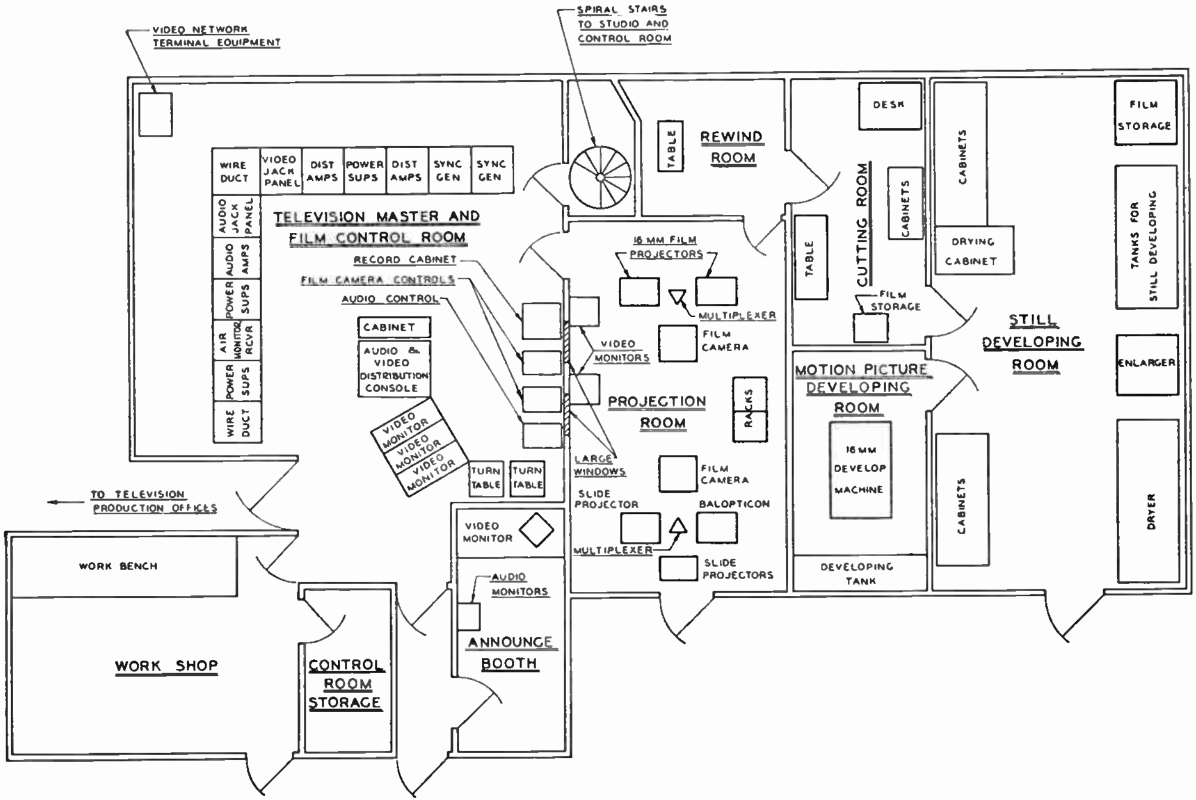

VIDEO NETWORK TERMINAL EQUIPMENT
SPIRAL STAIRS TO STUDIO AND CONTROL ROOM
WIRE DUCT
VIDEO JACK PANEL
DIST AMPS
POWER SUPS
DIST AMPS
SYNC GEN
SYNC GEN
AUDIO JACK PANEL
AUDIO AMPS
POWER SUPS
AIR MONITOR RCVR
POWER SUPS
WIRE DUCT
TELEVISION MASTER AND FILM CONTROL ROOM
RECORD CABINET
FILM CAMERA CONTROLS
AUDIO CONTROL
CABINET
AUDIO & VIDEO DISTRIBUTION CONSOLE
VIDEO MONITOR
VIDEO MONITOR
VIDEO MONITOR
TURN TABLE
TURN TABLE
TO TELEVISION PRODUCTION OFFICES
WORK BENCH
WORK SHOP
CONTROL ROOM STORAGE
VIDEO MONITOR
AUDIO MONITORS
ANNOUNCE BOOTH
TABLE
REWIND ROOM
16 MM FILM PROJECTORS
MULTIPLEXER
VIDEO MONITORS
FILM CAMERA
PROJECTION ROOM
RACKS
LARGE WINDOWS
FILM CAMERA
SLIDE PROJECTOR
BALOPTICON
MULTIPLEXER
SLIDE PROJECTORS
DESK
TABLE
CUTTING ROOM
CABINETS
FILM STORAGE
MOTION PICTURE DEVELOPING ROOM
16 MM DEVELOP MACHINE
DEVELOPING TANK
CABINETS
DRYING CABINET
STILL DEVELOPING ROOM
CABINETS
FILM STORAGE
TANKS FOR STILL DEVELOPING
ENLARGER
DRYER

FIG. 11.32

The film multiplexer makes use of two mirrors, mounted and arranged at the proper angle for projecting the images from one or two projectors onto the target of a pickup tube in a single TV camera. The multiplexer is also supplied with a slide projector, which permits the scanning of slide transparencies for purposes of station identification, the transmission of test pattern, and so on. The arrangement of the R.C.A. multiplexer is shown in Fig. 11.33. Even without the use of the multiplexer, slide pro-

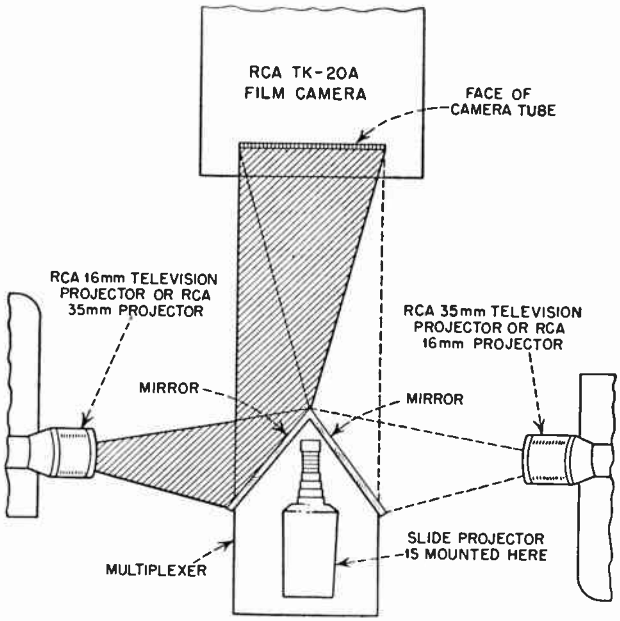


Fig. 11.33

jectors are essential to provide a complete layout of projection equipment. Many types are commercially available for the purpose (see Fig. 11.34).

When 35-mm. TV film projectors are employed, in most instances it is necessary to include a fireproof film vault for storage of the film. Because of the inflammability of the film stock, rather stringent fire regulations must be observed. The fireproof 16-mm. safety film may be handled without the limitations imposed by 35-mm. stock and has become the preferred film for television applications. It is, of course, much more inexpensive than 35-mm. film, although the resulting images are not of the high quality provided through use of the larger frame area.

The WCAU-TV film department makes use of a Houston 16-mm. motion-picture film developer which has a capacity of approximately 400 ft. of film each 45 sec. The installation of a cypress tank, chemical storage cabinets, other fireproof cabinets, and a complete outlay of processing accessories provides an up-to-date and efficient film-handling arrangement. Stainless-steel developing tanks and trays, together with a multi-size enlarging camera with tilt board, a drying cabinet, and a dryer, make it possible to process stills for subsequent scanning by the TV cameras.

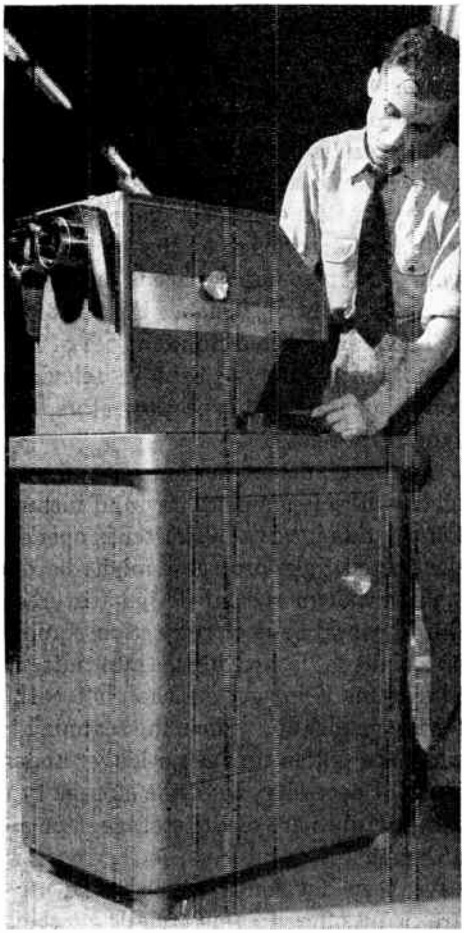


FIG. 11.34 A General Electric slide projector, type PF-3-C for television. This dual projector will accommodate standard slide transparencies, switching of slides being accomplished at the projector proper. With the dual-projector arrangment, one slide may be televised while the slide holder of the second projector is being loaded. Thus, rapid switching of slides may be accomplished. (Courtesy of General Electric Company.)

Film cutting and editing facilities enable the staff to service 16-mm. motion-picture film requirements rapidly.

The use of a balopticon makes it possible to project "stills" directly to one of two film cameras through use of an R.C.A. multiplexer, this latter device also reflecting the images of two slide projectors. A second multiplexer makes it possible to project the images of either of two 16-mm. TV film projectors to a second camera. Two picture monitors enable the projectionist to view the program as the production progresses, and he may thereby introduce film, slide, or still images upon a prearranged direct cue supplied by the program department. Cues may be taken directly from the screen of the picture monitor. It is also useful for the projectionist to follow a "marked" copy of the script outlining the production, the necessary cues being marked on the script copy wherever necessary. The projectionist is thus able to introduce film or other image sequences originating in the projection room and intended to make up part of the show.

The motion-picture film projectionist must have a thorough knowledge of film and slide projectors, film, the multiplexer, the balopticon, and he must be able to properly test and service the equipment under his supervision. A fundamental knowledge of television is most essential, as well as a knowledge of the special techniques involved in image projection. Of great importance is the ability to test and service the equipment, so as to maintain it at a high peak of operating efficiency.

There are three common types of motion-picture film-projection equipment which may be used in television; namely, the intermittent- and continuous-motion type projectors, and the pulsed-light, or shutterless, type of projector.

The intermittent-motion type of projector is one in which the motion-picture film is momentarily and instantaneously stopped in the film gate. During this interval a shutter is opened or a light flashed. By this token, the pulsed light projector might be described as one of the intermittent type, although special design features have led it to be considered as a third general type of projection equipment. When the shutter is opened or a light is flashed in the intermittent type of equipment, the projected film frame is imaged on the photocathode or mosaic of the electron tube for image pickup. Since the scanning takes place during the time interval when the optical image no longer appears on the mosaic, the pickup tube must, of necessity, be of the storage type. Both Iconoscope and Orthicon camera tubes are of the storage type and consequently both may be used, although the Iconoscope is the more widely used. Satisfactory systems have been developed which make use of orthicon type tubes, and they are being offered commercially at the present time.

The continuous-motion type of projector has the motion-picture film move at a constant rate through the film gate, the optical image being held in a fixed position by means of a suitable movement of prisms or lenses in the projector. Sometimes both prisms and lenses have been used. In some of these equipments, the transition from one picture to the next is made during the vertical blanking period or interval. This dictates that the projector must operate synchronously with the television field or frame rate. In a few projection systems of this type synchronism is unnecessary. The continuous-motion type of projection equipment has not seen widespread use in television.

The third type of equipment is the "pulsed-light," or "shutterless," type of equipment. Although essentially an intermittent-motion type, the principal difference between it and other intermittent projectors is the absence of the conventional shutter and the use of a pulsed source of light for illumination of the film frame. A projector of this type, manufactured by General Electric Company, is shown in Fig. 11.35. The lamp

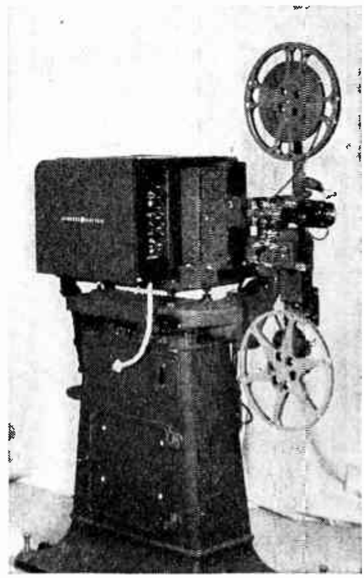


FIG. 11.35 A PF-2-B 16-mm. film projector for television, employing a synchro-lite pulsed-light source. (Courtesy of General Electric Company.)

is a Krypton-filled flash lamp (type FT-230) pulsed by means of a special circuit arrangement, only 400 w. of power being consumed by the Synchro-Lite. The projector-driving motor and film-rewind motor consume another 210 w. of power. Thus, the entire projector consumes less power than is ordinarily required for the conventional light source.

Whatever the type of projector used or the system employed, certain basic routine measurements are necessary in order to assure optimum performance of the apparatus. The projector must ordinarily be tested for "jump" and "weave" of the picture as well as for resolution of the optical system. The focus and alignment of the optical system must be checked and adjusted as a matter of routine maintenance. The size, position, and focus of the optical image at the mosaic or photocathode must be ascertained, and the sweep adjustment and electrical focus at the television camera must be checked.

It is important to have some knowledge of the amount of light available at the mosaic of the electron tube for image pickup. When an intermittent-type projector is used, the light is pulsed, and it becomes necessary to determine the width of the pulse by actual measurement. It is also important to determine the phase of the pulse in relation to the vertical blanking, and its phase relationship with respect to the time of pull-down of the film. When continuous-motion projectors are used, phasing of the time of picture change with the vertical blanking must be ascertained when synchronization is involved.

To ascertain whether the mechanical and optical performance of the television-film projection equipment is proper, it is common practice to pass a special test film through the projector, the resulting image being viewed at a suitable picture monitor, the signal input of which is connected in shunt with some appropriate monitoring point of the TV camera film chain. The output of the picture-line amplifier is usually chosen.

The special test films now used are available from the Society of Motion Picture and Television Engineers (342 Madison Avenue, New York 17). Visual test film VTF–1 is utilized in running tests on 35-mm. projection equipment. Proper use of this film will permit tests of jump and weave, focus and alignment of the image, travel ghost due to improper shutter synchronization, as well as lens aberration. Special films are also available for conducting the three indicated tests separately. The special film for test of jump or weave is described as VTF–JWS; the film for focus and alignment test, VTF–FAS; and the film for checking the presence of travel ghost, VRF–TGS.

For the checking of 16-mm. projection equipment, other test films and plates may be had from the same society. Lens performance can be measured by means of a test plate designated Z22.53–1946.

In checking synchronization where intermittent-type equipment is used, special techniques are necessary. The phasing of the light pulse with the vertical blanking necessitates the use of an oscillograph, the sweep of the instrument being synchronized from the vertical blanking pulse. The vertical deflection amplifier of the oscillograph must be capable of amplifying the vertical blanking impulse derived from the light source. The phasing of the light pulse with the pull-down in intermittent projectors or the phasing of the picture change with the vertical blanking is ascertained through use of the test film for 35-mm. projectors. When 16-mm. projectors are employed, S.M.P.T.E. test film Z22.54–1946 is used.

Proper mechanical operation of the projector is determined through insertion of the proper test film in the projector, after which the machine is placed in operation. When 35-mm. projection equipment is employed, the focus and alignment target is employed to adjust for proper size and optimum focus, as well as for proper centering of the optical image at the mosaic of the pickup tube. With the reproduced image being viewed at a picture monitor at the monitoring point in the system, the electrical centering, focus, and sweep amplitude may be adjusted. These adjustments are made with both the projector and camera chain in normal operation.

Jump and weave refer to any observed unsteadiness of the projected image in the vertical or horizontal directions, respectively. These movements are usually rapid and of extended duration where continuous-type machines are employed. Jump or weave are determined as prescribed in the instruction bulletin supplied with the test film. This S.M.P.T.E. bulletin must be carefully studied by the television engineer or projectionist charged with the maintenance of the film projection equipment. The reproduced image, with the test film in operation, is observed at an appropriate picture monitor. It must be determined that any horizontal or vertical movement of the reproduced picture is not the result of mechanical motion of the projector, the camera, the picture monitor, or the pickup tube in the camera. This motion sometimes results from improper installation of one or more of the parts involved, from poor mounting methods, or from insecure mounting of the iconoscope pickup tube. Where continuous-motion projectors are used, it should be determined whether any relatively long period movements in the order of 1 to 5 sec. duration are observed. These movements will usually be observed to occur in the vertical plane, and an unsteady picture is inevitably the result. Any television station will find the S.M.P.T.E. test films indispensable in maintaining the projection equipment in optimum operating condition. The control-room equipment, into which the signal from the film camera is fed, is shown in Fig. 11.36.

11.13 Production of Films for Television. At the present state of the art, both 16- and 35-mm. motion-picture cameras are being used to produce films for use at the television broadcast station. Whatever the type of camera, a standard speed of 24 frames per second is employed. Cameras are driven at synchronized speed when sound is recorded simultaneously. A principal demand for film has developed in the preparation of newsreels and for on-the-spot pickups where it is not desirable to dispatch a fully equipped mobile unit for reasons of operating economy.

In filming events for subsequent delivery to the film processing and projection room of the television station, composition is a most important consideration. Close-up scenes are to be preferred, since the screens of picture tubes employed for home use are, for the most part, small in area, and the field of action is strictly limited. Medium shots are employed at times, but long shots are generally frowned upon. The subject matter is kept as large as possible, although crowding of the action or characters is not to be recommended. It is good practice to keep all action or characters within the central part of the total area to be filmed, upper and lower margins of 8.5 per cent and side margins of 13 per cent being allowed. The reason is that the nonuniform adjustment of "sweeps" in home receivers results in nonuniformity of picture size. Strict adherence to the prescribed margins will result in most receivers reproducing all of the picture information transmitted.

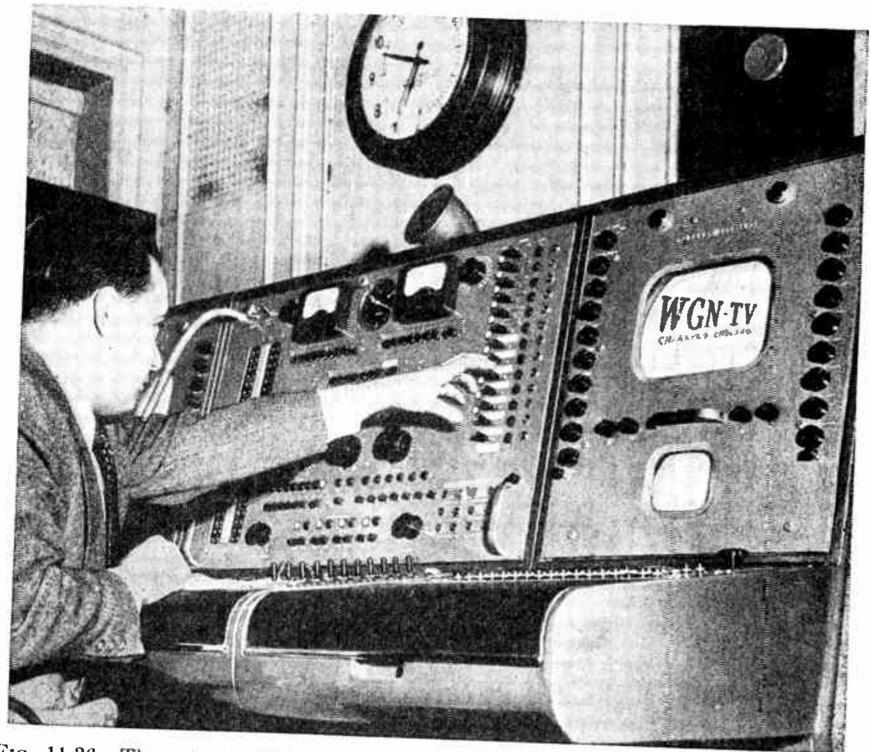


FIG. 11.36 The outputs of the film pickup camera are fed by means of coaxial cable to one or more video input positions at the master control switching and mixing desk. Illustrated is a General Electric master control desk as installed at Station WGN-TV, Chicago. The sound output of the special film projectors is fed to input positions at the master control room audio console. (Courtesy of General Electric Company.)

Authorities recommend that the composite of the subject matter be arranged in a checkerboard pattern, with many changes in contrast. This will reduce horizontal smear due to possible low-frequency distortion in the television system. Also, it is not recommended that large uniform-colored, dark areas, or small patterns be employed. This condition is very important with respect to the foreground and lower part of the scene to be filmed and subsequently televised.

It is generally considered unnecessary to employ flat lighting to ensure contrast within the brightness range of the television system. We, of course, refer to the lighting of a studio where motion pictures are being filmed for television use. Even lighting is of much greater importance. The same over-all illumination must be used throughout the picture area, so that a minimum amount of shading will be necessary when the film is televised. Foreground lighting is very important, since otherwise there will occur insufficient signal response in the foreground of the reproduced picture. This part of the scene will appear washed out. Intensity of illumination from scene to scene must be held constant, so that no marked change occurs in the resulting video signal as scenes rapidly follow one another. It also reduces the need for constant adjustment of the background illumination of the scene through operation of the pedestal control. Night scenes should be studiously avoided, as should scenes that are made dark for reason of effect. A television system converts light into electrical energy, and dark scenes will transmit little or no signal. There should be a rapid transition from one scene to another, and long fades, wipes, and dissolves should be kept to a minimum.

Furniture, clothing, accessories and properties should be large enough in physical size to be clearly visible on the screen of the home receiver. This condition dictates the elimination of objects having fine detail. Any titles employed should incorporate large bold face type or lettering on a textured background. The prescribed margins referred to above should be studiously observed. Otherwise, improper adjustment of sweep amplitude controls in home receivers may result in some of the title being cut off or lost to the viewer.

The projectionist will often be consulted by the program staff or motion-picture cameraman concerning the techniques that must be followed in producing film of acceptable quality for television. For this reason, the subject has been quite thoroughly covered in our discussion of the film projection room and general film handling techniques.

BIBLIOGRAPHY

1. MAUTNER, L., and A. J. BARACKET, "Engineering TV Master Control Equipment," *Tele-Tech*, March, 1947.
2. "Electrical Performance Standards for Television Relay Facilities," R.M.A. Standards Proposal No. 210, Sept. 26, 1947.
3. BLOECKER, W. E., "Interconnecting Facilities for Television Broadcasting," *Electronics*, November, 1947.
4. "N.Y.-Boston Microwave Television Relay," *Electronics*, January, 1948.
5. SMITH, H. R., and GORDON S. GREGORY, "Film Pickup System," *F.M. and Television*, March, 1948.
6. PALMER, R. C., "A TV Sync Stretcher," *Communications*, March, 1948.
7. PALMER, R. C., "Phasing of Remote TV Signals," *Communications*, April, 1948.

8. "Flying Spot for Studio Scanning," *Tele-Tech*, June, 1948.
9. RUSTON, J., "TV Control Console Design," *Communications*, October, 1948.
10. NIXON, G. M., "Planning Radio and Television Studios," *Broadcast News*, December, 1948.
11. "Practical Equipment Layouts for Television Studios," *Broadcast News*, December, 1948.
12. BLOUNT, R. E., "Lighting Requirements of Television Studios," *Tele-Tech*, May, 1949.
13. GORDON, G. E., "Video Recording Techniques," *Tele-Tech*, May, 1949.
14. GORDON, G. E., "Video Recording Techniques," *Tele-Tech*, June, 1949.
15. THOMPSON, R. D., "A Cathode-Ray Tube Video Scanner," a paper presented at the Third Annual N.A.B. Broadcast Engineering Conference, Chicago, Ill., April, 1949.
16. "Measurements of Film Projection Equipment," a bulletin of the General Electric Co., Electronics Park, Syracuse, N.Y., 1949.
17. LITTLE, R. V., "Television Film Recording," *Broadcast News*, April, 1949.
18. "Films in Television," a bulletin of the *Soc. Motion Picture Engrs.*, 1949.

REVIEW QUESTIONS

11–1. Describe several types of Image Orthicon tube used in TV broadcasting.

11–2. What are teletranscriptions? How are they produced, and for what purpose are they used?

11–3. (a) What is meant by "networking" in television? (b) Compare coaxial-cable vs. microwave relay operation. (c) Discuss the advantages and disadvantages of each type of relay.

11–4. Define the following terms: (a) intercity relay; (b) intracity relay; (c) parabolic reflector; (d) repeater station; (e) terminal station.

11–5. Discuss several TV motion-picture film projectors. (b) What are the advantages and disadvantages of each?

11–6. (a) Discuss studio operations in television. (b) What are the responsibilities of the personnel engaged in these operations? (c) What are the functions of the technical director and supervising engineer?

11–7. (a) Describe the sound system employed in a typical television studio. (b) How is it similar to that employed in AM or FM broadcasting? (c) What types of microphones are ordinarily employed?

11–8. (a) What are the important considerations when filming subjects for television? (b) How do the techniques in producing television films differ from those employed in making films for theater use?

11–9. (a) What is a picture distribution amplifier? (b) Describe its function.

11–10. (a) Explain the functions of the master control room. (b) What is its purpose in the over-all system?

GLOSSARY

Definitions of engineering and technical terms given here are based on the most recent definitions made available by the Institute of Radio Engineers, American Standards Association, American Institute of Electrical Engineers, and the Federal Communications Commission, and other authorities.

Terms Useful in Television Engineering

A

aberrations An image defect occurring in the electron lens system of a cathode-ray tube.

aberration, chromatic This image defect is due to the variations in the initial velocities of the electrons as they leave the cathode of the tube.

aberration, spherical This image defect occurs when rays of electrons leaving the cathode of the tube along its principal axis do not converge at the paraxial image point.

accelerating electrode The electrode of a cathode-ray tube (anode 2) which functions to increase the kinetic energy of the electron beam through increasing its velocity.

activation The process in the manufacture of an electron tube for image pick-up in television, whereby the tube is sensitized through the admission of caesium, and for oxidizing the silver surface of the target, as well as baking of the tube to provide a reaction between the silver oxide (or other activating agent) and alkali.

activator The agent employed in the activation of an electron tube for image pickup. See also *activation*.

active transducer A transducer containing one or more sources of energy.

adjacent-channel interference Interference caused in one radio circuit by a transmitter which is assigned for operation in an adjacent channel.

all-pass network A network designed to introduce phase shift or delay without introducing appreciable attenuation at any frequency.

a-c transmission In this mode of transmission, a fixed setting of the controls makes any instantaneous value of signal correspond to the same value of brightness only for a short time.

NOTE: Usually, this time is not longer than one field period, and may be as short as one line period. If the signal is considered to be an *amplitude-modulated wave*, then "instantaneous value of signal" should be interpreted as "instantaneous value of envelope." If the signal is considered to be a *frequency-modulated wave*, then "instantaneous value of signal" should be interpreted as "instantaneous frequency of the modulated wave."

amplifier A device which, by enabling a received wave to control a local source of power, is capable of delivering an enlarged copy of the wave.

NOTE: The amplifying element may be any of various devices such as electron tubes, magnetic circuits, and so on.

amplitude distortion A type of distortion that occurs in an amplifier or other device when the amplitude of the output is not exactly a linear function of the input amplitude.

amplitude-frequency response characteristic The variation with frequency of the transmission gain or loss of a device or system. Sometimes called *sine-wave response; response characteristic; amplitude characteristic; frequency characteristic.*

amplitude-modulated transmitter A transmitter that transmits an amplitude-modulated wave.

NOTE: In most amplitude-modulated transmitters the frequency is stabilized.

amplitude modulation (AM) Modulation in which the amplitude of a wave is the characteristic subject to variation.

amplitude-modulation noise The noise produced by undesired amplitude variations of a radio-frequency signal.

antenna A means for radiating or receiving radio waves.

antenna array A system of antennas coupled together for the purpose of obtaining directional effects.

antenna field gain In a television antenna, the ratio of the effective free-space field intensity produced at one mile in the horizontal plane, expressed in millivolts per meter for one kilowatt antenna input power, to 137.6 millivolts per meter.

antenna height above average terrain The average of the antenna heights above the terrain from two to ten miles from the antenna.

NOTE: In general, a different antenna height will be determined by each direction from the antenna. The average of these various heights is considered the antenna height above average terrain.

antenna resistance Equal to the power supplied to the entire antenna circuit divided by the square of the effective antenna current at a specified point.

NOTE: Antenna resistance is made up of such components as radiation resistance, ground resistance, radio-frequency resistance of conductors in antenna circuit, equivalent resistance due to corona, eddy currents, insulator leakage, and dielectric power loss.

artificial antenna (dummy antenna) A device which simulates a real antenna in its impedance characteristics and power-handling capabilities, but does not radiate or receive radio waves.

artificial load A dissipative but essentially nonradiating device having the impedance characteristics of an antenna, transmission line, or other practical utilization circuit.

aspect ratio The numerical ratio of the picture width to the picture height.

astigmatism (electron-optical) In an electron beam tube, a focus condition in which the shape as well as the size of the spot changes with focus adjustment.

attenuation distortion That form of distortion resulting from failure to amplify or attenuate uniformly over the frequency range required for transmission.

attenuation-frequency distortion That form of wave distortion in which the relative magnitudes of the different frequency components of a wave are changed.

audio-frequency peak limiter A circuit used in an audio-frequency system to cut off peaks that exceed a predetermined value.

aural signal A radio-frequency carrier wave modulated by an audio signal.

aural transmitter The radio equipment for the transmission of the aural signals only.

automatic background control An electric circuit or device for automatically adjusting the average brightness of the received television image.

automatic frequency control (a.f.c.) An arrangement whereby the frequency of an oscillator is automatically maintained within specified limits.

automatic grid bias The grid bias provided by the difference of potential across a resistance in the grid or cathode circuit; it is due to grid or cathode current, or both.

average power output of an amplitude-modulated transmitter The radio-frequency power delivered to the transmitter output terminals averaged over a modulation cycle.

B

back porch That portion of a composite picture signal at blanking level which lies between the trailing edge of the horizontal synchronizing signal and the trailing edge of the horizontal blanking signal.

balanced Signifies (1) symmetrical with respect to ground; or (2) arranged to provide conjugacy between certain sets of terminals.

balanced amplifier, push-pull amplifier An amplifier circuit in which there are two identical signal branches connected so as to operate in phase opposition and with input and output connections each balanced to ground.

balanced oscillator An oscillator in which at the oscillator frequency the impedance centers of the tank circuit are at ground potential and the voltages between either end and their centers are equal in magnitude and opposite in phase.

balanced transmission line A transmission line having equal conductor resistances per unit length and equal impedances from each conductor to earth and to other electrical circuits.

band of frequencies The entire range of frequencies between two specified limits.

bandwidth The number of cycles per second between two defined frequency limits.

bandwidth, effective In a band-pass filter, the width of a hypothetical rectangular band-pass filter that would pass the same mean-square value of noise current or voltage with the same transfer ratio at the reference frequency (usually mid-band). It is equal to the integrated product of the incremental bandwidth multiplied by the square of the current- or voltage-transfer ratio divided by this ratio at the reference frequency.

bazooka (balun) A device employed in transferring power from the balanced output of a source of radio frequency power to an unbalanced transmission line.

black compression Amplitude compression of the signals corresponding to the black regions of the picture, thus modifying the tonal gradient.

black level The instantaneous amplitude of the television signal which corresponds to a black area in the received picture.

NOTE: The brightness of the received picture in the black area may not be the same from scene to scene. If the signal is considered to be an *amplitude-modulated wave,* then "instantaneous value of signal" should be interpreted as "instantaneous value of envelope." If the signal is considered to be a *frequency-modulated wave,* then "instantaneous value of signal" should be interpreted as the "instantaneous frequency of the modulated wave."

black peak The maximum excursion of the picture signal in the black direction at the time of observation.

black saturation Distortion of the picture signal consisting of extreme compression of the blackest range, usually the result of the amplitude of the picture signal exceeding the reference black level.

blacker-than-black region That portion of the standard television signal devoted to the synchronizing signal. These synchronizing signals are transmitted at greater peak power than are the blackest portions of the pictures.

blanking The substitution for the picture signal, during prescribed intervals, of a signal whose instantaneous amplitude is such as to make the return trace invisible.

blanking, horizontal The blanking signal at the end of each line.

blanking level The level of the signal during the blanking interval. It coincides with the level of the base of the synchronizing pulse.

blanking pulse A negative pulse of voltage applied to the grid of a cathode-ray tube for the purpose of cutting off the electron beam during the return time.

blanking signal A wave constituted of recurrent pulses, related in time to the scanning process, used to effect blanking.

blocking oscillator A relaxation oscillator consisting of an amplifier (usually single-stage) with its output coupled back to its input by means which include capacitance, and mutual inductance.

bootstrap circuit A single-stage circuit in which the output load is connected between the negative end of the plate supply and the cathode, the signal voltage being applied between the grid and cathode.

NOTE: The term "bootstrap" arises from the fact that a change in grid voltage changes the potential of the input source with respect to ground by an amount equal to the output signal.

bounce The term applied to any unintentional vertical movement in the reproduced television image as viewed at the fluorescent screen of any cathode-ray tube in the system.

bridge rectifier A full-wave rectifier with four rectifying elements or groups of elements connected as in a bridge circuit.

bridging A bridging connection is one by which a signal appearing in a circuit otherwise free of such connection may be obtained without perceptible effect on the normal operation of said circuit.

bridging connection A parallel connection by means of which some of the signal energy in a circuit is withdrawn, frequently with imperceptible effect on the normal operation of the circuit.

brightness (fluorescent screen) In the fluorescent screen of a cathode-ray tube, the relative brightness in foot-lamberts of the light emitted from the screen of the tube, as measured at a distance of one foot from the screen and along the principal axis of the tube.

brightness control The manual bias control of a picture tube.

NOTE: The brightness control affects both the average brightness and the contrast of the picture.

C

camera tube An electron beam tube in which an electron-current or charge-density image is formed from an optical image and scanned in a predetermined sequence to provide an electrical signal.

carrier A wave suitable for modulation by a modulating wave.

NOTE: Examples of carriers are a sine wave and a recurring series of pulses.

carrier-amplitude regulation (carrier shift) The change in amplitude of the carrier wave in an amplitude-modulated transmitter when modulation is applied under conditions of symmetrical modulation.

carrier frequency See *center frequency.*

carrier-frequency range of a transmitter The range of frequencies to which the transmitter may be adjusted for normal operation.

carrier-frequency stability of a transmitter A measure of the ability of the transmitter to maintain an assigned average frequency.

carrier noise The noise produced by undesired variations of a radio-frequency signal in the absence of any intended modulation.

carrier-power output rating In the aural transmitter, the power available at the output terminals of the transmitter when the output terminals of the transmitter are connected to the normal load circuit or to a circuit equivalent thereto.

carrier-reference white level As the term is applied to the visual transmitter, the carrier amplitude corresponding to reference white level.

carrier shift See *carrier-amplitude regulation.*

cathode follower An amplifier in which the output load is connected in the cathode circuit of a vacuum tube and the input is applied between the control grid and the remote end of the cathode load.

NOTE: The circuit is characterized by low output impedance, high input impedance, and voltage gain less than unity. Its name derives from the tendency of the cathode to follow the control grid in voltage.

cathode modulation Modulation produced by application of the modulation voltage to the cathode of any electron tube in which the carrier is present.

NOTE: Modulation in which the cathode voltage contains externally generated pulses is called "cathode pulse modulation."

cavity resonator A region substantially enclosed by conducting walls, within which resonant fields may be excited.

center frequency In frequency modulation, the center frequency is the average frequency of the emitted wave when modulated by a symmetrical signal.

characteristic distortion A displacement of signal resulting from the persistence of transients caused by preceding transitions.

characteristic wave impedance In a transmission line, the wave impedance of the line in the absence of reflected waves.

china marking The act of identifying certain parts, portions, or points along the screen of a cathode-ray tube for reference purposes by means of a china marker. Also, the mark due to application of the china marker.

chromatic aberration See *aberration*.

clamper A pulse-operated device which functions during a portion of the blanking interval of the picture signal to fix the level at some predetermined reference level.

clamping The process that establishes a fixed level for the repetitive components of the video signal. In current practice, clamping is accomplished during the interval of the horizontal synchronizing pulse or the back porch.

clamping circuit A circuit which adds a fixed bias to a wave at each occurrence of some predetermined feature of the wave so that the voltage or current of the feature is held at or "clamped to" some specified level. The level may be fixed or variable.

class A amplifier An amplifier in which the grid bias and alternating grid voltages are such that plate current in a specific tube flows at all times.

NOTE: To denote that grid current does not flow during any part of the input cycle, the suffix 1 may be added to the letter or letters of the class identification. The suffix 2 may be used to denote that grid current flows during some part of the cycle.

class AB amplifier An amplifier in which the grid bias and alternating grid voltages are such that plate current in a specific tube flows for appreciably more than half but less than the entire electrical cycle.

class B amplifier An amplifier in which the grid bias is approximately equal to the cutoff value so that the plate current is approximately zero when no exciting grid voltage is applied, and so that plate current in a specific tube flows for approximately one half of each cycle when an alternating grid voltage is applied.

class C amplifier An amplifier in which the grid bias is appreciably greater than the cutoff value so that the plate current in each tube is zero when no alternating grid voltage is applied, and so that plate current flows in a specific tube for appreciably less than one half of each cycle when an alternating grid voltage is applied.

class A modulator A class A amplifier used for the specific purpose of supplying the necessary signal power to modulate a carrier.

class B modulator A class B amplifier used for the specific purpose of supplying the necessary signal power to modulate a carrier.

NOTE: In such a modulator the class B amplifier is normally connected in push-pull.

clipper An electrical circuit employed to clip off or remove one or both extremities of a sinusoidal wave, or to clip the peak of an impulse or similar type of waveform.

coaxial line (concentric line) A transmission line formed by two coaxial conductors, each insulated from the other by some suitable dielectric material, such as air or polyethylene.

color transmission The transmission of a signal wave that represents both the brightness values and the chromaticity values in the picture.

Colpitts oscillator An electron-tube oscillator in which a parallel-tuned tank circuit is connected between grid and plate, with the tank capacitance containing two voltage-dividing capacitors in series and having their common connection at cathode potential. When the two voltage-dividing capacitances are the plate-to-cathode and the grid-to-cathode capacitances of the tube, the circuit is known as the "ultra-audion oscillator."

coma an image defect as applied to the operation of cathode-ray tubes.

NOTE: Even in the absence of spherical aberration or astigmatism, the image of a point off the principal axis of the bundle of electron rays (beam) may not be sharp, but will assume a comet-shaped area whose vertex coincides with the first-order image point. Because of the shape of the image when this defect is present, the term "coma" is applied.

communication band Consists of the band of frequencies due to modulation necessary for a given type of modulation.

composite picture signal A signal consisting of the blanked picture signal and the synchronizing signals.

compression The reduction of the amplitude range or of the ratio of the maximum to minimum signal levels occurring between two points in a system.

constant-current modulation A method of amplitude modulation in which a constant-current source supplies a radio-frequency generator and a modulation amplifier in parallel, the variations in the current taken by the latter causing equal and opposite variations in the former, resulting in corresponding modulation of the carrier output.

continuous waves Waves whose successive oscillations are identical under steady-state conditions.

contrast The ratio between the maximum and the minimum brightness values in a picture.

NOTE: The contrast control affects both the brightness and the contrast of the picture.

controlled carrier A system of modulation wherein the carrier is amplitude-modulated by the signal frequencies and in addition the carrier is amplitude-modulated in accordance with the envelope of the signal, so that the modulation factor remains constant regardless of the amplitude of the signal.

corner reflector As used in television relay antenna installations, a reflecting object consisting of two or three mutually intersecting conducting surfaces.

corner reflector antenna An antenna consisting of a primary radiating element and a dihedral corner reflector. This type of antenna is sometimes used in television relay broadcasting.

corrective network (shaping network) An electrical network designed to be inserted in a circuit to improve its transmission properties or its impedance properties, or both.

cross neutralization A method of neutralization used in push-pull amplifiers whereby a portion of the plate-cathode a-c voltage of each tube is applied to the grid-cathode circuit of the other tube through a neutralizing capacitor.

crossfire Interfering current in one signaling channel resulting from signaling currents in another channel.

cross talk The signal that results from one channel interfering with the signal in another channel.

crystal In communication practice, the word "crystal" signifies one of the following: (1) a piezoelectric crystal; (2) a piezoelectric crystal plate; (3) a crystal rectifier. (See also *piezoelectric crystal unit; piezoelectric crystal plate; crystal rectifier.*)

crystal-controlled transmitter A radio transmitter whose carrier frequency is directly controlled by a crystal oscillator.

crystal rectifier A device in which a nonlinear circuit element is formed at a contact between a metal and a semiconductor.

crystal-stabilized transmitter A radio transmitter employing automatic frequency control in which the reference frequency is that of a crystal oscillator.

current amplification The ratio of the current produced in the output circuit of an amplifier (as a result of the current supplied to the input circuit) to the current supplied to the input circuit.

cutoff frequency The point along an amplitude versus frequency response curve at which the amplitude falls to zero, or approximately zero. It may be either a theoretical cutoff frequency or an effective cutoff frequency.

D

de-emphasis The intentional alteration (from uniform response) of either or both of the amplitude versus frequency and the phase versus frequency response characteristics to complement pre-emphasis. (See also *pre-emphasis.*)

de-emphasis network A network inserted in a system in order to restore the pre-emphasized frequency spectrum to its original form.

deflection polarity of an oscilloscope The relationship between the direction of displacement and the polarity of the applied signal wave.

deflection yoke An assembly of one or more coils, whose magnetic field deflects an electron beam.

delayed sweep A sweep of the electron beam of a cathode-ray tube in which the beginning of the sweep is delayed for a time after the pulse which initiates the sweep.

dipole antenna A straight radiator, usually fed at the center in transmission and producing a maximum of radiation in the plane normal to its axis. The length specified is the over-all length.

NOTE: Common usage considers a dipole antenna to be a metal radiating surface which supports a line-current distribution similar to that of a thin straight wire a half wavelength long and so energized that the current has two modes, one at each of the far ends.

d-c reinsertion In a video amplifying system responsive to a-c voltage only, restoration at some point in the system of the d-c video component, or its equivalent.

d-c restorer In a circuit incapable of transmitting slow variations but capable of transmitting components of higher frequency, a means by which a d-c or low-frequency component is reinserted after transmission.

d-c transmission An arrangement in which a fixed setting of the controls makes any instantaneous value of signal correspond to the same value of brightness of all times.

d-c video component That part of the television signal corresponding to the average brightness of the scene televised; the part of the signal due to the average steady background illumination of the scene being transmitted.

directional antenna An antenna radiating or receiving radio waves more effectively in some directions than in others.

directional pattern A graphical representation of the radiation or reception of the antenna as a function of direction. Cross sections in which directional patterns are frequently given are vertical planes and the horizontal plane, or the principal electric and magnetic polarization planes.

directive gain The directive gain of an antenna in a given direction is 4π times the ratio of the radiation intensity in that direction to the total power radiated by the antenna.

NOTE: The term is also applied to receiving antennas.

directivity In an antenna, the value of the directive gain in the direction of its maximum value.

director A parasitic element located in a direction of the major lobe of radiation for the purpose of increasing radiation in that direction.

dissector tube A camera tube having a continuous photocathode on which is formed a photoelectric emission pattern that is scanned by moving its electron-optical image over an aperture.

distortion A change in waveform occurring in a transducer or transmission medium. The principal sources of distortion are *nonlinear relation* between input and output at a given frequency; *nonuniform transmission* at different frequencies; *phase shift* not proportional to frequency.

dolly The mobile support for a television studio or field camera; also, the act of moving the television camera towards or away from the subject being televised.

dominant wave-guide transmission mode The mode with the lowest cutoff frequency.

NOTE: Designations for this mode are $TE_{1,0}$ and $TE_{1,1}$ for rectangular and circular wave guides, respectively.

double superheterodyne reception The method of reception in which two frequency converters are employed before final detection.

double-tuned circuit A circuit whose response is the same as that of two single-tuned circuits coupled together.

driver An electronic circuit which supplies input to another electronic circuit.

driving pulses A series of pulses of either line frequency ($1/H$) or field frequency ($1/V$) so related to other pulse components of a composite picture signal that scanning timed by these driving pulses is correctly related to other pulse components.

driving signals In television, signals that time the scanning at the pickup point.

dynatron oscillator A negative-resistance oscillator in which negative resistance is derived between plate and cathode of a screen-grid tube operating so that secondary electrons produced at the plate are attracted to the higher potential screen grid.

E

Eccles-Jordan circuit A flip-flop circuit consisting of a two-stage resistance-coupled electron-tube amplifier with its output similarly coupled back to its input, the two conditions of permanent stability being provided by the alternate biasing of the two stages beyond cutoff.

echo A wave reflected at one or more points in the transmission medium with sufficient magnitude and time difference to be perceived in some manner as a wave distinct from the wave of the main transmission.

effective area The effective area of an antenna in any direction is the square of the wavelength multiplied by the power gain (or directive gain) in that direction and divided by 4π.

effective bandwidth In a communication system, the true bandwidth divided by the number of times this bandwidth may be used again by other transmissions of the same effective bandwidth without cross talk between the various systems.

effective height (1) The height of an antenna's center of radiation above the effective ground level. (2) In low-frequency applications the term applied to loaded or nonloaded vertical antennas, being equal to the moment of current distribution in the vertical section divided by the input current.

effective percentage modulation In a single sinusoidal input component, the ratio of the peak value of the fundamental component of the envelope to the d-c component in the modulated condition expressed in per cent.

effective radiated power The product of the antenna power (transmitter output power less transmission line loss) times (a) the antenna power gain or (b) the antenna field gain squared.

electrical distance The distance traveled by radio waves in a unit of time. A convenient unit of electrical distance is the light microsecond, or about 983 feet (300 meters). In this unit the electrical distance is numerically equal to the transmission time in microseconds.

electrically connected Signifying "connected by means of a conducting path or through a capacitor" as distinguished from connection merely through electromagnetic induction.

electron-coupled oscillator An oscillator employing a multigrid tube with the cathode and two grids operating as an oscillator in any conventional manner, and having the plate circuit load coupled to the oscillator through the electron stream.

electron multiplier An electron tube in which an initial current is amplified by one or more successive stages of secondary electron emission.

electrostatic focusing A method of focusing an electron beam by the action of an electric field.

elemental area See *picture element.*

equalizing pulses In the standard television signal, pulses at twice the line frequency occurring just before and just after the vertical synchronizing pulses.
Note: The equalizing pulses minimize the effect of line-frequency pulses on the interlace.

equivalent circuit of a piezoelectric crystal unit An electric circuit having the same impedance as the unit in the frequency region of resonance. It is usually represented by an inductance, capacitance, and resistance in series, shunted by the direct capacitance between the terminals of the crystal unit.

excitation drive A signal voltage in electron-tube circuits applied to a control electrode of a vacuum tube.

expanded sweep A sweep of the electron beam of a cathode-ray tube in which the movement of the beam is speeded up during a part of the sweep.

expansion An increase in white-to-black amplitude range or frequency swing between two points in a system.

F

fading The variation of radio-field intensity caused by changes in the transmission medium.

feedback Feedback in a transmission system or section thereof is the returning of a fraction of the output to the input.

fidelity The degree to which a system, or a portion of a system, accurately reproduces at its output the essential characteristics of the signal that is impressed upon its input.

field One of the two (or more) equal parts into which a frame is divided in interlaced scanning.

field frequency The product of the frame frequency multiplied by the number of fields contained in one frame.

fixed transmitter A transmitter that is operated in a fixed or permanent location.

fixed-frequency transmitter A transmitter designed for operation on a single carrier frequency.

flip-flop circuit. A trigger circuit having two conditions of permanent stability, with means for passing from one to the other by an external stimulus.

fly-back The shorter of the two intervals of time which comprise a saw-toothed wave.

focus In the CR tube, this refers to the spot of light on the fluorescent screen. The tube is said to be focused when the spot is of smallest diameter.

focusing The process of controlling the convergence and the divergence of an electron beam.

folded dipole antenna An antenna composed of two parallel, closely spaced dipole antennas connected together at their ends with one of the dipole antennas fed at the center. It is used in both television transmission and reception.

frame The total area, occupied by the picture, which is scanned while the picture signal is not blanked.

frame frequency The number of times per second that the frame is scanned.

free-space field intensity The field intensity that would exist at a point in the absence of waves reflected from the earth or other reflecting objects.

frequency band of emission The frequency band required for a given type of transmission and speed of signaling.

frequency characteristic Sometimes used for amplitude-frequency response characteristic.

frequency divider A device delivering an output wave whose frequency is a proper fraction of the input frequency. Usually the output frequency is an integral submultiple or an integral proper fraction of the input frequency.

frequency-modulated transmitter A transmitter which transmits a frequency-modulated wave.

frequency modulation (FM) Angle modulation in which the instantaneous frequency of a sine-wave carrier is caused to depart from the carrier frequency by an amount proportional to the instantaneous value of the modulating wave.

frequency monitor An instrument for indicating the frequency deviation of a signal from its assigned value.

frequency multiplier A device delivering an output wave whose frequency is an integral multiple of the input frequency. Frequency doublers and triplers are special cases of frequency multipliers.

frequency pulling The change of the generated frequency caused by a change of load impedance of an oscillator.

frequency range of a transmission system The frequency band covering those frequencies at which the system is able to transmit power without attenuating or distorting it more than an arbitrarily specified amount.

frequency stabilization The process of controlling the center or carrier frequency so that it differs from that of a reference source by not more than a prescribed amount.

frequency swing In frequency modulation, the peak difference between the maximum and minimum values of the instantaneous frequency.

frequency tolerance of a television transmitter The extent to which the carrier frequency of a television transmitter may be permitted to depart from the frequency assigned by the licensing authority.

fringing Pertaining to the outer extremities of an area or surface.

front porch That portion of a composite picture signal at blanking level which lies between the leading edge of the horizontal blanking signal and the leading edge of the horizontal synchronizing signal.

front-to-rear ratio The ratio of the effectiveness toward the front and toward the rear of a directional antenna.

fundamental frequency The frequency of a sinusoidal component having the same period as the periodic quantity.

G

gain of an antenna The measured gain of one transmitting or receiving antenna over another is the ratio of the signal power one produces at the receiver input terminals to that produced by the other, the transmitting power level remaining fixed.

gamma The slope of the characteristic expressing the output amplitude as a function of the input amplitude, both indicated on a logarithmic scale.

gate A device used for gating.

geometric distortion Any aberration which causes the reproduced picture to be geometrically dissimilar to the perspective-plane projection of the original scene.

ghost The spurious image resulting from an echo. See also *echo*.

gradient In the subjective sense, the term gradient refers to the progressive change in tones or shades along a monochromatic scale.

grid modulation Modulation produced by the application of the modulating voltage to the control grid of any tube in which the carrier is present.

grid neutralization The method of neutralizing an amplifier in which the necessary 180-deg. phase shift is obtained by an inverting network in the grid circuit.

grounded-cathode amplifier An electron-tube amplifier with cathode at ground potential at the operating frequency, with input applied between control grid and ground and the output load connected between plate and ground.

grounded-grid amplifier An electron-tube amplifier circuit in which the control grid is at ground potential at the operating frequency, with input applied between cathode and ground and output load connected between plate and ground.

guard band A frequency band left vacant between two channels to give a margin of safety against mutual interference.

H

halation The ring of illumination which surrounds the point at which the electron beam strikes the fluorescent screen.

Hartley oscillator An electron tube oscillator in which a parallel tuned tank circuit is connected between grid and plate, the inductive element of the tank having an intermediate tap at cathode potential.

high boost Increasing the relative amplitude response of high frequencies over that of the low and middle frequencies of the video band.

high-level modulation Modulation produced at a point in a system where the power level approximates that at the output of the system.

horizontal blanking The blanking signal at the end of each line.

horizontal hold control The control which varies the free-running period of the horizontal deflection oscillator.

horizontally polarized wave A linearly polarized wave whose direction of polarization is horizontal.

I

Iconoscope A camera tube in which a high-velocity electron beam scans a photoactive mosaic which has electrical storage capacity.

Image Orthicon A television camera pickup tube in which a low-velocity beam scans a secondary emissive surface having storage capability and upon which is focused an electron image originating at a separate photoemitting surface and producing electron multiplication by secondary emission.

impulse An electric wave having a high peak value of short duration and having substantially zero value elsewhere than its peak.

impulse noise Noise characterized by transient disturbances separated in time by quiescent intervals. The frequency spectrum of these disturbances must be substantially uniform over the useful pass band of the transmission system.

induction loudspeaker A moving-conductor loudspeaker in which the moving conductor is in the form of a coil inductively coupled to the source of electrical energy.

inductive neutralization A method of neutralizing an amplifier whereby the feedback susceptance due to an interelement capacitance is canceled by the equal and opposite susceptance of an inductor.

intensity modulation. The control of the brilliance of the trace on a cathode-ray screen in accordance with the magnitude of a signal.

interference In a signal transmission path, extraneous power which tends to interfere with the reception of desired signals.

interference guard bands The two bands of frequencies additional to, and on either side of, the communication band and frequency tolerance, which may be provided in order to minimize the possibility in interference.

interlaced scanning A scanning process in which the distance from center to center of successively scanned lines is two or more times the nominal line width, and in which the adjacent lines belong to successive fields.

intermodulation The modulation of the components of a complex wave by each other, producing waves having frequencies equal to the sums and differences of integral multiples of the component frequencies of the complex wave.

intermodulation distortion That distortion due to modulation of the components of a complex wave by each other, as the result of which waves are produced that have frequencies equal to the sums and differences of integral multiples of the components of the original complex wave.

ion spot A localized deterioration of the screen of a cathode-ray tube which is caused by bombardment by heavy negative ions.

ionosphere That part of the earth's outer atmosphere where ions and electrons are present in quantities sufficient to affect the propagation of radio waves.

NOTE: According to current opinion, the lowest level of the ionosphere is approximately fifty km. above the earth's surface.

iterative impedance The iterative impedance of a transducer is that impedance which, when connected to one pair of terminals, produces a like impedance at the other pair of terminals.

NOTE: (a) It follows that the iterative impedance of a transducer is the same as the impedance measured at the input terminals when an infinite number of identically similar transducers are formed into an iterative or recurrent structure of infinite length by connecting the output terminals of the first transducer to the input terminals of the second, the output terminals of the second to the input terminals of the third, etc.

(b) The iterative impedances of a four-terminal transducer are, in general, not equal to each other but for any symmetrical transducer the iterative impedances are equal and are the same as the image impedances. The iterative impedance of a uniform line is the same as its characteristic impedance.

J

jitter Short-time instability of a signal. The instability may be in either amplitude or phase, or both. The term is applied especially to signals reproduced on the screen of a cathode-ray tube.

K

keystone distortion The keystone-shaped raster produced by scanning in a rectilinear manner with constant-amplitude saw-toothed waves a plane target area which is not normal to the average direction of the beam.

kinescope See *picture tube.*

L

level The magnitude of a quantity, especially when considered in relation to an arbitrary reference value. Level may be stated in the units in which the quantity itself is measured (volts, ohms, etc.) or in units expressing the ratio to a reference value.

light-microsecond The distance over which light travels in free space in 1 microsecond, i.e., about 983 ft. (300 m.). This distance is employed as a unit for expressing electrical distance.

line frequency The number of times per second that a fixed vertical line in the picture is crossed in one direction by the scanning spot. Scanning during vertical return intervals is not counted.

line noise Noise originating in a transmission line.

line sync Sync pulses at line frequency.

linearity The distribution of picture elements over the image field.

linearity control A control varying the distribution of scanning speed throughout the trace interval.

link In communication practice, a channel or circuit designed to be connected in tandem with other channels or circuits.

lip microphone A microphone adapted to positioning in contact with the upper lip of the mouth.

load circuit The complete circuit required to transfer power from a source, such as an electron tube, to a load.

load-circuit efficiency The ratio between useful power delivered by the load circuit to the load and the load (anode)-circuit power input.

lobe A portion of the directional pattern bounded by one or two cones of nulls.

local control A system or method of radio-transmitter control whereby the control functions are performed directly at the transmitter.

local oscillator The oscillator that produces the heterodyne frequency in a superheterodyne radio receiver.

loudspeaker An electroacoustic transducer designed to be actuated by electric waves and to produce substantially equivalent sound waves, usually for effective radiation at a distance.

loudspeaker system The combination of one or more loudspeakers and all associated baffles, horns, and dividing networks arranged to work together as a unit, comprising all of the elements interposed between the driving electrical circuit and free air.

loudspeaker voice coil The moving coil of a moving-coil loudspeaker.

low-level modulation The modulation produced at a point in a system where the power level is low compared with the power level at the output of the system.

M

magnetic focusing A method of focusing an electron beam by the action of a magnetic field.

magnetic loudspeaker A loudspeaker in which acoustic waves are produced by mechanical forces resulting from magnetic reactions.

magnetic microphone A microphone which depends for its operation on variations in the reluctance of a magnetic circuit.

magnetic yoke The assembly of pairs of horizontal and vertical deflecting coils about the neck of a cathode-ray tube, its purpose being to deflect the electron beam in the horizontal or vertical plane (or both) during the scanning process.

magnetostrictive microphone A microphone which depends for its operation on the generation of an electromotive force by the deformation of a material having magnetostrictive properties.

major lobe The lobe containing the direction of maximum radiation or reception.

matched transmission line The term applied to any transverse section of a transmission line if there is no reflected wave at that section.

maximum average output power The maximum radio-frequency output power which can occur under any combination of signals transmitted, averaged over the longest repetitive modulation cycle.

minor lobe Any lobe except the major lobe.

mixer (1) A device ordinarily consisting of one or more potentiometers for combining the audio-frequency output signals of two or more microphones or other audio-frequency signal sources in any desired proportion at the input of a main audio-frequency amplifier. (2) The stage in a heterodyne receiver in which the incoming modulated radio-frequency signal is mixed with the signal from the local oscillator to produce the intermediate-frequency signal.

modulated amplifier An amplifier stage into which the modulating signal is introduced and modulates the carrier.

modulated continuous wave A wave in which the carrier is modulated by a constant audio-frequency tone. In telegraphic service it is understood that the carrier is keyed.

modulation capability (aural transmitter) The maximum percentage modulation that can be obtained without exceeding a given distortion figure.

modulation factor In an amplitude-modulated wave, the ratio of half the difference between the maximum and minimum amplitudes to the average amplitude.

NOTE: In linear modulation the average amplitude of the envelope is equal to the amplitude of the unmodulated wave, provided there is no zero-frequency component in the modulating signal wave (as in telephony). For modulating signal waves having unequal positive and negative peaks, positive and negative modulation factors may be defined as the ratios of the maximum departures (positive and negative) of the envelope from its average value to its average value.

monochrome transmission (black and white) In television, the transmission of a signal wave which represents the brightness values in the picture, but not the chromaticity values.

monoscope A signal-generating electron-beam tube in which a picture signal is produced by scanning an electrode, parts of which have different secondary-emission characteristics.

mosaic The photosensitized target of a particular type of electron tube for image pickup used in the television camera.

moving-coil loudspeaker A moving-conductor loudspeaker in which the moving conductor is in the form of a coil conductively connected to the source of electrical energy.

moving-coil microphone A moving-conductor microphone in which the movable conductor is in the form of a coil.

moving-conductor loudspeaker A magnetic loudspeaker in which acoustic waves are produced by mechanical forces resulting from magnetic reactions between the field of the moving conductor and the steady applied field.

moving-conductor microphone A microphone in which the electrical output results from the motion of a conductor in a magnetic field.

multivibrator A form of relaxation oscillator which comprises two stages so coupled that the input of each one is derived from the output of the other.

Note: A multivibrator is termed "free running" or "driven" according to whether its frequency is determined by its own circuit constants or by an external synchronizing voltage, respectively. The name "multivibrator" was originally given to the free-running multivibrator, having been suggested by the large number of harmonics produced.

N

narrow band A band of frequencies, usually less than 300 kc. wide.

negative modulation In an AM television system, that form of modulation in which an increase in brightness corresponds to a decrease in transmitted power.

negative transmission A term meaning that a decrease in initial light intensity causes an increase in transmitted power.

negative-resistance oscillator An oscillator produced by connecting a resonant circuit to a two-terminal negative-resistance device.

Note: A dynatron oscillator and an arc converter are examples.

neutralization The method of modifying the effect of spurious feedback in an amplifier.

noise An unwanted disturbance within the useful frequency band.

noise level The value of noise integrated over a specified frequency range with a specified frequency weighting and integration time. It is expressed in decibels relative to a specified reference.

nominal line width The reciprocal of the number of lines per unit length in the direction of line progression.

nonlinear distortion That form of distortion which occurs in a system when the ratio of voltage to current using r.m.s. values (for analogous quantities in other fields) is a function of the magnitude of either.

nonlinearity The result of picture elements being either widely separated or crowded. See also *geometric distortion.*

nondirectional microphone A microphone the response of which is essentially independent of the direction of sound incidence.

number of scanning lines The ratio of line frequency to frame frequency.

O

omnidirectional antenna An antenna having essentially uniform response in azimuth and a directional pattern in elevation.

orthicon A camera tube in which a low-velocity electron beam scans a photoactive mosaic that has electric storage capacity.

overload capacity The current, voltage, or power level beyond which permanent damage occurs to the device being considered.

overload level That level at which operation ceases to be satisfactory as a result of signal distortion, overheating, damage, and so forth.

overshoot An increase in magnitude of response to a unidirectional change in input with respect to the steady-state response which would exist if the system reproduced the unidirectional change with no distortion.

P

packing The tendency for portions of the television image or picture to pack or compress in either the horizontal or vertical plane, the result of a nonlinear saw-toothed scanning wave.

parasitic oscillations Unintended self-sustaining oscillations.

pass band (1) A band of frequencies which is transmitted freely without intentional attenuation or reduction in amplitude of signals. (2) The band of frequencies being passed.

passive transducer A transducer containing no source of energy.

peak-to-peak The amplitude difference between the most positive and the most negative excursions of a signal.

peak power output The output power averaged over a carrier cycle at the maximum amplitude that can occur with any combination of signals to be transmitted.

peaking circuit A circuit used to increase the amplitude of certain frequencies over that of certain other frequencies, sometimes used as a means of correction for amplitude (and phase) deficiencies in a previous circuit.

peaking network An interstage coupling network used in a video amplifier to enhance the output at some portion of the frequency range.

pedestal level See *blanking level.*

percentage modulation The modulation factor expressed in per cent.

NOTE: It is sometimes convenient to express percentage modulation in decibels below 100 per cent modulation.

percentage sync The ratio of the difference in amplitude between sync peaks and blanking level to the difference in amplitude between sync peaks and reference white level, expressed in percentage.

phase vs. frequency response characteristic In a visual transmitter, the curve describing the phase of the visual transmitter output envelope with respect to the signal at the input terminals, as the video input frequency is changed.

phosphor A substance capable of luminescence.

photoelectric emission The phenomenon of emission of electrons by certain materials upon exposure to radiation in and near the visible region of the spectrum.

pickup (1) A device that converts a sound, scene, or other form of intelligence into corresponding electric signals (e.g., a microphone, a television camera or a phonograph pickup). (2) The minimum current, voltage, power, or other value at which a relay will complete its intended function. (3) Interference from a near-by circuit or system.

pickup tube See *camera tube*.

picture element Any segment of a scanning line the dimension of which along the line is exactly equal to the nominal line width.

picture signal The signal resulting from the scanning process.

picture-signal amplitude The difference between white peak and blanking level of the television signal.

picture transmitter See *visual transmitter*.

picture tube A cathode-ray tube used to produce an image by variation of the beam intensity as the beam scans the raster.

Pierce oscillator An oscillator produced by connecting a network having a phase shift of an odd multiple of 180 deg. per amplifier stage at the frequency of oscillation, between the output and the input of an amplifier. When the phase shift is obtained by resistance-capacitance elements the circuit is an *r-c phase-shift oscillator*.

piezoelectric crystal plate (piezoelectric crystal) A section of piezoelectric material cut and finished to specific dimensions and having two major surfaces which are essentially parallel.

piezoelectric crystal unit A complete assembly comprising a piezoelectric crystal plate mounted, housed, and adjusted to the desired frequency, with means provided for connecting it in an electric circuit. Such a device is commonly employed for purposes of frequency control, frequency measurement, electric wave filtering, or interconversion of electric waves and elastic waves.

Note: Sometimes a piezoelectric crystal unit may be an assembly having in it more than one piezoelectric crystal plate. Such an assembly is called a "multiple-crystal unit."

plate-load impedance The total impedance between anode and cathode exclusive of the electron stream.

plate efficiency The ratio of load circuit power (a-c) to the plate power input (d-c).

plate modulation Modulation produced by application of modulating voltage to the plate of any tube in which the carrier is present.

Note: Modulation in which the plate voltage contains externally generated pulses is called "plate-pulse modulation."

plate neutralization The method of neutralizing an amplifier in which the necessary 180 deg. phase shift is obtained by an inverting network in the plate circuit.

plate-power input The d-c power delivered to the plate (anode) of a vacuum tube by the source of supply. It is the product of the mean anode current and mean anode voltage.

polarity of picture signal In television, the sense of the potential of a portion of the signal representing a dark area of a scene relative to the potential of a portion of the signal representing a light area. Polarity is stated as being "black negative" or "black positive."

portable transmitter A transmitter that can be carried on a person and may or may not be operated while in motion.

NOTE: This term includes so-called "walkie-talkies," "handy-talkies," and "personal" transmitters. A portable transmitter as defined above has been called a "transportable" transmitter, but the designation "portable" is preferred.

positive modulation In an AM television system, that form of modulation in which an increase in brightness corresponds to an increase in transmitted power.

positive transmission See *positive modulation.*

power amplification The ratio of the power at the output terminals of an amplifier to that at the input terminals. It is also called "power gain."

power gain The power gain of an antenna in a given direction is 4π times the ratio of the radiation intensity in that direction to the total power delivered to the antenna.

NOTE: The term is also applied to receiving antennas.

power supply variation A term including all differences between the standard rated voltage and the frequency of the power supply, and the corresponding characteristics of the actual power supply.

pre-emphasis The intentional alteration of the normal signal wave by emphasizing one range of frequencies with respect to another.

pressure microphone A microphone that is essentially responsive to variations in pressure at one location in the sound wave.

progressive scanning A rectilinear scanning process in which the distance from center to center of successively scanned lines is equal to the nominal line width.

pulling The tendency for portions of the television picture to pull or stretch, the result of a nonlinear saw-toothed scanning wave; the opposite of packing.

pulling figure The pulling figure of an oscillator is the difference between the maximum and minimum values of the oscillator frequency when the phase angle of the load-impedance reflection coefficient varies through 360 deg., while the absolute value of this coefficient is constant and equal to 0.20.

pulse A single disturbance characterized by the rise and decay in time or space or both of a quantity whose value is normally constant.

pulse amplitude The maximum instantaneous value of a pulse.

NOTE: Spikes and ripples superimposed on the pulse are commonly considered to be separate transients, and are ignored in considering dimensions of the pulse itself.

pulse-decay time The interval of time required for the trailing edge of a pulse to decay from 90 per cent to 10 per cent of the pulse amplitude.

pulse duration The time interval between the points on the leading and trailing edges at which the instantaneous value bears a specified relation to the pulse amplitude.

NOTE: Frequently the specified relation is taken as 50 per cent.

pulse operation The method of operation in which the energy is delivered in pulses.

NOTE: It is usually described in terms of the pulse shape, the pulse duration, and the pulse-recurrence frequency.

pulse-rise time The interval of time required for the leading edge of a pulse to rise from 10 per cent to 90 per cent of the pulse amplitude.

pulse regeneration The process of restoring a series of pulses to their original timing, form, and relative magnitude.

pulse width The time duration of any single electrical wave of an impulse type measured at a specified level. In current practice the base pulse width is measured at 10 per cent of normal amplitude and the peak pulse width is measured at 90 per cent of normal amplitude.

push-pull amplifier See *balanced amplifier*.

push-pull microphone A microphone comprising two like elements which function 180 deg. out of phase.

Q

Q (quality factor) (1) A measure of the relationship between stored energy and rate of dissipation in certain types of electric elements, structures or materials. (2) In an inductor at any frequency, the magnitude of the ratio of its reactance to its effective series resistance at that frequency. (3) In a capacitor at any frequency, the magnitude of the ratio of its susceptance to its effective shunt conductance at that frequency. (4) In a simple resonant circuit comprising an inductor and a capacitor, Q is given as:

$$Q = \frac{Q_L Q_C}{Q_L + Q_C}$$

where Q_L and Q_C are the Q's of the inductor and capacitor, respectively, at the resonant frequency. If the resonant circuit comprises an inductance L and a capacitance C in series with an effective resistance R, the value of Q is

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

An approximately equivalent definition, which can be applied to other types of resonant structures, is that the Q is the ratio of the resonant frequency to the bandwidth between those frequencies on opposite sides of the resonant frequency where the response of the resonant structure differs by 3 db. from that at resonance.

In a magnetic or dielectric material at any frequency, Q is equal to 2π times the ratio of the total stored energy to the energy dissipated in the material per cycle.

R

radiating element A basic subdivision of an antenna which in itself is capable of radiating or receiving radio-frequency energy.

radiation resistance The quotient of the power radiated by an antenna divided by the square of the effective antenna current referred to a specified point.

radio communication circuit A radio system for carrying out one communication at a time in either direction between two points.

radio field intensity The electric or magnetic field intensity at a given location associated with the passage of radio waves. It is commonly expressed in terms of the electric field intensity, in microvolts, millivolts, or volts per meter. In the case of a sinusoidal wave, the r.m.s. value is commonly stated. Unless otherwise stated, it is taken in the direction of maximum field intensity.

radio frequency A frequency used for radio transmission.

NOTE: The present practicable limits of radio frequency are roughly 10 kc. per sec. to 100,000 mc. per sec.

radio relay system A point-to-point radio transmission system in which the signals are received and retransmitted by one or more intermediate radio stations.

radio-wave propagation The transfer of energy by electromagnetic radiation at frequencies lower than about 3×10^{12} c.p.s.

rain In television, the irregular fall of multitudinous secondary electrons upon the photosensitized target or mosaic of an electron tube for image pickup, resulting in the production of a spurious shading signal which must be compensated for.

random (or fluctuation) noise Noise characterized by a large number of overlapping transient disturbances occurring at random.

raster A predetermined pattern of scanning lines which provides substantially uniform coverage of an area.

rated power supply In television, the rated power supply of the transmitter is described by specifying the voltage, the number of phases, and the frequency of the supply with which the transmitter shall be required to meet all applicable standards of performance for such apparatus (F.C.C., R.M.A., and I.R.E.).

rectilinear scanning In television, the process of scanning an area in a predetermined sequence of narrow, straight parallel strips.

reference black level The level at the point of observation corresponding to the specified maximum excursion of the picture signal in the black direction.

reference white level The level in the television signal that corresponds to the maximum permissible excursion of the instantaneous picture in the white direction.

reflection factor Between two impedances Z_1 and Z_2 the reflection factor is

$$\frac{\sqrt{4Z_1Z_2}}{Z_1 + Z_2}$$

reflection loss For a given frequency at the junction of a source of power and a load, the reflection loss is equivalent to

$$20 \log_{10} \frac{Z_1 + Z_2}{\sqrt{4Z_1Z_2}} \text{ db.}$$

where Z_1 is the impedance of the source of power and Z_2 is the impedance of the load. Physically, the reflection loss is the ratio, expressed in decibels, of the scalar values of the volt-amperes delivered to the load to the volt-amperes that would be delivered to a load of the same impedance as the source. The reflection loss is equal to the number of decibels which corresponds so the scalar value of the reciprocal of the reflection factor.

NOTE: When the two impedances have opposite phases and appropriate magnitudes, a reflection gain may be obtained.

reflector A parasitic element located in a direction other than the general direction of the major lobe of radiation or reception, applied to TV antennas.

regulation of output In a visual transmitter, the change in peak signal and amplitude with the change in brightness of the transmitted picture.

remote control A system or method of radio-transmitter control whereby the control functions are performed from a distance, electrically, over intervening wire or radio circuits.

RC coupling Coupling between two circuits, usually amplifier stages, by means of a combination of resistive and capacitive elements.

RC oscillator An oscillator in which the frequency is determined by resistive and capacitive elements.

resolution In communication, (1) the act of deriving from a sound, scene, or other form of intelligence, a series of discrete elements wherefrom the original may subsequently be synthesized; or (2) the degree to which nearly equal values of a quantity can be discriminated.

resonant mode A component of the response of a linear device which is characterized by a certain field pattern, and which when not coupled to other modes is representable as a single-tuned circuit.

NOTE: When modes are coupled together, the combined behavior is similar to that of the corresponding single-tuned circuits correspondingly coupled.

response A quantitative expression of the output of a device or system as a function of the input under conditions which must be explicitly stated. The response characteristic often gives the response as a function of some variable, such as frequency or direction.

retrace interval See *return interval*.

return interval The interval corresponding to the direction of sweep not used for delineation.

return trace The path of the scanning spot during the return interval.

rhombic antenna A directional antenna composed of long wire radiators comprising the sides of a rhombus, the two halves of the rhombus being fed equally in opposite phase at an apex.

ribbon microphone A moving-conductor microphone in which the moving conductor is in the form of a ribbon which serves also as the moving acoustic element.

S

saw-toothed wave A periodic wave whose amplitude varies, substantially linearly with time, between two values, the interval required for one direction of progress being longer than that of the other.

scanning In television, the process of analyzing or synthesizing successively according to a predetermined method the light values of picture elements constituting a picture area.

scanning line A single continuous narrow strip which is determined by the process of scanning.

NOTE: In most television systems, the scanning lines which occur during the return intervals are blanked.

scanning linearity The uniformity of scanning speed during the trace interval.

scanning spot The area with which the scanned area is being explored at any instant in the scanning process.

scanning yoke See *deflection yoke.*

screen-grid modulation Modulation produced by application of the modulating voltage to the screen grid of any multigrid tube in which the carrier is present.

selective fading Fading which affects the components of a modulated wave unequally so as to cause distortion.

service area In television broadcasting the area resulting from an assigned effective radiated power and antenna height above average terrain, i.e., the area in square miles effectively served by the station's signal.

setup The ratio of the difference between reference black level and blanking level to the difference between reference white level and blanking level, usually expressed in per cent.

shading In television, the process of compensating for the spurious signal generated in a camera tube during the trace intervals.

shield wire A wire employed for the purpose of reducing the effects on electric supply or communication circuits of electromagnetic fields from extraneous sources.

side band A band of frequencies on either side of the carrier frequency produced by the process of modulation.

sine-wave response Sometimes used for amplitude-frequency response characteristic.

single-ended amplifier An amplifier in which each stage normally employs only one tube; or, if more than one tube is used, they are connected in parallel so that operation is asymmetric with respect to ground.

signal-to-noise ratio. The ratio of the value of the signal to that of the noise.

NOTE: This ratio is usually expressed in terms of peak values in the case of impulse noise, and in terms of the r.m.s. values in the case of random noise. When there is a possibility of ambiguity, suitable definitions of the signal and noise should be associated with the term, as, for example, peak signal to peak noise ratio, etc.

single-shot blocking oscillator A blocking oscillator modified to operate as a single-shot trigger circuit.

single-shot multivibrator A multivibrator modified to operate as a single-shot trigger circuit.

single-shot trigger circuit A trigger circuit in which a triggering pulse initiates one complete cycle of conditions ending with a stable condition.

single-tuned circuit A circuit which may be represented by a single inductance and a single capacitance, together with associated resistances.

slop-over The result of increasing the amplitude of either the horizontal or vertical saw-toothed scanning wave, or both, the effect being to make the picture "slop-over" into the region of blanking.

slug tuning A means of varying the frequency of a resonant circuit by introducing a slug of material into either the electric or magnetic fields or both.

snow Small particles observed throughout the entire picture raster in the presence of a picture signal and resembling snow, the result of extraneous random-noise voltages reaching the modulating electrode of the picture tube.

spectrum In a wave, the distribution of the amplitude (and sometimes phase) of the components of the wave as a function of frequency. Spectrum is also used to signify a continuous range of frequencies, usually wide in extent, within which waves have some specified common characteristic.

spherical aberration See aberration.

spike A transient of short duration, comprising part of a pulse, during which the amplitude considerably exceeds the average amplitude of the pulse.

stage efficiency The ratio of useful power delivered to the load (a-c) to the plate input power (d-c).

standard aural-transmitter input signal The aural portion of a composite television signal, having a level of 10 dbm. plus or minus 2 dbm.

standard composite picture signal A composite picture signal having a waveform specified in the R.M.A. Sub-Committee on Studio Facilities Drawing entitled "Picture Line Amplifier Standard Output," revised Oct. 9, 1946.

standard picture-line amplifier output signal A signal conforming in amplitude and wave shape to the R.M.A. Sub-Committee on Studio Facilities Drawing entitled "Picture Line Amplifier Standard Output," revised Oct. 9, 1946.

standard television signal A signal which conforms to the television transmission standards.

standard visual-transmitter input signal A composite picture signal having a waveform specified in the R.M.A. Sub-Committee on Studio Facilities Drawing entitled "Picture Line Amplifier Standard Output," revised Oct. 9, 1946 (0.250–0.625 volts).

standing wave ratio The ratio of the amplitude of a standing wave at an antinode to the amplitude at a node.

studio equipment (studio facility) That portion of the television system utilized to convert program information to corresponding visual and aural signals.

sweep A steady change in the value of a quantity in order to delineate a characteristic. Examples of swept quantities are the displacement of a scanning spot on the screen of a cathode-ray tube and the frequency of a wave.

sweeps A term that has come into common usage to describe the deflecting potentials.

sync compression The reduction in the percentage sync resulting from a reduction in the relative sync amplitude.

NOTE: Sync compression is normally compensated for by means of a device known as a "sync stretcher." There are several types of such equipment commercially available.

synchronizing of images The maintaining of the time, and thus space, relations between parts of the transmitted and reproduced pictures.

synchronizing level The level of the peaks of the synchronizing signal.

synchronizing potentials The signals employed for the synchronizing of transient visual images.

synchronizing signal amplitude The difference between synchronizing level and blanking level.

synchronizing signals In television, the signals employed for the synchronizing of scanning.

T

tank circuit A parallel resonant circuit connected in the plate circuit of an electron-tube generator.

television The electrical transmission and reception of transient visual images.

television broadcast band In the United States the band containing those frequencies which are assignable by the F.C.C. to television broadcast stations (54 to 216 mc.).

television broadcast signal A combination of two radio frequency carriers spaced by 4.5 mc. per sec., the lower one being amplitude-modulated by a standard composite picture signal, the upper one being frequency-modulated by the accompanying audio signal.

television broadcast station A radio station for transmitting visual signals and usually simultaneous aural signals for general reception.

television receiver A receiver for converting incoming electric signals into television pictures and customarily associated sound.

television relay input signals The signals available on separate circuits and consisting of a standard composite picture signal and, optionally, the accompanying audio, auxiliary, and control signals.

television relay signal A radio-frequency wave modulated primarily by a composite picture signal. It may or may not include the accompanying audio, auxiliary, and control signals.

television transmission standards The standards which determine the characteristics of the television signal as radiated by a television broadcast station, and, in the United States, as set forth in the "Standards of Good Engineering Practice concerning TV Broadcast Stations" as promulgated by the F.C.C.

television transmitter The radio-frequency and modulating equipment for transmitting modulated radio-frequency power representing a complete television signal (including audio, video, and synchronizing signals).

theoretical cutoff frequency In an electrical structure, a frequency at which, disregarding the effects of dissipation, the image-attenuation constant changes from zero to a positive value or vice versa.

throat microphone A microphone normally actuated by mechanical contact with the throat.

time constant of fall The time required for a pulse to fall from 70.7 to 26 per cent of its maximum amplitude excluding spike.

time constant of rise The time constant of rise of a pulse is the time required for the pulse to rise from 26 to 70.7 per cent of its maximum amplitude excluding spike.

time of rise The duration on a time scale of the nearly vertical portion of a signal measured between arbitrary level points.

tip side (tip wire) That conductor of a circuit which is associated with the tip of a plug, or the tip spring of a jack. Video lines now receive and in turn furnish "black negative" on the tip.

trace interval The interval corresponding to the direction of sweep used for delineation.

transducer A device capable of being actuated by waves from one or more transmission systems or mediums and of supplying continuously related waves to one or more other transmission systems or mediums.

NOTE: The waves in either input or output may be of any type (e.g., electrical, mechanical, or acoustical).

transition time The time required for the waveform to progress from 10 to 90 per cent of the final steady-state amplitude.

transitron oscillator A negative-transconductance oscillator employing a screen-grid tube with negative transconductance produced by a retarding field between the negative screen grid and the control grid which serves as the anode.

transmission mode A form of propagation along a transmission line characterized by the presence of any one of the elemental types of TE or TM or TEM waves.

NOTE: Wave-guide transmission modes are designated by integers (modal numbers) associated with the orthogonal functions used to describe the waveform. These integers are known as "wave-guide mode subscripts." They may be assigned from observations of the transverse field components of the wave and without reference to mathematics. A wave-guide transmission mode is commonly described as a $TE_{m,n}$ or $TM_{m,n}$ mode, the subscripts $_{m,n}$ being numerics according to the following system:

(a) *Waves in Rectangular Wave Guides.* If a single wave is transmitted in a rectangular wave guide, the field that is everywhere transverse may be resolved into two components parallel to the wide and narrow walls, respectively. In any transverse section, these components vary periodically with distance along a path parallel to one of the walls.

Thus, m = the total number of half-period variations of either components of field along a path parallel to the wide walls.

n = the total number of half-period variations of either component of field along a path parallel to the narrow walls.

(b) *Waves in Circular Wave Guides.* If a single wave is transmitted in a circular wave guide, the transverse field may be resolved into two components, radial and angular, respectively. These components vary periodically along a circular path concentric with the wall and vary in a manner related to the Bessel function of order m along a radius,

where m = the total number of full-period variations of either component of field along a circular path concentric with the wall.

n = one more than the total number of reversals of sign of either component of field along a radial path.

This system can be used only if the observed waveform is known to correspond to a single mode.

transmission system In communication practice, an assembly of elements capable of functioning together to transmit signal waves.

transfer characteristic That function of the input magnitude which expresses the output magnitude. Transfer characteristic has also been defined as the relation between the brightness of portions of the televised subject to the brightness of the same portions of the reproduced image, plotted to logarithmic scale.

transmission band The band of frequencies utilized for transmitting information electrically.

transmission line A material structure forming a continuous path from one place to another for directing the transmission of electromagnetic energy along this path.

transmission time The absolute time interval from transmission to reception of a signal.

transmitter input level for rated modulation The peak-to-peak voltage required at the input terminals to modulate the transmitter in accordance with the F.C.C. Standards of Good Engineering Practice concerning TV Broadcast Stations (U.S.A.).

transmitter input polarity The polarity of a picture signal determined by the potential of a portion of the signal representing a dark area of a scene relative to the potential of a portion of the signal representing a light area. For convenience, polarity will be given in terms of the black direction of the signal, such as "black negative" or its opposite "black positive."

transverse electromagnetic wave An electromagnetic wave in which both the electric and magnetic fields are everywhere transverse to the direction of propagation.

trigger circuit A circuit that has two conditions of stability, with means for passing from one to the other when certain conditions are satisfied, either spontaneously or through application of an external stimulus.

troposphere That part of the earth's atmosphere in which temperature generally decreases with altitude, clouds form, and convection is active.

NOTE: Experiments indicate that the troposphere occupies the space above the earth's surface to a height of about 10 km.

tuned-grid oscillator An oscillator whose frequency is determined by a parallel-resonant circuit in the grid circuit coupled to the plate to provide the required feedback.

tuned-grid tuned-plate oscillator An oscillator having parallel-resonant circuits in both plate and grid circuits, the necessary feedback being obtained by the plate-to-grid interelectrode capacitance.

tuned-plate oscillator An oscillator whose frequency is determined by a parallel-resonant circuit in the plate circuit coupled to the grid to provide the required feedback.

turnstile antenna The combination of two dipole antennas normal to each other with their axes intersecting at their mid-points. Usually the currents are equal and in phase quadrature. In the super-turnstile antenna, the pairs of dipoles are stacked and so phased as to increase the gain of the array.

turret The rotatable plate at the front of the television camera into which the camera lenses are physically inserted.

U

underthrow distortion The distortion resulting when the maximum amplitude of the signal-wave front is less than the steady-state amplitude which would be attained by a prolonged signal wave.

unidirectional antenna An antenna having a single well-defined direction of maximum radiation intensity.

velocity microphone A microphone that is essentially responsive to the particle velocity resulting from the propagation of a sound wave through an acoustic medium.

vertical hold control The control which varies the free-running period of the vertical deflection generator or oscillator.

vestigial sideband The transmitted portion of the sideband that has been largely suppressed by a transducer (in certain types of transmitting equipments) having a gradual cutoff in the neighborhood of the carrier frequency, the other sideband being transmitted without much suppression.

vestigial-sideband transmission That method of signal transmission in which one normal sideband and the corresponding vestigial sideband are utilized.

video A term pertaining to the bandwidth and spectrum position of the signal resulting from television scanning.

video frequency band The band of frequencies into which the video signal can be resolved.

video signal A signal resulting from television scanning; or, by extension, any signal of the pulse type which covers approximately the same frequency range.

viewfinder An auxiliary optical or electronic device attached to a television camera which enables the operator to see the scene as the camera sees it.

visual frequency The frequency of the visual carrier of the television transmitter.

visual signal A radio-frequency carrier wave modulated by a composite picture signal.

visual transmitter The radio equipment for the transmission of the visual signals only.

visual-transmitter power The peak power output when transmitting a standard television signal.

voltage amplification The ratio of the voltage produced at the output terminals of an amplifier, as a result of the voltage impressed at the input, to the voltage impressed at the output.

volume-limiting amplifier An amplifier containing an automatic device which maintains the output volume substantially constant when the input volume exceeds a predetermined level.

W

wave antenna A directional antenna composed of a system of parallel, horizontal conductors from a half to several wavelengths long and terminated to ground at the far end in its characteristic impedance.

white compression Compression in the signals corresponding to the white regions of the picture, thus modifying the tonal gradient.

white peak The maximum excursion of the picture signal in the white direction at the time of observation.

white saturation Distortion of the picture signal consisting of extreme compression of the whitest range, usually the result of the amplitude of the picture signal exceeding the reference white level. White saturation has also been defined as the undesirable compression in the apparent brightness of gray shades near white in the television picture which results in a low physiological discrimination between those shades when the picture is viewed.

Z

zoom The act of rapidly changing the physical position of the television camera or camera lens with reference to the fixed subject being televised, or the simulation of the effect of this act by other means.

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