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Antennas for Television Broadcast

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Television broadcast antennas presently operate at the following frequencies:

Channels 2 to 6, 54 to 88 MHz
Channels 7 to 13, 174 to 216 MHz
Channels 14 to 83, 470 to 890 MHz

Television antennas are unique with respect to several characteristics. Since each channel is 6 MHz in width, the antenna must have the proper performance characteristics over this band. Since higher gain antennas are used, especially at the higher frequencies, the vertical pattern must be suitable for the population distribution in the vicinity of the antenna so as to provide adequate field strength for television service.

Definition of Antennas

An antenna is defined as a structure associated with the transition between a guided wave such as may exist in a transmission line and a free-space wave. Such a structure usually consists of radiating elements and means for distributing the energy to these elements.

Antenna Terminals

The antenna terminal is defined as an accessible point where the entire antenna including the distribution system terminates into one[1] feed[2] line at the design characteristic impedance.

Broadcast-Antenna Requirements

Azimuthal Pattern

Definition. An azimuthal pattern is a plot of the free-space radiated field intensity versus azimuth at a specified vertical angle with respect to a horizontal plane (relative to smooth earth) passing through the center of the antenna.

A horizontal pattern is an azimuthal pattern when the specified vertical angle is zero.

For many higher gain antennas where beam tilt is employed, the azimuthal pattern at the specified beam tilt is significant. In general it has been customary to determine television broadcast-antenna radiation by an azimuthal pattern at the specified beam tilt and a sufficient number of vertical plane patterns all taken at various frequencies in the channel.

An omnidirectional antenna is defined as one that is designed to be omnidirectional. Antennas with variations up to ±3 dB have rendered satisfactory service and are considered to be omnidirectional.

A directional antenna is one which is designed to be directional.

Present FCC Standards have limited the maximum to minimum radiation at 10 dB for Channels 2-13, and 15 dB for Channels 14-83.

Vertical Pattern

Definition. A vertical pattern is a plot of free space radiated field intensity measured in the Fraunhofer region versus vertical angle in any specified vertical plane which contains the center of the antenna and the center of the earth.

The Fraunhofer region,[3] or "far field," as usually defined extends beyond a point where the distance between the transmitting and receiving point is $2a^2/\lambda$, where a is the length of the radiating portion of the antenna and λ is the wavelength.

Requirement for broadcast service. A free-space radiated field should not be influenced by the proximity of the earth in such a way as to set up a nonuniform field over the antenna aperture, and proper precautions must be taken to accomplish this.

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[1] Or two lines for a quadrature system.

[2] In accordance with Electronics Industries Association Standards.

[3] Kraus, "Antennas," Sec. 1-2.

Gain

Definition. Gain[4] is the ratio of the maximum[5] power flow per unit solid angle from the subject antenna to the maximum power flow from a thin, lossless, half-wave, horizontally polarized dipole[6] having the same power input when the measurements are made in the Fraunhofer region.

As can be seen from the above, gain depends on several factors.

1. The amount of power concentrated in the maximum direction
2. Losses in the antenna, which include ohmic and other losses such as energy radiated at polarizations other than the desired one

The amount of power concentrated in the maximum direction can be determined by a comparison with a reference antenna[7] or by integrating the total power flow through a sphere,[8] which is done by taking a sufficient number of vertical patterns and an azimuthal pattern.

Both methods are capable of giving accurate results when the proper precautions are taken.

Ohmic losses are taken into account in the comparison method or can be calculated when using the power integration method. Cross-polarized radiated energy can be measured.

The measurement of gain must be carefully done with a full knowledge of all the problems that are involved.

Gain Requirements. Gain requirements for a television broadcast antenna depend on transmitter power, economics, and field-strength requirements as determined by the terrain and population distribution.

Transmitter Power. The maximum effective radiated powers currently permitted by FCC are:

Channels 2 to 6, 100 kw
Channels 7 to 13, 316 kw
Channels 14 to 83, 5,000 kw

For the most popular transmitter sizes in each range, the following gains are needed allowing 75 percent transmission-line efficiency:

Channels 2 to 6, 4 to 6
Channels 7 to 13, 12 to 18
Channels 14 to 83, 25 to 60

Economics. Economics is a factor in antenna choice. As a general rule, combined costs of transmitters and antennas are less to achieve a given effective radiated power when a higher gain antenna is used. This is true until unsupported antenna heights are of the order of 200 ft., where structural considerations cause antenna costs to go up rapidly.

Input Impedance

Input impedance is the complex impedance looking into the antenna terminals throughout the television channel.

Most antennas are designed for the same input impedance as the standard transmission line at the antenna terminal. Impedance-matching requirements for television antennas are generally more severe than for other types to avoid reflected energy which would cause an echo or ghost in the picture when the antenna does not terminate the line properly.

ANTENNA SPECIFICATION CONSIDERATIONS

An antenna specification should assure the purchaser that all of the important parameters such as gain, pattern requirements, and impedance are in accordance with the best state of the art, but, at the same time, not so unduly restrictive that cost becomes excessive without any improvement in actual performance. Specifications are a basic requirement for governmental agencies which must buy on a bid basis but are not usually required for commercial stations where the selection is often made on the basis of other considerations. The specification can be summarized on a sheet such as shown on Fig. 1.

General Comments Relating to Specifications

Gain

In achieving the given effective radiated power required to serve the area under consideration, there is a choice between using a low power transmitter and a high gain antenna or vice-versa.

For VHF antennas, the transmitter power to antenna gain ratios are fairly well established. For Channels 2-6, antennas usually use gain values from about 4 to 6 depending upon the length of the transmission line run. For the Channels 7-13 band gain values vary from 12 to 18 depending upon the transmitter power and the length of the transmission line run. For UHF antennas, it is economically not feasible to use low gain antennas such as are used for VHF, for several reasons:

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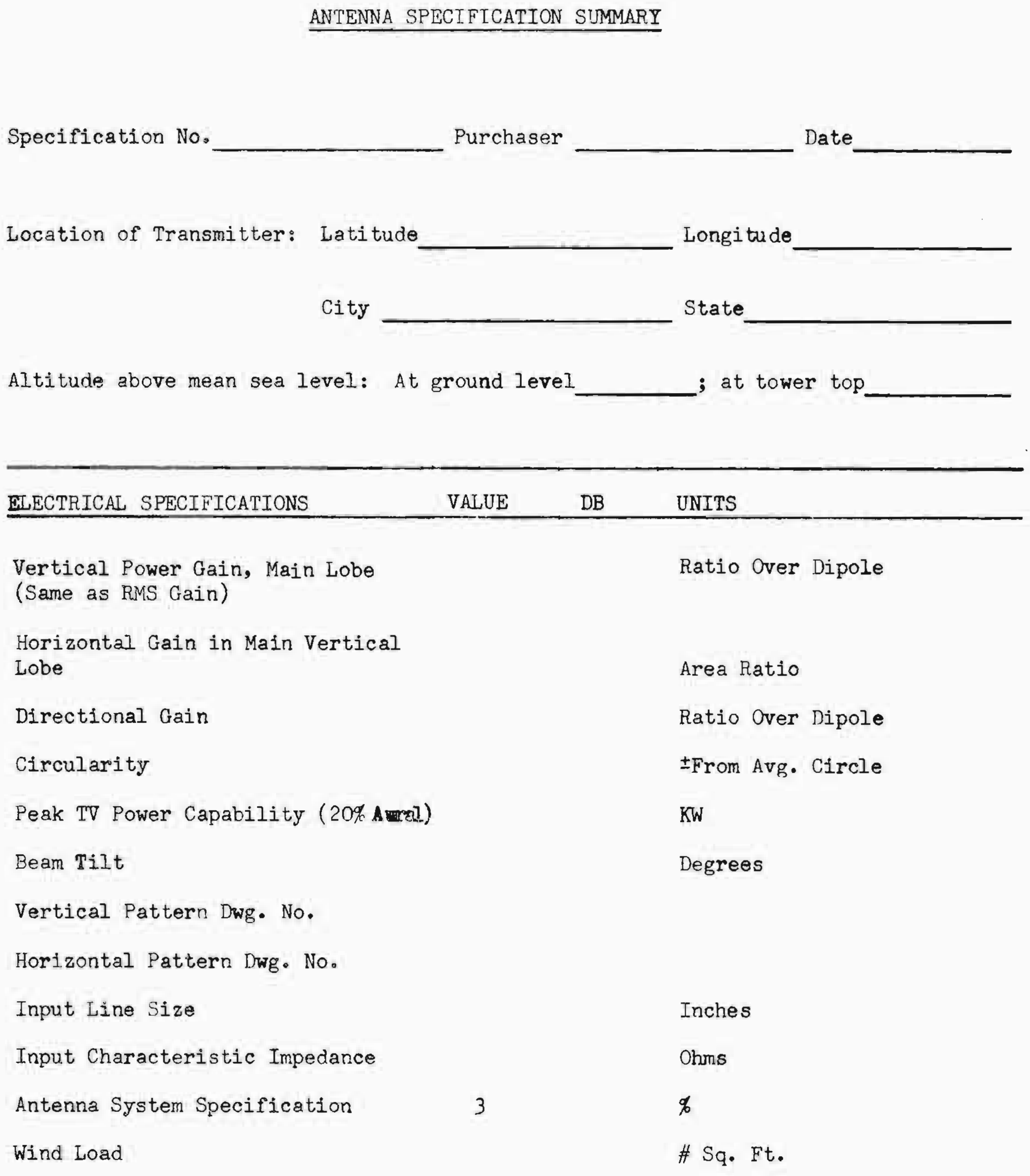
[4] *Ibid.*, Sec. 2.

[5] "Maximum" refers to the maximum in the vertical plane. For an omnidirectional antenna these maxima must be averaged for a number of vertical patterns taken at various azimuths.

[6] The directivity of a ½ wavelength dipole antenna over an isotopic antenna is 1.64.

[7] "IRE Standards," Antennas, Methods of Testing. C.C. Cutler, A.P. King, and W.E. Kock, Microwave Antenna Measurements, *Proc. IRE,* vol. 35, pp. 1462–1471, December, 1947.

[8] E.H. Shively and L.D. Wetzel, Pattern Measurements of RCA UHF TV Antennas, *Broadcast News,* vol. 82, pp. 14–21, February, 1955.



ANTENNA SPECIFICATION SUMMARY

Specification No.________ Purchaser ________ Date________

Location of Transmitter: Latitude________ Longitude________

City ________ State________

Altitude above mean sea level: At ground level________; at tower top________

ELECTRICAL SPECIFICATIONS	VALUE	DB	UNITS
Vertical Power Gain, Main Lobe (Same as RMS Gain)			Ratio Over Dipole
Horizontal Gain in Main Vertical Lobe			Area Ratio
Directional Gain			Ratio Over Dipole
Circularity			±From Avg. Circle
Peak TV Power Capability (20% Aural)			KW
Beam Tilt			Degrees
Vertical Pattern Dwg. No.			
Horizontal Pattern Dwg. No.			
Input Line Size			Inches
Input Characteristic Impedance			Ohms
Antenna System Specification	3		%
Wind Load			# Sq. Ft.

Fig. 1. Antenna specification summary for bid requests.

1. The ERP values permitted are higher in order to compete with VHF performance.

2. Transmitters must therefore generate higher powers and are therefore more costly.

3. However, the antenna gain must also be increased since otherwise the cost of the transmitter would be excessive. Hence, vertical gains of the order of 25 to 60 are used. It is feasible to do this since the mechanical structures are of a reasonable height because of the shorter wavelength.

However, the higher gain requires some special considerations since the higher gain results from narrowing the main beam. For a given transmitter input, the high gain antenna may sacrifice local coverage for more distant coverage, see Fig. 2.

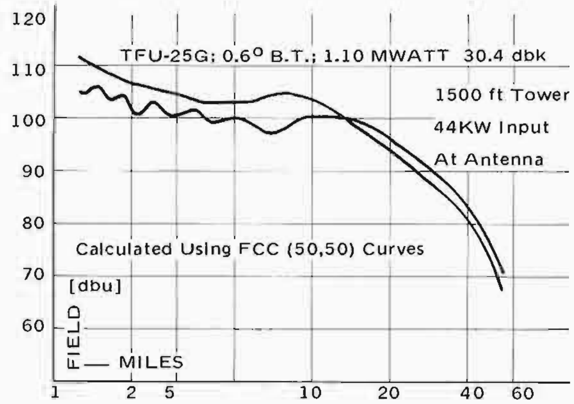


Fig. 2. Comparison of high and medium gain antenna performance with the same power input. Note the reduction in local coverage. For the same ERP raise the TFU 25G curve by 2.6 dB.

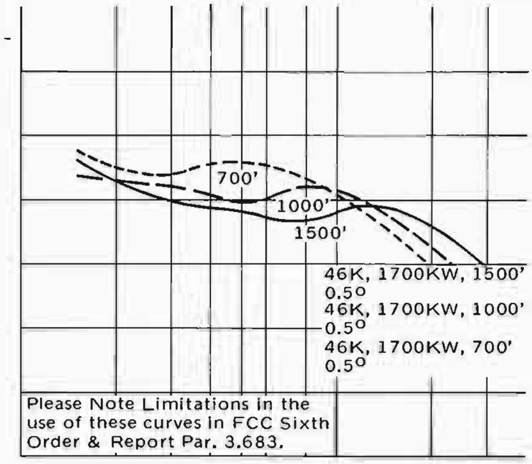


Fig. 3. Comparison of the same antenna, and the same ERP at a height of 700, 1000, and 1500 feet. Note the reduction of local coverage with an increase in height.

Hence, if a higher gain antenna is contemplated, local field strengths should be calculated, using the FCC (50,50) propagation curves. It is generally advisable to maintain a 100-dB level over the important local area to be covered. Most vertical patterns are designed to accomplish this with an effective radiated power of the order of 1 megawatt at a 1,000 ft. In hilly terrain it may be desirable to increase this figure by 10 dB or more and in heavy populated cities with large structures by 6 dB or more.

If fields of this order cannot be achieved with a high gain antenna, the transmitter power should be increased to achieve it, or a lower gain antenna used.

An increase in height over terrain has the same general effect as increasing the gain of an antenna. For distant areas within line of sight covered by the main beam of the antenna the field strength in millivolts per meter for a given ERP increases approximately as the height over smooth terrain. However, the nearby areas generally receive less field strength since the vertical angle looking up towards the antenna is steeper to a point where the vertical pattern usually radiates less energy. See Fig. 3 comparing a 46 gain antenna at three heights. Hence, an increase in height should be studied in the same manner as an increase in gain.

Beam Tilt

Beam tilt is necessary to bring the main vertical beam tangential to the earth, which is curving away from it. To accomplish this for a 1000 foot elevation a beam tilt of about 0.5° is required. The beam tilt for other heights can be calculated from the relationship:

$$\text{Beam tilt angle} = .0153\sqrt{\text{height over service area}}$$

It should be noted that height over the service area may not necessarily be the height over average terrain especially in a mountainous area. Also if a body of water limits the service area, as in the case of Los Angeles, with the transmitter on Mt. Wilson, it may be desirable to aim the main beam to a point somewhat short of the coast line.

In some cases, a little higher beam tilt may be desirable to improve local coverage. Beam tilt does reduce the vertical power gain in the horizontal direction especially for a higher gain antenna. However, the loss in local coverage is generally a more important consideration than vertical power gain in the horizontal direction.

Power Capability

Power in TV systems is usually in terms of "Peak TV Power," which is the instantaneous power developed in the peak of the synchronizing pulse of the visual transmitter. Since the black level signal is 0.75 of the total voltage value of the pulse, the black level power (for a totally black picture) is 0.75^2 or 0.5625. The duty cycle of the synchronizing pulses, both horizontal and vertical, adds about 4 percent to this power so that black level power is 0.6 of the peak TV power. Since the aural FM transmitter is usually 0.2 of the peak TV power, the total heating or CW power in a TV signal is 0.8 of the peak TV power.

Transmission line powers are usually quoted in terms of CW power for unity VSWR values, unless otherwise specified and would, hence, require a power capability of 0.8 of the peak TV power for the conditions stated.

Antenna power ratings are also in terms of peak TV power including the 0.2 aural power. The antenna power rating also makes an allowance for the VSWR which is likely to be encountered inside the antenna.

Hence, a 110-kw antenna power rating would mean that the antenna could take the full output of a 110-kw visual transmitter including the 0.2 aural power. Actually the long transmission lines usually encountered in TV service attenuate this power to a lower value so that for an 80 percent line efficiency, the antenna requirement would be only 88 kw for a 110-kw transmitter.

Vertical Patterns

The vertical pattern is usually shown as a plot on rectangular coordinate paper of relative voltage versus depression angle below the horizontal (see Fig. 4).

The angular width of the main beam of the antenna is directly related to the gain although this may vary somewhat with the method of pattern synthesis. For most null-filled antennas, the beam width at the half power or 0.707 voltage point is 58.3 divided by the gain for 0° beam tilt and no null fill. Thus for a vertical gain of 24, it would be about 2.4° and for a gain of 42, it would be about 1.4°.

Hence, the specified gain generally determines the shape of the main beam. The amount of fill at greater depression angles than the main beam can be varied within limits although this will also decrease the gain. The greater the fill, the lower the gain. These relationships can be seen from the patterns Fig. 4 and the table below where the same number of layers for a given beam tilt will have gains and values of fill as follows:

Fill Value for Null No. in Percentages

Gain	*1*	*2*	*3*
34.7	11	1	2
31.6	15	6	5
30.0	21	7.5	6
22.5	39	17	10

The amount of null fill and the number of nulls that need to be filled depends upon how close the populated area is to the transmitter site. Allowance should of course be made for population movement towards the site in the future. The depression angle below the horizontal, which requires null fill, can be calculated approximately by the following relationship:

$$\text{Depression angle in degrees} = \frac{.0109 \times \text{height of antenna in feet over service area}}{\text{miles to nearest population.}}$$

If the angle is less than 3°, regular curves or tables which appear in manufacturer catalogues should be used because they allow for the earth's curvature. If it is more than 15°, the tangent of the angle should be used. If the transmitter site is in the center of the population area or right on the edge of it, consideration should be given to a "shaped" pattern of the types shown in Fig. 5 which will provide fill to fairly steep angles which is not necessarily true for a null-filled pattern. The "shaped" pattern is somewhat higher in cost.

Horizontal Pattern

Most omnidirectional antennas have a circular pattern with a "circularity" of the order of ±1 to ±2 dB.

A directional antenna is advisable only for special terrain situations, such as the San Joaquin Valley in California, or where the antenna is located near a large body of water, or where the service areas are at certain separated locations. It must be recognized that the number of square miles over which a given field strength is obtained is always less with a directional antenna. The most optimum condition in this regard is an omnidirectional antenna located in the center of the area to be served. This can be seen from the following considerations:

Some relative approximate relationships can be deduced from propagation formulas which pertain within the radio horizon over plane earth as follows:

$$r \propto \sqrt[4]{p}$$

$$A \propto \sqrt{p}$$

$$P \propto \sqrt{h}^{2}$$

Where r is the distance to a given field contour; p is the "effective radiated power" in the main beam;[9] A is the area served within a given field contour; h is the height of the antenna above the service area.

In Fig. 6 the area enclosed by a given field intensity contour for a relative "effective radiated power" of "1" and a relative height of "1" is πr^2. The transmitting site can also be moved to the perimeter of the circle and a directional antenna employed which has a horizontal pattern in the shape of a quarter of a circle as shown in Fig. 6b. The horizontal gain of such an antenna is four, hence, $P = 4$.

From the relationship above $r \propto \sqrt[4]{p}$, r becomes the $\sqrt{2}$. The area to the same field intensity contour served is then:

$$A = \frac{\pi(\sqrt{2r})^2}{4} = \frac{\pi r^2}{2}$$

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[9] The value here used is not only the product of transmitter power and antenna gain, but also the increase in "effective radiated power" due to an increase in height.

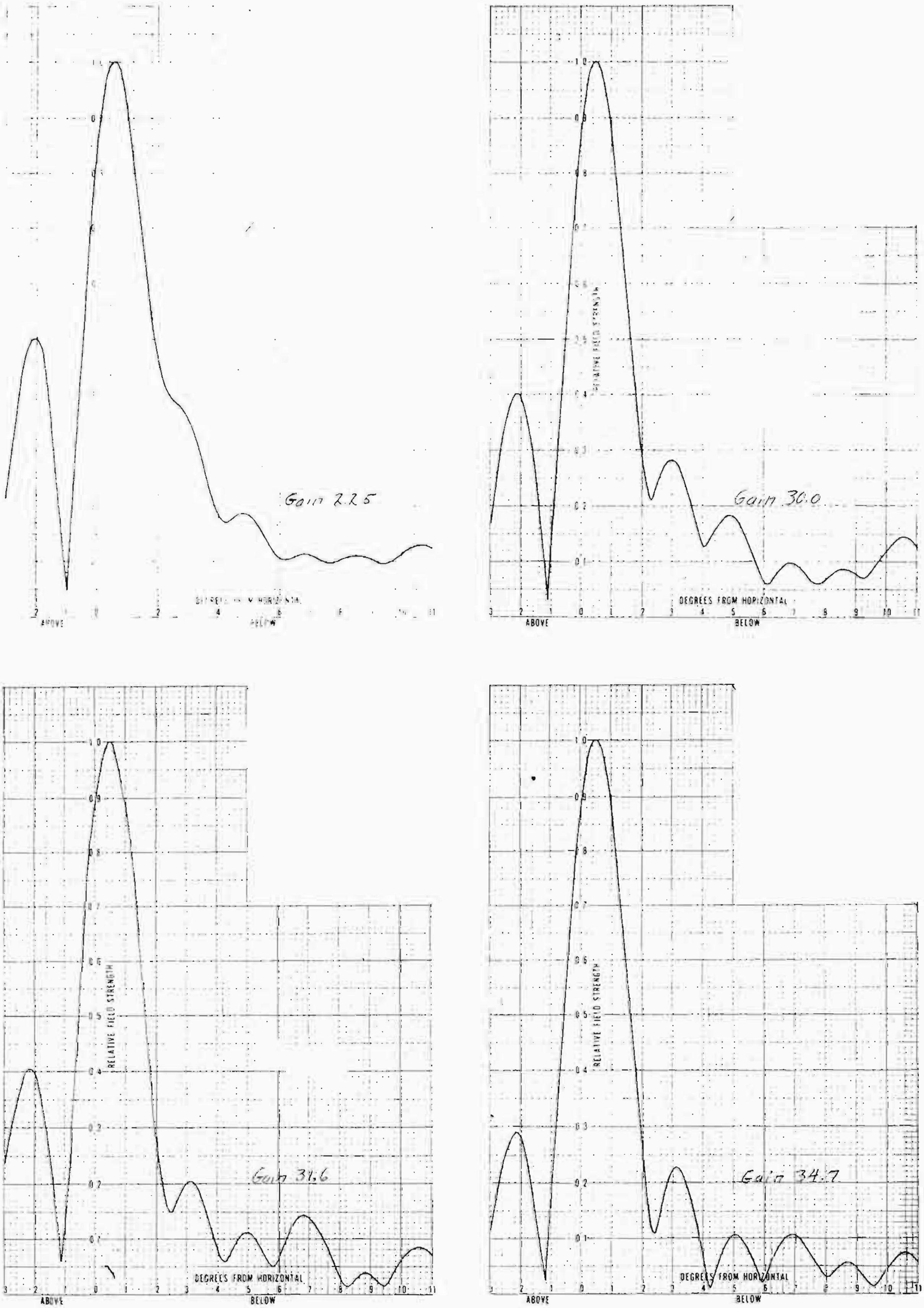

Fig. 4. Four vertical patterns of the same thirty-one layer antenna. Note the decrease in gain as the fill from 2.5° to 11° is increased.

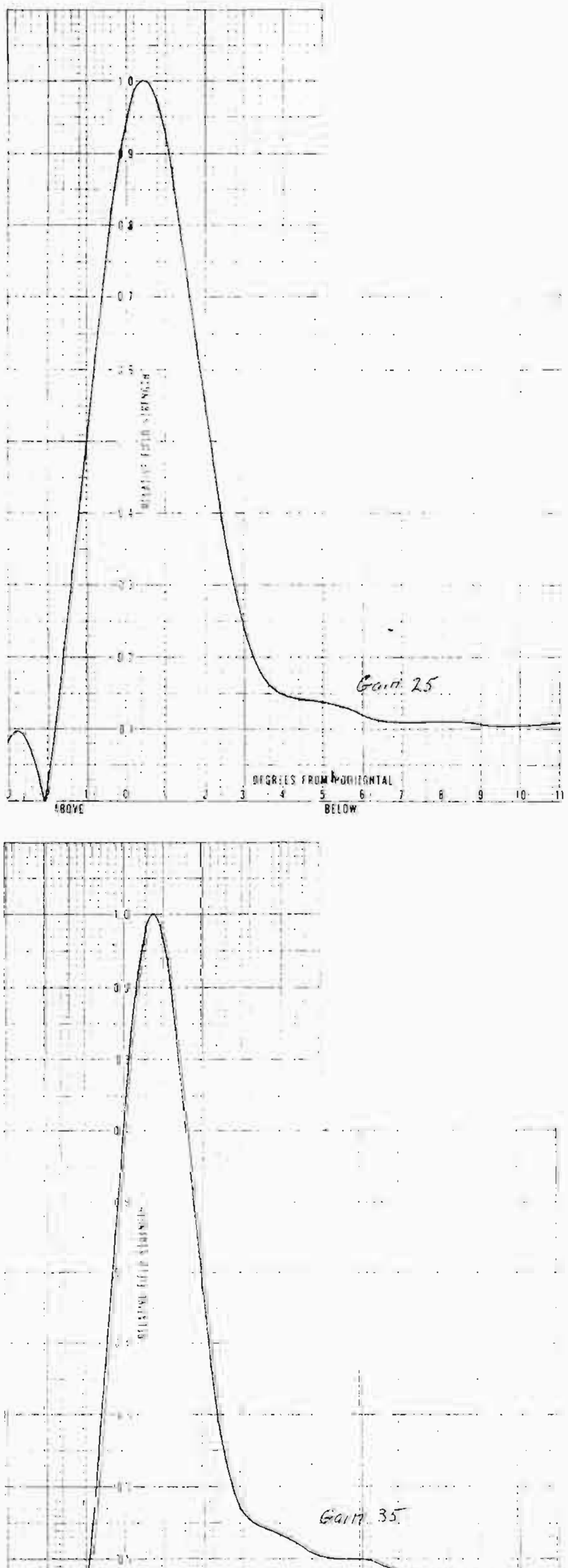

Fig. 5. The "shaped" pattern is achieved by methods described on pages 2-262 ff. They are generally used in large metropolitan centers where the service area starts very close to the antenna.

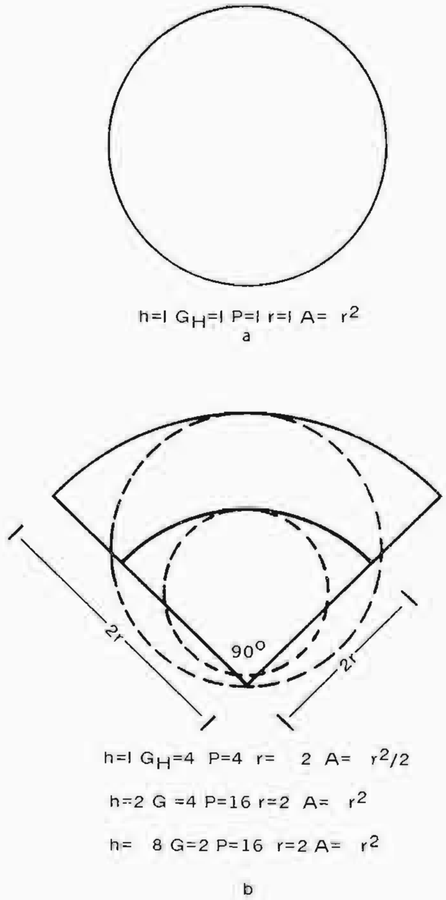

Fig. 6. The most efficient coverage is obtained when the antenna is located centrally in the service area. Only one half of the area is covered with the same input power at the same height from the perimeter using a directional antenna.

Hence, using the same transmitter power with an optimum directional antenna with a horizontal gain of 4, only one half of the area is covered as compared to Fig. 6a and, hence, the coverage efficiency is 50 percent.

It can be stated generally that because of the fourth root relationship between distance and radiated power that the center of the area to be covered is the best location for maximum coverage efficiency.

However, there is another factor: height. From the relationship above, it is noted that if the height is doubled, the "effective radiated power" increases four times. Hence, in Fig. 6b, doubling the height will provide "effective radiated power" "*p*" of 16 and "*r*" becomes 2. The area covered is then:

$$A = \frac{\pi(\sqrt{2}r)^2}{4} = \pi r^2$$

which is the same as for "*a*."

The antenna postulated in "*b*," however, is not permitted under the 15 dB rule. A practical antenna may have a horizontal gain of about 2. To obtain an "effective radiated power" of 16 will require a height increase of $\sqrt{8}$ or 2.8 times.

Another general rule is that where a sufficient natural height can be obtained a directional antenna can be an advantage. To obtain any advantage, however, heights beyond a relative value of 2.8 must be obtained under the conditions postulated above. Hence, it can be seen that the maximum area is covered with a given ERP from the center of the area to be served. If the antenna is located on the perimeter instead of in the center of the same area using a directional antenna, the area covered drops to approximately one-half or less. This results from the fact that the service radius varies approximately as the fourth root of the ERP. If a natural low cost height, such as a mountain site, is available at the perimeter which is approximately three times as high as that which would be used in the valley, the full area can be recovered. The economics of each situation should be studied. Because of the fourth root relationship between the service radius and the ERP, a voltage plot of a directional antenna can be misleading. The area to be covered should be calculated using propagation formulas to obtain a true evaluation. Often the benefits may be found to be marginal and possibly detrimental.

Antenna Input Impedance Specification:

The primary purpose of an input impedance specification is to obtain a good match to the transmission line which carries the power up to the antenna. If the mismatch is too great, the reflected power may be of such magnitude that it travels back to the transmitter where it is generally re-reflected back to the antenna and appears as a secondary image on the television picture. The image is delayed by twice the length of the transmission line.

Subjective experiments have established that the reflection should be no greater than 3 percent of the incident voltage. The method of measuring this is described under "System Specifications."

However, when the antenna is being designed and tested, a complete system is not available so that VSWR (voltage standing wave ratio) across the channel is used as a design guideline.

The relationship between the percentage of reflection and the VSWR of the antenna to achieve it can be related by a computer program.[10] Due to the concentration of energy at picture carrier and 3/4 mc above, the VSWR values should be kept fairly low in this region, say below a VSWR of 1.05 at visual carrier. The values below visual carrier are not as critical since the slope in the receiver cuts off most of the energy in this region as shown in Fig. 7. Hence, the VSWR over the balance of the picture pass band can be as shown in Fig. 8.

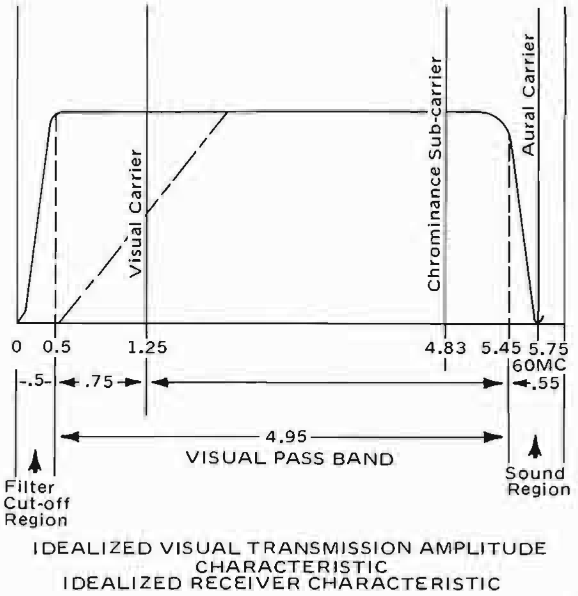

Fig. 7. Note that the visual band is located one half megacycle away from the edges of the channel. Due to the receiver characteristic the VSWR values below visual carrier have a relatively lesser effect on the RF pulse reflection value.

However, these values are really only design guidelines and should not be used as a specification since the real criteria is the 3 percent pulse reflection value, which is the only specification that is really meaningful. It is a temptation to include as many specifications as possible in the hopes of arriving at a good system. However, specifications that are redundant and more stringent than necessary only serve to increase costs without any improvement in performance.

System Specification Performance After Erection

The primary purpose of testing the antenna system is threefold:

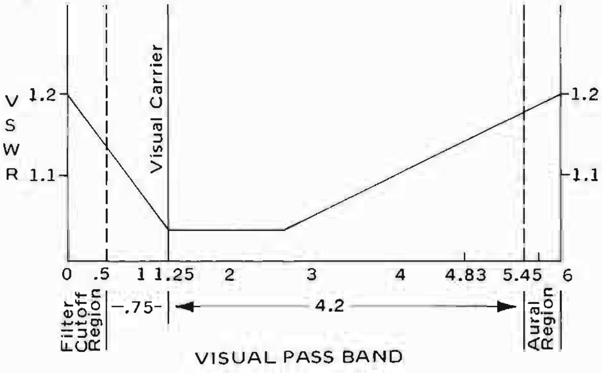

Fig. 8. Based on the visual energy distribution in the channel and the receiver response, the above VSWR versus frequency characteristic will achieve better than a 3 percent pulse reflection value.

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[10] See *Pulse Techniques* by Dr. M.S. Siukola, published in the IEEE transactions on Antenna Propagation.

1. That the transmission line and components are properly assembled.

2. To determine that the reflection from the antenna and other components at or near the tower top are sufficiently well matched so that no visible ghost occurs.

3. That the impedance presented to the transmitter is within proper limits. Actually if Conditions 1 and 2 are met, Condition 3 will be met.

Transmission Line and Components

For an extremely broad band device like a transmission line which is usually designed to cover the entire, or at least, a large portion of the TV band, the dc pulse is a very effective test to determine if the line and components have been properly assembled. This is a short pulse of perhaps 20 nanoseconds at about a 15,000 cycle repetition rate. The wave front is steep enough so that each section of line can be discerned on an oscilloscope. Each joint will manifest itself as a separate vertical line. If one of the pulses is higher than the others, the joint should be investigated for an improper connection or other fault. It is sometimes good practice to assemble the line from the bottom up so that the reflection from each piece can be seen so it is inserted and an immediate correction made. It is also advisable to tap each joint with rubber mallet to locate incipient trouble due to single point contact or improper connection.

Since the pulse covers a wide frequency band, components optimized for a specific channel will manifest themselves as a discontinuity. However, since their location is known and since the distance to their location can be determined from the oscilloscope, this should not present a problem.

As a further check on the frequency sensitive components, the RF pulse test described below can be used since it displays the transmission line run and the antenna on a time base on the oscilloscope. See Fig. 11 which shows a typical RF pulse response. Any value over 1 percent in the transmission line run should be investigated.

The combination of a dc pulse test and RF pulse test will give a thorough evaluation of the transmission line system. These tests will then assure meeting requirements of "1" above.

Proper Match of Far-end Components

A number of methods are possible to determine this match after installation. Industry practice has generally settled on two methods one for VHF and the other UHF, each of which are best adapted to the particular requirements.

For VHF the RF sweep measurement method is generally used. This method has a distinct advantage over a straight VSWR measurement taken in the station in that the close-in components and the far-end components have a different periodicity on the oscilloscope trace. This enables each to be determined separately, and the match at the far end can be determined. This method has been used successfully at VHF for many years. It is, however, not as well adapted to UHF since a suitable delay line which is sufficiently smooth and has a low attenuation is not readily available. Hence, the RF pulse method is used at UHF when a system performance specification is required.

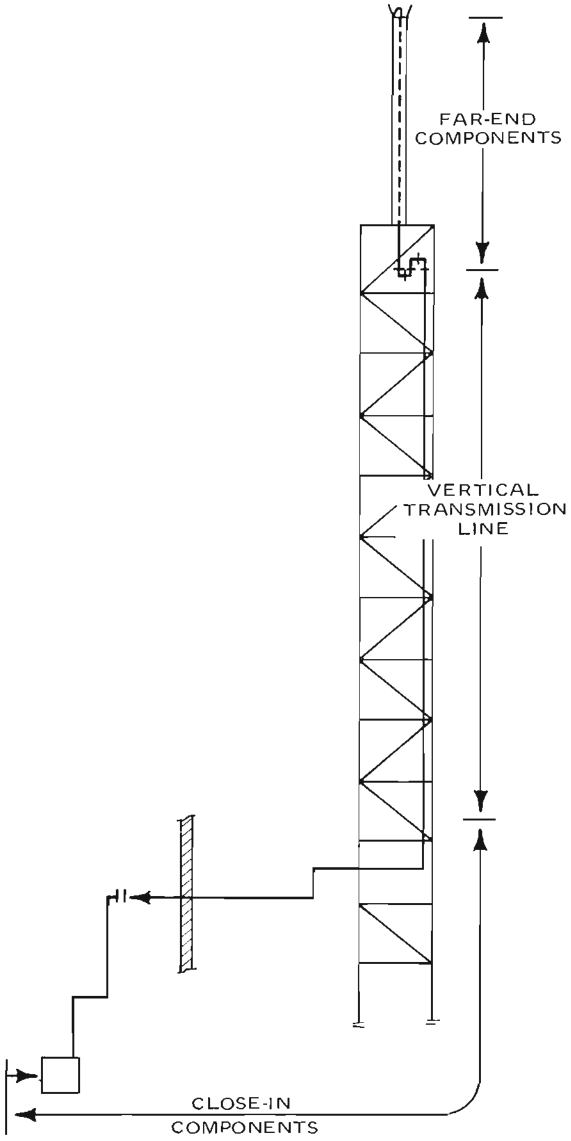

Fig. 9. The three elements of an antenna system can be treated as two discontinuities separated by a long transmission line. As the electrical length of the line changes with frequency the impedances alternately add and subtract.

The RF pulse test was designed to simulate actual picture transmission, which is a series of pulses. It is, of course, possible to transmit a regular picture to see if any "ghosts" exist. However, the antenna system may be completed before the transmitter is operative and the picture test is only qualitative rather than quantitative.

To simulate the most pessimistic condition, a 0.25 microsecond pulse is used which has a band width of ±4 megahertz, and which covers the picture band plus about 3-1/4 megahertz of the lower sideband region where the antenna is not matched. Hence, a vestigial system must be used to receive the return pulse just as in normal home reception.

The 0.25 microsecond pulse simulates the smallest picture element that is transmitted. With this pulse width all of the tower top components would appear as a single reflection. With the proper instrumentation, the percentage of reflection can be measured. The criterion used in the industry is 3 percent which was determined by subjective tests of an ideal system by a number of experienced viewers and has been found to be completely adequate.[11] (See Fig. 10.)

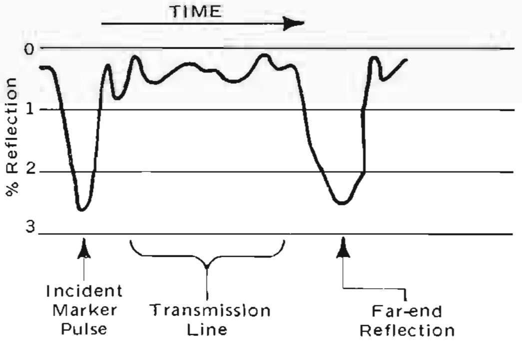

Fig. 10. A typical VSWR versus frequency characteristic of an antenna system based on the alternate addition and subtraction of the close-in and far-end discontinuities.

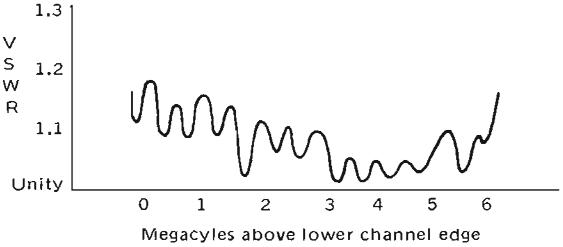

Fig. 11. Typical oscilloscope trace of an antenna system using the RF pulse method. The evaluation is based on the transient response of the system which is directly related to picture quality rather than the less meaningful steady state values such as VSWR which can be misleading.

The Third requirement is Presenting a Proper Impedance to the Transmitter

A typical antenna system is shown in Fig. 9. This system consists of the "far-end components," the transmission line run, and the close-in components in the station. At a given frequency in the channel the electrical length of the transmission line becomes a multiple number of half-wave lengths in which case the far-end and close-in impedances add. At a slightly higher or lower frequency, the electrical length becomes an odd multiple of quarter wavelengths in which case the far-end and close-in impedances subtract. The number of complete cycles in the 6 megacycle channel is L in feet/82. For a 984-foot line there would be 12 cycles in the channel. Fig. 10 shows a typical VSWR plot versus frequency.

Because some of the components are at the end of a long transmission line and others are adjacent to the transmitter, there are two effects with regard to the transmitter. The close-in discontinuities which are usually within less than 100 feet from the transmitter will reflect back towards the transmitter in 0.1 to 0.2 microseconds and become a part of the initial pulse. This has a first order effect of a constant alteration of the load which the transmitter sees. This can be resolved by changing the output coupling for that load condition. Usually the change is of the order of 10 to 20 percent and has no effect on the picture quality.

If the close-in components have a VSWR value of 1.1 and the far-end components also have a value of 1.1 the total variation will be from 1.0 to 1.2 or 0.2 which for the worst generator impedance has the effect of a 20 percent change in impedance and, hence, in power which amounts to only an 0.8 dB variation and is not detrimental.

Even this high VSWR variation to our knowledge has never caused any problems.

However, the VSWR variation is automatically limited by the 3 percent pulse requirement which in the higher energy content portion of the channel limits the value to a 12 percent or a 0.5 dB variation.

Hence if the 3 percent pulse specification is met it automatically takes care of the transmitter impedance considerations.

VSWR System Measurement

This measurement has been used in the past as the only system requirement. Since it adds up the close-in and far-end components, it leaves much to be desired as a meaningful specification since it is often difficult to resolve which is which. The close-in values are of little significance to picture quality and the far-end components are quite important. Hence, it lumps together the im-

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[11] For a fuller discussion of RF pulse techniques see *Pulse Techniques* by Dr. M.S. Siukola published in the IEEE Transactions on Antennas and Propagation.

portant and the unimportant with a rather indeterminate means of separating the two.

In an attempt to make it meaningful, the VSWR values have been limited to absurdly low values in specifications which have added considerably to the cost without adding anything in the way of performance.

This constitutes an improper use of specifications since economically there is no justification for the stringent values.

The measurement, however, does have one value in that it affords a quick check of the system since VSWR measuring equipment is more readily available than pulse equipment. A record measurement without reference to values taken after the installation can be filed and used as a periodic check on the system or to determine if changes have occurred or if problems are suspected.

Summary

The antenna specifications cover gain, beam tilt, power capability, vertical pattern, horizontal pattern for directional antennas and antenna impedance requirements to meet the 3 percent system pulse specifications.

The antenna system specification includes a dc and RF pulse test of the transmission line and the antenna, and for record purposes only, the system VSWR.

Electrical Performance Changes Due to Mechanically Imposed Conditions

Deflection of Antenna and Tower Due to Wind

Guy tension in guyed towers is usually adjusted so that the tower deflects as a straight member. Towers for broadcast service when so specified are designed for a maximum deflection of 0.5°, which means that the top plate will deflect this amount for the maximum wind velocity. For instance, a 40-lb tower will thus deflect 0.5° for a 100-mph wind. Since tower deflection varies as the square of the wind velocity, the deflection will be 0.125° for a 50-mph wind.

Structurally a free-standing antenna can be considered as a cantilever beam in which the deflection increases toward the end. Antenna deflection is stated as the angle from the vertical of the chord that connects the base to the top of the antenna.

In order to evaluate the effects of deflection, an example for a high-gain UHF antenna will be given.

Figs. 12 and 13 show the pattern variations of a UHF antenna of the slotted cylinder type with a gain of 46 when the antenna is 102.8 feet in height. The entire antenna is constructed of 18-in. steel tube with a 1.218 wall using six peripheral slots in each layer.

The phase and amplitude of each layer of the antenna were synthesized to obtain a vertical pattern for the curved condition where the antenna was bent toward the service area and away from it.

Two conditions are shown for a wind velocity of 50 and 100 mph as summarized in Table 1.

The 50-mph wind condition is one that may occur[12] twenty-five times a year at a 1,000-ft elevation above terrain and about four times a year at a 500-ft elevation.

TABLE 1

Wind Velocity mph	50.	100.
Wind load psf	10.	40.
Deflection of antenna at top, in.	4.9	0.914
Deflection, degrees, of chord from bottom to top	.227	0.914
Tower deflection degrees	.125	0.5
Antenna and tower deflection degrees	.352	1.414

Signal Variation for Deflection Extremes, dB	Toward Service Area	Away from Service Area	Toward Service Area	Away from Service Area
At horizon (main beam) antenna only	−0.5	−0.3[a]	−7.8	−5.8
At horizon for antenna and tower	−0.7	−0.4	−18.8	−13.4
At a location with respect to the vertical pattern where the greatest signal variation occurs for antenna only	+3.6	−2.7	+6	−10.8
At a location with respect to the vertical pattern where the greatest signal variation occurs for antenna and tower	+4.2	−5.3	+12.7	−5.2

[a] Values are not the same, since in this antenna, radiation above the horizon has been suppressed and the pattern is not symmetrical.

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[12] Report of TASO Committee 1.3 on Television Antennas. Final Report of TASO Sub-Committee 1.3.2. on Towers, Sec. 3.6.

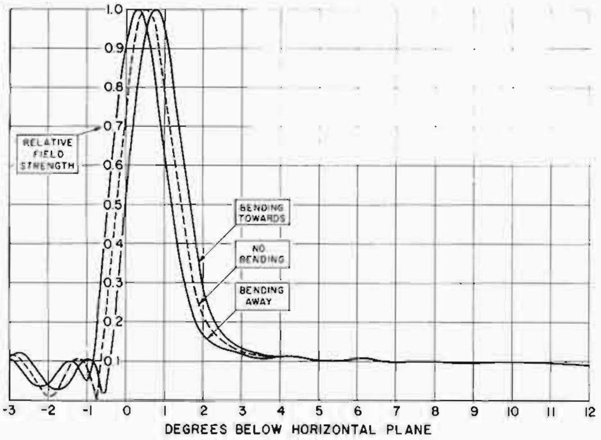


Fig. 12. Calculated vertical patterns of the TFU-46C antenna affected by static load: flat-surface wind load 10-psf, wind velocity 50 mph.

The 100-mph wind is a design-limit figure which rarely occurs and is one during which there would probably be little television viewing. Most outdoor receiving antennas would probably be severely damaged in such a wind, and power service seriously curtailed.

Hence the 50-mph figure is one that is generally considered applicable for an evaluation of this type.

Most television receivers are designed to have a flat AGC response down to 100 microvolts across the receiver terminals. Hence no effects due to wind acting on the transmitting antenna will be noticeable except in fringe areas where the signal drops below this value.

In the case cited above, the signal variation in the fringe area would be less than 1 dB and could be considered negligible.

The maximum variation in the case cited above occurs at 1.75° below the horizon or at 6.3 miles for a 1,000-ft difference in elevation between the transmitting and receiving antenna. At this distance the field strength is usually at a sufficiently high level so that a 2-to-1 variation will not go below the 100 microvolt level at the receiver terminals.

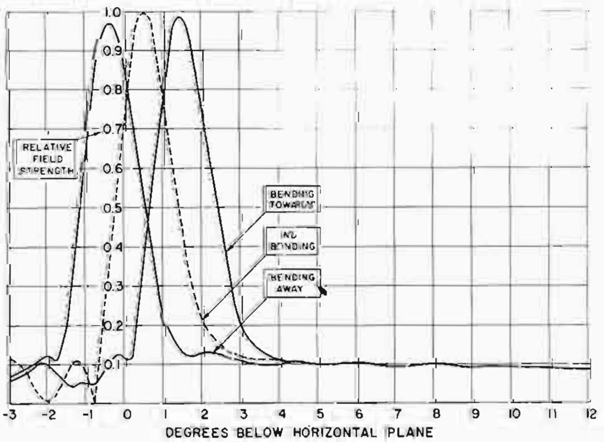


Fig. 13. Calculated vertical patterns of the TFU-46C antenna affected by static wind load: flat surface wind load 40psf, wind velocity 100 mph.

Analyzed on this basis even the 100-mph wind condition is not too serious except in the fringe area. It should be noted that the variations are limited by the fact that the antenna is designed not to have nulls near the main beam.

For lower gain antennas with a wider beam the variation would be even less than those shown.

DESIGN AND THEORY

Elemental Radiators

Television antennas in common use are developments of one or another of a few basic types of radiator. These are the half-wave dipole, the loop (magnetic doublet), the slot, and the helical. Some of the antennas combine characteristics of more than one of these types.

For purposes of mathematical representation or as a reference for comparison of charactertics of antennas, the concepts of "point source"—a fictitious emitter so small as to have no dimensions—and "isotropic radiator"—which radiates energy uniformly in all directions—are sometimes used.

Antennas of the horn, lens, and long horizontal (Beveridge) or vertical wire types do not currently find application at television frequencies and are not considered herein.

Half-wave Dipole

If the ends of an open-wire transmission line are turned outward, as shown in Fig. 14a, they form what is known as a dipole. The electric (*E*) fields, at right angles to and connecting the two sides of the transmission line, extend outward, forming circles in all planes passing through the axis of the dipole, as shown in Fig. 14b. The magnetic (*H*) fields which, in the transmission line encircled the separate wires and tended to cancel each other owing to the opposing directions of the flow of current in the two wires, now appear as circles about the dipole.

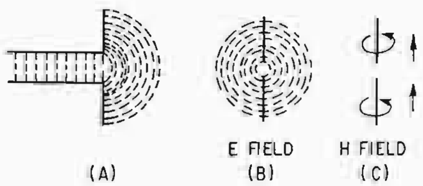


Fig. 14. Electric (E) field, and magnetic (H) field of a dipole.

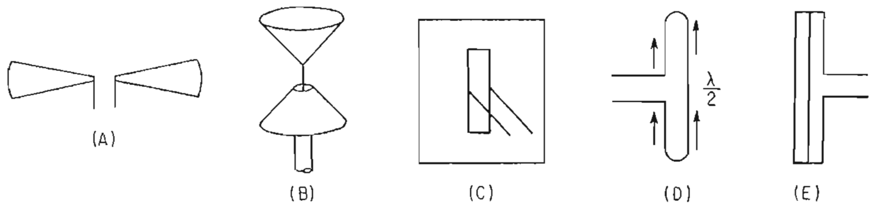


Fig. 15. Examples of radiators having dipole-like characteristics: (A) and (B) biconical antennas, (C) slot-fed sheet, (D) folded dipole, (E) folded dipole with additional element.

If the length of the dipole is made a half wavelength long at the frequency of an imposed signal, it becomes, in a sense, a resonator, with energy reflected from the ends of the radiator setting up standing waves. The energy is alternately stored in the electric and magnetic fields.

At high frequencies, the fields so formed do not have time to collapse completely before other fields, of opposite polarity, are set up. The result is that outer portions of the field never return but are pushed out of the area close to the antenna known as the "induction-field" region and move away, forming the "radiation field."

Since the power in the field is dissipated power (I^2R) in the same sense that power appearing as heat due to ohmic resistance in the dipole is dissipated power, it is convenient to relate this power to the current which produces it by a fictitious "radiation resistance." This is in addition to the ohmic resistance in the radiator circuit.

The ratio of stored energy to dissipated energy is called the Q of the antenna circuit. As any circuit contains L, C, and R, this is a function of the relationship between the inductive reactance of the circuit and the resistance. In the case of the dipole the inductance decreases with increasing diameter of the dipole arms. Also the amount of energy reflected from the ends, resulting in greater stored energy, is reduced by increasing the size of the arms. This results in greater bandwidth. Application of this fact leads to the biconical radiators in Fig. 15a and 15b and to the slot-fed sheet radiator, Fig. 15c.

Another form of the dipole is the half-wave folded type shown in Fig. 15d. Here, the ends of a simple dipole have been joined by another closely spaced element. Since the voltage distribution is the same in both, the currents are in the same phase and direction. The result is an input impedance of 300 ohms as compared with 73 ohms for a simple half-wave dipole. Addition of rectangles as in Fig. 15e increases the input impedance by a still greater factor.

Because the folded ends act like stubs, they become capacitive at higher frequencies. This is opposite to the tendency of the series *LCR* circuit by which a dipole can be represented. The result is a cancellation to some degree of the reactances and a tendency for the impedance to remain constant, making the antenna more broadband than the half-wave dipole.

The distant radiated field of the folded dipole is the same as that of the simple dipole.

Loop

The folded dipole discussed above may be considered as a special case of a loop antenna as well as a type of dipole. In fact, any closed loop of conductor which does not carry equal and opposite currents very close together, that is, within the "near," or "induction," zone, will fall into this category and will radiate at least some of the power supplied to it.

The loop or ring radiator may be rectangular or circular, as seen in Fig. 16a and b.

Variation in the size of the loop yields radiation patterns of various shapes, in planes at right angles to that of the loop, as could be expected by comparison with the horizontal fields of two AM radiators with various spacing and phase relationship. That is, if sides 1 and 2 of the square loop in Fig. 16a are considered to be the two AM radiators, the combined radiation pattern in a plane at right angles to them will vary with the spacing between them. For loops with diameters less than 0.585 the maximum field will be in the plane of the loop, and loops much smaller than a wavelength are therefore most commonly used as elements of television antennas. Radiation in a direction normal to the loop is always zero, regardless of the size of the loop.

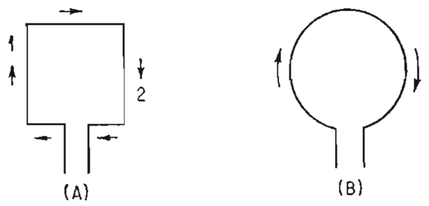


Fig. 16. (A) Square loop and (B) ring radiator.

Slot Antenna

As has been mentioned under Half-wave Dipole, the slot antenna has a great similarity to a dipole.

Figs. 17a and 17b show the two types, oriented so that the (*E*) fields of both are horizontal. Currents in the slot type spread out over the entire sheet, and radiation takes place from both sides of the sheet.

The resemblance between the two becomes even more pronounced when it is recognized that the field patterns of the two will be equivalent if the physical dimensions of the slot and the cross section of the dipole are the same. For example, the fields of the two radiators in Fig. 17c and 17d are the same. A very similar situation occurs in optics, where the phenomenon is known as Babinets principle. Using a term from optics, the antennas are said to be complementary where this situation exists.

Furthermore, the impedance of the slot is proportional to the admittance of the dipole of the same dimensions by the relationship

$$Z \text{ slot} = \frac{35,476}{Z \text{ dipole}}$$

and the bandwidth characteristics of one are the same as those of the other.

Actually, the above discussion is rigorously accurate only if the sheet is of infinite extent, but it is substantially correct if the edge of the slot is half a wavelength from the slot.

The input resistance to a slotted sheet is of the order of 500 ohms. This can be modified by shifting the position of feed along the slot. A value of 50 ohms can, for example, be obtained with the feed about 0.1 of the slot length from one end.

Radiation can be limited to one side of a very large sheet by boxing in the slot on the other side. If the depth of the box is such as to present zero susceptance at the feed point, the input impedance will be appropriately double that of the same antenna without the box (see Fig. 18).

Bending the sheet into a cylinder results in another form of slot antenna which also takes on characteristics of a stack of coaxial rings (Fig. 19).

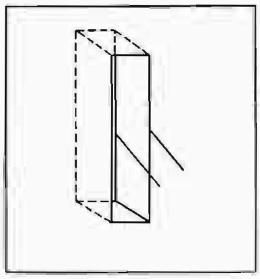


Fig. 18. Slot-fed sheet radiator with slot boxed to limit radiation to one side of sheet.

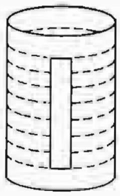


Fig. 19. Slot-fed sheet radiator bent to form a cylinder, showing resemblance to stack of ring radiators.

Helical Element

A conductor wound in the form of a helix can be made to have maximum radiation either in the axial direction or in a direction normal to the axis, depending on the circumference of the helix and on its pitch. For radiation in the "normal" (or sidefire) mode, the helix dimensions must be small compared with a wavelength (see Figs. 20a and 20b).

The limitation on the size of a helix for normal operation imposes restrictions on bandwidth. This can be offset to some extent by phase-shifting devices along the helix which compensate for variations in impedance with frequency.

Since the helical element is used in almost a pure form in a commercial antenna to be described under Helical Antennas, further discussion will be left till that section.

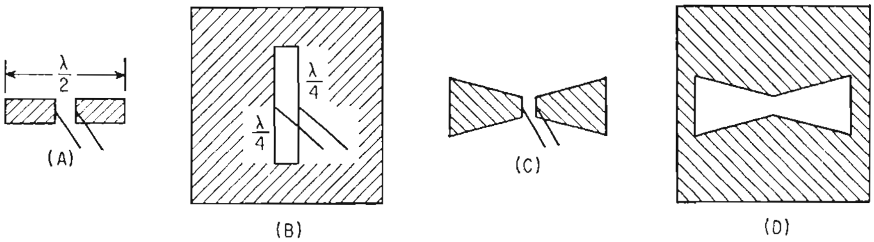


Fig. 17. Dipoles (A) and (C), with complementary slot-fed sheet radiators (B) and (D).

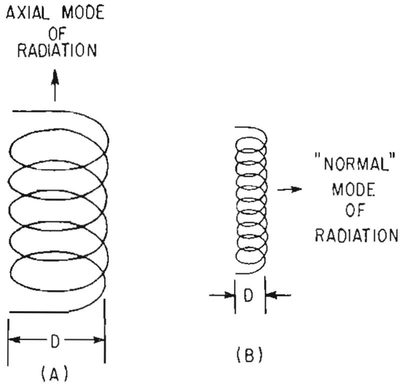


Fig. 20. Helical antennas, showing effect of pitch and diameter on direction of maximum radiation.

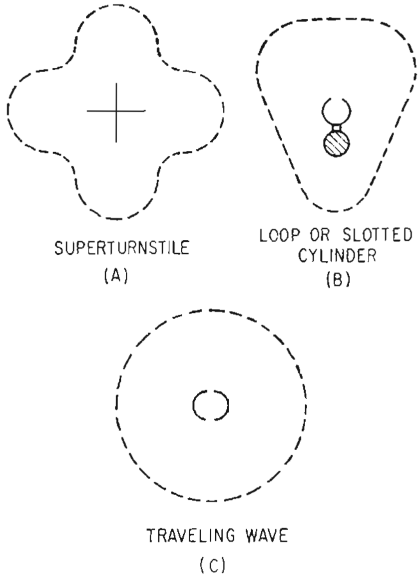


Fig. 21. Typical azimuthal patterns of well-known types of TV broadcast antennas.

Antenna Patterns

Azimuthal Patterns

In television, with the inherent limitations on coverage due to high-frequency propagation effects and the limitation on the number of stations with any area as set up in the existing allocation plan of the Federal Communications Commission, the large majority of requirements have been for omnidirectional antennas.

As is pointed out in the discussion of omnidirectional patterns, the primary criterion of a truly circular or omnidirectional pattern is the intent to make it omnidirectional. In the past, variations of 3 dB on each side of a true circle have been accepted as within the meaning of the word omnidirectional.

Since energy flows equally in all directions from a theoretical "point source," its horizontal pattern is a true circle. A thin dipole, vertical to the earth's surface (i.e., with vertical polarization), most nearly approaches this and has a similar azimuthal pattern. Except for these two cases, however, the finite physical size of television transmission antennas and the physical irregularities of their surfaces, due to the requirements of mechanical construction, result in the sum of the energies from various portions of the antenna as received in one direction varying from that received in another. Typical azimuthal patterns of some well-known antennas are shown in Fig. 21.

Except for the effects of supporting structures upon which they are mounted, rings or cylindrical antennas inherently have better circularity than other shapes. Ingenious methods have been used, however, to combine noncircular patterns of several radiators to obtain circularity. An illustration of this is the so-called turnstiling principle applied to dipoles. Fig. 22a shows the typical "figure-eight" horizontal pattern of a very small dipole. If a second dipole is placed at right angles

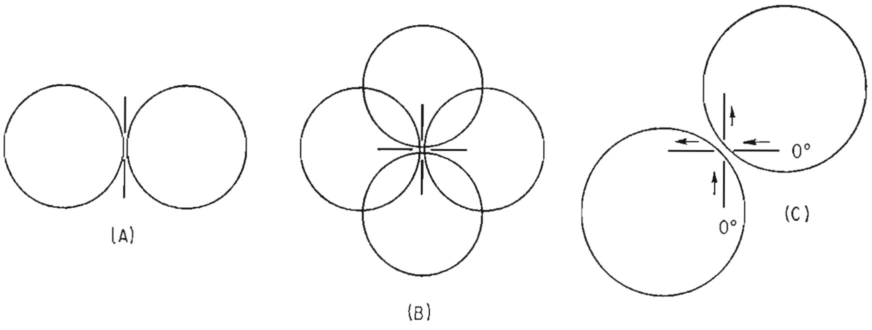


Fig. 22. Addition of fields of crossed dipoles. (A) Figure-eight patter of a single dipole, (B) superposition of a second dipole at right angles, (C) pattern obtained when both dipoles are fed in phase.

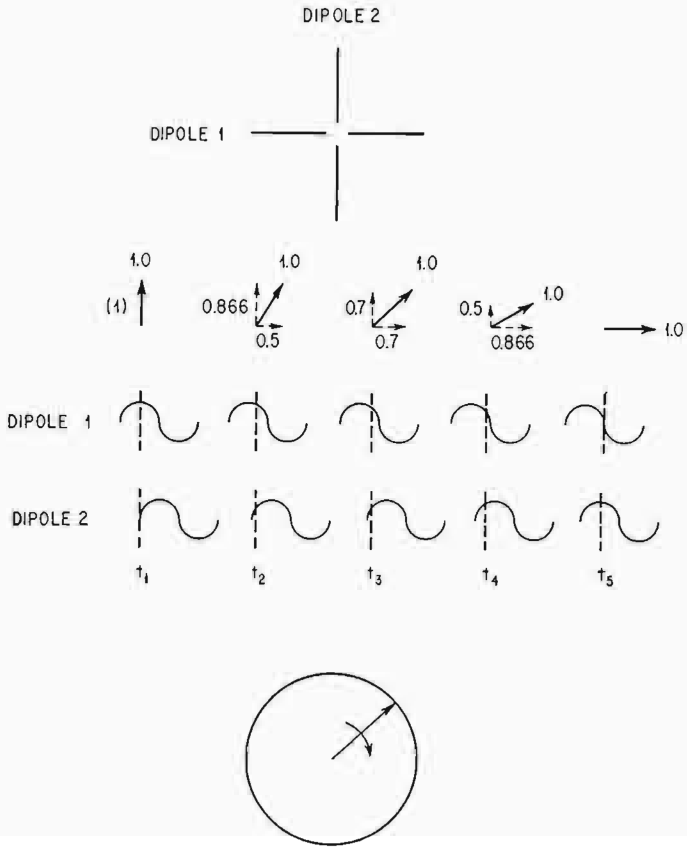


Fig. 23. Addition of field of crossed dipoles using "turnstiling" principle to produce circular pattern.

to the first, the two patterns will overlap, as shown in Fig. 22b. If both are fed in phase, addition of the radiated energies will result in a pattern such as is shown in Fig. 22c.

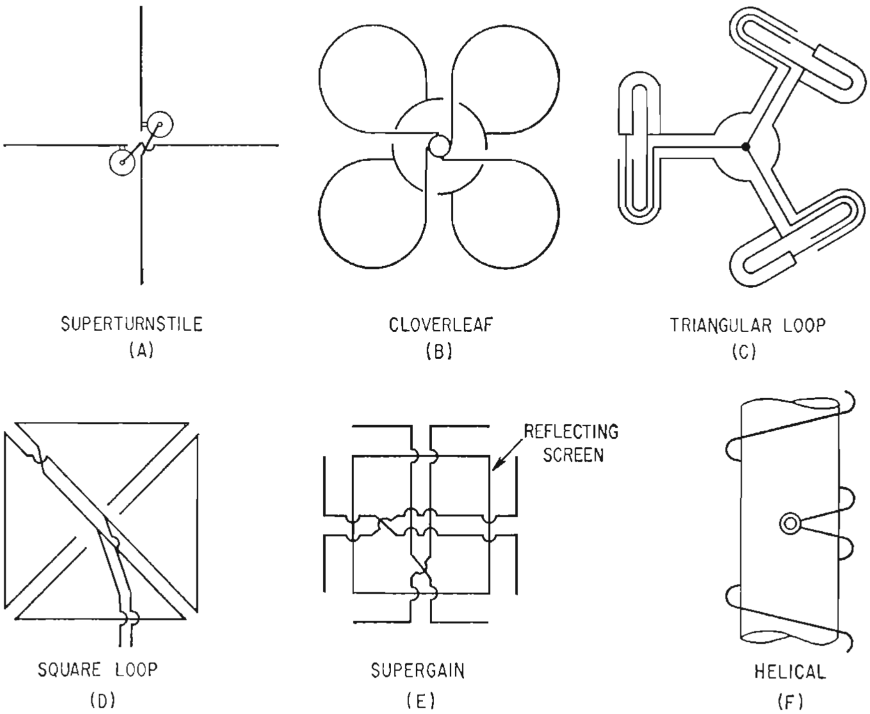
If the dipoles are fed 90° out of phase, the separate fields will add as shown in Fig. 23. Here we have two dipoles 1 and 2 placed in space quadrature, with current conditions in the radiators as shown at various times. At time t_1 the current dipole 1 and the resultant field of that dipole will be at a maximum, represented by a vector of unity length pointing upward. For dipole 2 they will be zero. The combined field will be unity. At time t_2, 30° in phase later, the field of dipole 1 will have reduced to 0.866 of its value and that of dipole 2 will be 0.5 of its maximum value. Addition of these two vectors at 90° in space phase will produce a resultant which again has a value of unity.

Analysis of the conditions at t_3, t_4, and t_5 indicates that the same total field will be obtained in each case. Ideally, then, we see that turnstiling produces a constant field rotating in the horizontal plane at the rate of the signal frequency.

In actual practice the dipoles are not infinitesimally small, and a supporting pole and feed lines tend to distort the fields of the dipoles from the ideal. The vectors do not then add in such a way as to result in the same total in all directions. The normal pattern is then scalloped, as shown in Fig. 21a, with the amount of variation from circular increasing with size of the supporting pole at a given frequency and with increase in frequency for a given-size pole.

Other methods of obtaining omnidirectional patterns which have been used are the "clover leaf" of small loops (Fig. 24b), the triangle of folded dipoles (Fig. 24c), the small loop (Fig. 24d), the "supergain" with the dipoles backed by screens and fed in quadrature (as are the turnstiled dipoles) (Fig. 24e), and the helix wound around a tower structure with phase compensators to maintain correct phase relationship between successive turns of the helix (Fig. 24f).

Although omnidirectional antennas predominate in television broadcasting, there are locations where their use is impractical and even insufficient, and it becomes obviously desirable to direct the main portion of the radiated energy in both the horizontal and vertical planes to serve specific areas best. Examples in the United States are the Denver, Colo., area, where the presence of mountains to the rear of logical transmitting sites would set up undesirable reflections if the signal



SUPERTURNSTILE (A) CLOVERLEAF (B) TRIANGULAR LOOP (C)

SQUARE LOOP (D) SUPERGAIN (E) HELICAL (F)

Fig. 24. Configuration of elements used to obtain omnidirectional patterns.

were allowed to radiate toward them, and the southeast coast of Florida, where the populated area borders the coast for great distances with only swamp immediately to the west.

Here the irregularities of the so-called omnidirectional patterns can be exploited to some extent, but truly "directional" patterns are more desirable. In order to obtain directional patterns, in either the vertical or the horizontal planes, correct relation in amplitude and phase of the signal coming from different portions of the antenna is necessary. This can be accomplished to some extent by physically spacing the radiating elements properly. For a given spacing, the pattern can be further modified by varying the phase and amplitude of the respective radiated signals. An example of this is shown in Fig. 25a where two point sources are fed in phase with each other but are spaced 180° apart. By the time the signal from *A* reaches *B*, the phase of the signal being radiated from *B* will have changed 180°. If the signals are equal in magnitude, they will cancel in the direction to the right. The same line of reasoning shows that no signal will be radiated to the left. Toward the top and bottom of the page, the signals will always be in phase,

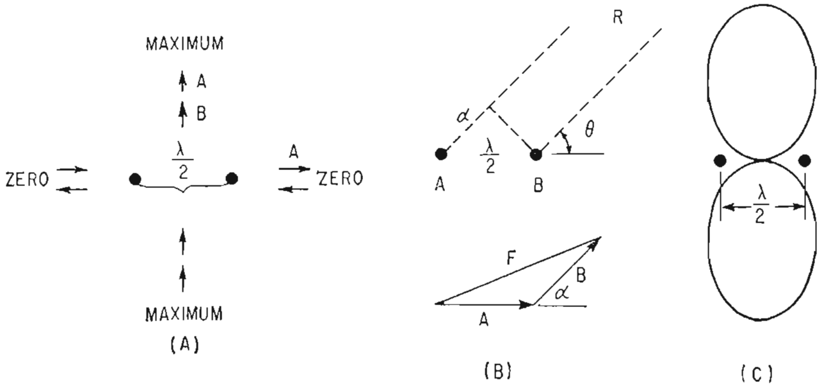


Fig. 25. Formation of field pattern from two sources placed a half wavelength apart, as shown in (a) and fed in phase. Leg of signal from source *A* in direction *R* is shown in (B) and the sum *F* of the signals from *A* and *B* are shown in (C).

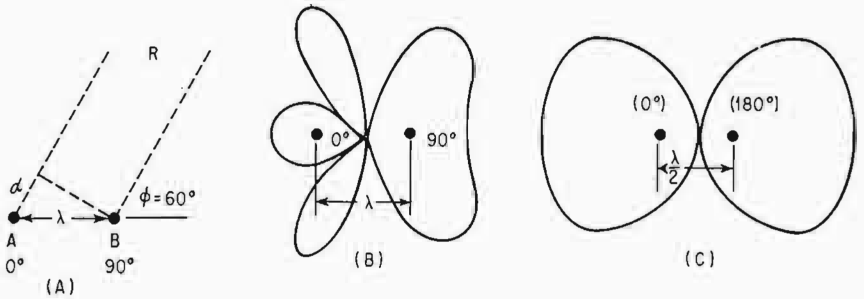


Fig. 26. Field pattern resulting from sources (C) a half-wavelength apart fed 180° out of phase and (B) a wavelength apart fed 90° out of phase. (A) Formation of null at ϕ = 60° for condition (B).

giving a total radiation equal to the sum of the two individual ones. Factors showing amplitude and relative phase are given in all four cases.

At some other angle in the plane of the paper, conditions shown in Fig. 25b will pertain. At some great distance R, the signal from A will lag that from B by an amount ϕ. The sum of the two will have a value F, somewhat less than the sum of A and B, as shown. If this process of analysis is continued for all angles of ϕ and the values plotted as relative magnitudes, a radiation pattern like the one shown in Fig. 25c (commonly called a figure-eight pattern) will be obtained.

If A and B are radiating 180° out of phase with the same spacing, signals to the right and left will reinforce each other, and they will be the same reasoning cancel at right angles to this, as shown in Fig. 26c.

For a spacing of one wavelength and a phase difference of 90° the signal from A will lag that of B by 90° toward the right, giving a resultant of 0.707 of the value of one signal. At an angle of $\phi =$ 60° toward R, the two will become equal but opposite in phase and the signals will cancel (Fig. 26a). Continuing this analysis yields a pattern shown in Fig. 26b.

It can be seen that varying the third parameter, amplitude of signal, from either or both sources will increase the number of patterns which can be obtained, since the vectors now being added vary in length as well as in angle to each other.

The same method of analysis can be applied to more than two sources, with a corresponding increase in the number of vectors. In fact, the effect so analyzed actually takes place with any type of antenna which is not a point source, since each small portion of the antenna acts as a point source with particular phase, amplitude, and position relationship to each other such position.

Where individual radiators of finite size, having by themselves patterns which are directional in character (as, for example, a dipole), are grouped to form an "array," it is customary to consider each as a point or isotropic radiator in determining the phase at which their signals must be added to those of the other individual radiators, or "elements." For arrays of reasonable complexity, this relationship can usually be expressed as an equation, and the pattern which it represents is known as the "array pattern."

If the pattern of the individual element is itself expressed as an equation, the total field pattern (i.e., pattern of relative magnitudes of field intensity) of the array can be obtained as the *product* of the "element pattern" and the array pattern.

To find the phase of the resultant signal in any direction, it is necessary to *add* the phase of the element pattern to that of the array pattern in that direction.

As pointed out above, an "element" may be considered in turn as a group of smaller elements. We have thus a tool for handling the calculation for quite complex arrays as illustrated in Fig. 27a. Assume that elements 1 and 2 are fed in phase and 3 and 4 are fed in phase but 1 and 3 are fed 90° out of phase. One and 2 give a pattern shown in Fig. 27b.

Now if 1 and 2 are considered as one single element with effective center of radiation halfway between the two and 3 and 4 are considered another element, the array pattern of the two new elements is a cardioid (Fig. 27c). Multiplying the patterns of Fig. 27b and c together in all directions yields the pattern shown in Fig. 27d.

If all elements of an array do not have the same element pattern, or if the array is quite complex in phase, amplitude, and geometry of elements, it is necessary to combine the element patterns on an angle-by-angle basis taking into account the array factor. An illustration of the method is shown in Fig. 28, where two point sources are fed with unequal currents in the ratio of 2 to 1 and with the upper one lagging the lower by 30°. In the direction ϕ = 60, A lags B by $\lambda / 2$ owing to its relative position. It lags an additional 30° due to the imposed phase. The unequal vectors are therefore combined at an angle of 90° + 30° = 120°, giving a total amplitude of 1.732. Increasing the number of elements simply requires the

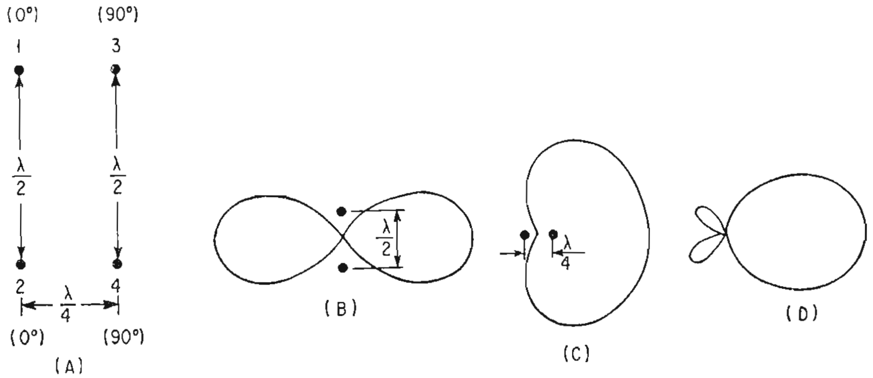


Fig. 27. Evolution of a pattern (D) by multiplication of an element pattern (B) by an array pattern (C). [Sources located and phased as shown in (A).]

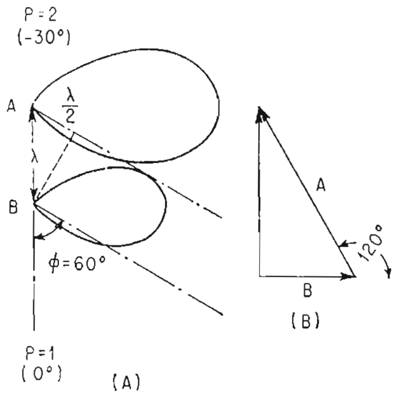


Fig. 28. Combination of signals from two sources having unequal currents and phase and positioned a wavelength apart.

addition of more vectors with correct relative signal strength and phase.

Examples of directional patterns of antennas in current use are shown in Fig. 29.

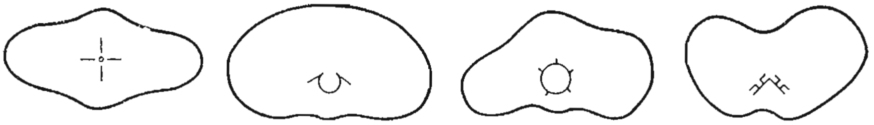
A reversal of the above procedure makes it possible to start with a desired pattern and to determine what relative phases and amplitudes are required to obtain it. A particular type of element and form of array must be presumed, of course, to make such a computation possible. This procedure is known as pattern sythesis. The speed of electronic computing devices renders this approach highly practical and effective.

The above discussion of the calculation of patterns has ignored the effects on element patterns of the presence of other radiators in close proximity. Mutual effects among elements alter current and phase conditions within the element and must be taken into account if the effect is appreciable.

A word should be said about the limitation on the use of directional antennas for commercial television in the United States. Where there is clear indication that directionalizing will not be against the best interests of the market area being served, the Federal Communications Commission will approve its use. The broadcaster may desire this to conserve power by limiting radiation over nonpopulated areas or to avoid multipath echoes from nearby mountain ranges. There is currently in effect a rule which provides that the difference in field strength between the maximum signal and the minimum signal in the horizontal plane shall not exceed 10 dB.

Vertical Patterns

The need for higher gain (see under Gain) than can be obtained with a single radiating element requires "stacking" the elements one above another. This, on the undesirable side, increases



(A) SUPERTURNSTILE, WITH UNEQUAL POWER DIVISION

(B) SLOTTED RING, WITH PATTERN SHAPING MEMBERS

(C) HELICAL, WITH STUBS FOR VARYING PHASE

(D) SUPERGAIN, WITH RADIATORS AT ANGLES

Fig. 29. Examples of directionalized horizontal patterns in current use.

the condition of "lobing," or wide variations in the amplitude of the resultant radiation pattern in the vertical planes. On the desirable side, however, it provides more separate elements by control of which the patterns can be made nearly ideal for television broadcasting.

Reference is made to the discussion of Azimuthal Patterns for an outline of the theory of pattern formation. The same principles apply in the vertical plane. Fig. 30a shows the vertical pattern of a point source or of a horizontal dipole. Fig. 30b and 30c show the effect of stacking two- and six-point sources one above another, a half wave apart, with currents of equal amplitude and phase. Fig. 30d shows the same information as Fig. 30c for the portion of the pattern between $\phi = 0°$ (horizontal) and $\phi = 270°$, on rectangular coordinates, with field intensities plotted against angle below the horizontal. This is the customary method of pattern representation, enabling one to see in convenient manner the relative field strength at any angle into the area served by a broadcast station down to the base of the antenna tower.

The presence of nulls in the pattern of a television broadcast antenna is undesirable, because receiving areas at the angles where nulls are indicated received either less than the required signal or one which is the sum of reflections from objects which lie outside the null area. This latter condition often results in multiple "echoes" in the received picture.

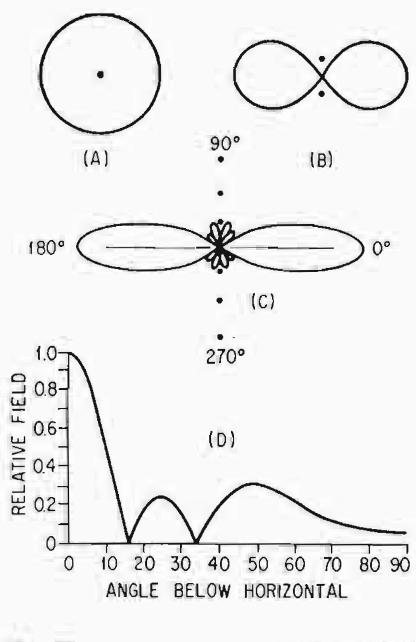


Fig. 30. Effect of stacking several point sources having equal currents and phase. (A) Vertical pattern of single source, (B) two sources, (C) six sources. Information given in (C) is shown in rectangular coordinate form in (D) for angles between horizontal (0°) and directly below the array (270°).

The angles at which nulls appear for the case of a vertical array of equally spaced radiators fed by signals of equal amplitude and phase can be approximately found by the relation

$$\phi = \arctan \frac{\pm K}{nd}$$

where K is the null in question (the one nearest the main beam having a K value of 1, the next one 2, and so on). The number of elements is given by n, and the spacing of elements in wavelengths by d.

A quick rule-of-thumb method to obtain the distance of a null is to multiply the antenna height by the antenna gain and divide by K, thus

$$d = \frac{hg}{K}$$

Various methods are used in the design of antennas to "fill in" the null axis. Simple power division, whereby the upper or lower half of the elements are fed with a greater amount of power than the other half, results in the elimination of all odd-numbered nulls (see Fig. 31a).

A more complex power distribution was proposed by J. S. Stone, wherein successive elements are fed with amplitudes proportional to the coefficients of a binomial series. Thus for three elements the distribution would be in the relation 1, 2, 1, and for five 1, 4, 6, 4, 1. The result is an elimination of all minor lobes and all nulls except the ones directly at the base of the tower and directly above the antenna.

A similar result is obtained if the amplitude is exponentially tapered from one end of the an-

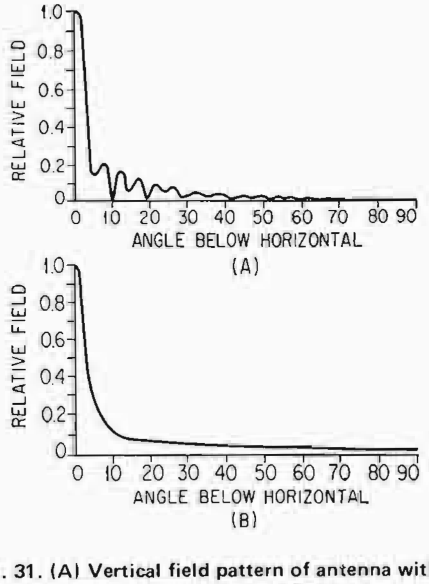


Fig. 31. (A) Vertical field pattern of antenna with a gain of 12 having twice as much power in the upper half as in the lower half. (B) Vertical field pattern of an antenna with many separate radiating elements with ideal phase and power distribution to obtain smooth pattern.

tenna to the other, as in the traveling-wave antenna.

Still more elaborate is a combination of power division and phasing to obtain specific desired pattern shaping (see under UHF Antennas).

With the number of elements available in antennas having gains of 30 and upward, patterns have been obtained by these methods which are almost without a visible ripple (see Fig. 31b).

The filling of nulls, while highly desirable in cases where the area served would be otherwise affected, must be done at the expense of gain to some extent, since power is usually drawn from the main beam to furnish the filling signals. Proper pattern synthesis can, however, reduce this effect to a minimum, taking power instead from the portion of the pattern above the horizon, where it would otherwise serve no useful purpose.

Directionalizing the vertical pattern so as to direct the main lobe of energy at other than the horizontal direction is permitted by the Federal Communications Commission where it can be shown that the public can be more adequately served. Certain restrictions limit the type and amount of such directionalizing, however, namely:

1. The power radiated in the main lobe may not exceed that authorized for nondirectional operation for the particular area.
2. Power radiated in any direction above the horizontal may not exceed the power radiated in the horizontal after directionalizing.
3. Requirements for Class A and Class B coverage must still be met.

Directionalizing in the vertical planes is normally accomplished by variation in phasing among elements in the array. This may be a lumped effect, as when the lower half of an antenna is fed in such a way as to lag the upper half in phase, or it may be a smooth transition of progressive phasing throughout the length of the antenna. In either case, the net result is to tilt the main beam downward, so that it points to the horizon or below. Antennas on Mt. Wilson in California, serving the Los Angeles area, offer examples of this type of directionalizing to obtain maximum coverage of the area with the least loss of power over the ocean beyond.

Combinations of electrical and mechanical "tilt" are used when the antenna is on top of a plateau overlooking a city in which a strong signal is desired. When the electrical and mechanical tilt are made equal, the total tilt toward the city is double the electrical tilt alone, with no tilt in the opposite direction along the plateau.

In considering the formation of total patterns a word should perhaps be said on the effect of distance on this formation. With antennas having a length (or "aperture") of several wavelengths, there is a distance within which the shape of the pattern is found to vary. This occurs because the distance is so small that radiation from the separate elements comes to the receiving point at different angles from the source rather than along parallel paths. Movement changes the angles and the distances from the separate elements at an unequal rate, resulting in variations in the sums of the individual signals. The field within this region has not "stabilized," and calculations which assume parallel paths of the rays do not yield an accurate result. The region from the outer border of the near or "induction-field" zone to the point at which the rays become essentially parallel and the pattern stable is known as the Fresnel zone. Beyond this region the formed pattern takes the form investigated by Fraunhofer, and the region is known as the Fraunhofer zone. For practical purposes the distance of the boundary between the zones is

$$d = \frac{2a^2}{\lambda}$$

where a is the total aperture in wavelengths.

Gain

Directionalizing horizontal and vertical patterns has been discussed in previous sections. The object is to force the energy to radiate in directions in which it can be usefully employed. In television broadcasting, these directions involve all the region below a plane tangent to the earth's surface and passing through the antenna. The area with which we are concerned is from the base of the antenna out to points somewhat beyond the horizon. Power radiated above this region serves little useful purpose, and it is desirable to reduce it as much as possible.

To indicate the effectiveness of this directional process, the increase of signal intensity obtained thereby is related to the signal intensity which would be received from some standard reference antenna such as a half-wave dipole or an isotropic source having the same input power. The value of the ratio so obtained is called the "gain" of the antenna. A more specific definition of gain is given on page 330.

It should be noted that because of the fixed relationship between the shapes of the patterns of the two antennas commonly used for reference, a gain value as compared with a half-wave dipole can be converted to a corresponding value using an isotropic source as a base of comparison by use of a multiplying factor of 1.64.

As has been seen, the effect of adding more and more basic elements in a linear array with equal spacing between them and energized by equal currents in the same phase is to force the formation of a major lobe of energy. The result is greater gain in the direction of that (main) lobe. Gain can just as well be stated for any other direction, and at times this is done, but usually statements of gain are limited to the main-lobe direction.

Ideally, the determination of the value of gain of an antenna would be made by measurement of the received signal in the direction being considered followed by the same measurement with the reference antenna inserted in place of the antenna being evaluated. This is one of the methods in use. Various precautions must be taken to ensure accuracy, such as the construction of a theoretically exact reference antenna and recognition of the change in propagation conditions during the substitution process and of the difference caused by the electrical effect of the environmental condition (the supporting structure, for instance).

For all practical purposes, it has been found to be just as accurate to measure the radiated pattern of the antenna being considered in as much detail as is necessary to be able effectively to reproduce a solid, the distance to each point of which from the antenna position within it is representative of the relative value of field strength in that direction.

To determine the gain, it should be remembered that with the same input power to the two antennas being compared and omitting ohmic losses, the total radiated power will be the same in both cases. If, then, we imagine the solid referred to above as being remolded into a sphere (in the case of comparison with an isotropic source) of the same volume, this volume will be the same as that of the pattern of the reference antenna with the same power input. With this condition and holding the volume constant, if the pattern of the measured antenna is allowed to re-form to its proper shape, the main lobe will project beyond the surface of the sphere. The radius of the sphere and the distance to the tip of the main lobe will be in terms of volts. Corresponding powers will be proportional to the squares of these values. Comparison of these powers will give the power gain desired as compared with an isotropic source in this instance.

An illustration of this in one plane only is given in Fig. 32. The circle contains the same area as the pattern being considered and represents the field pattern of an isotropic course with the same power input. The gain in the main lobe, ignoring losses, will be

$$G = \frac{E_A}{E_i}$$

For an antenna having the same vertical pattern in all directions of azimuth, comparison using the pattern in only one plane is sufficient, since such an ideal case never exists. However, integration of the entire pattern is required to take account of directivity of the horizontal pattern and variations in the shape of the vertical patterns.

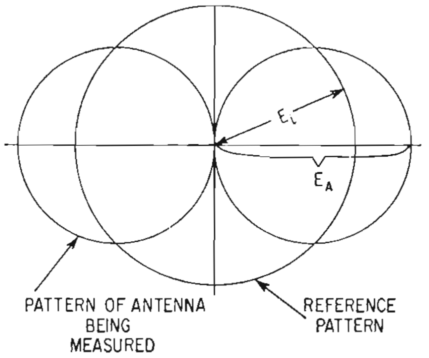


Fig. 32. Comparison of pattern of a measured antenna with circle of equal area to determine gain.

As an example, gain determination of a superturnstile antenna is found to be quite accurate if one horizontal pattern is taken along with vertical patterns every 30° about the antenna. These patterns can, of course, be computed for a given antenna if enough information of the characteristics is available to justify confidence in the accuracy of computations. Determination of the gain in this case follows the same method as with measured patterns.

The method of obtaining measured field patterns of broadcast television antennas is to support the antenna in a horizontal position at a sufficient distance from ground and nearby objects to minimize the effects of reflection. By the principle of reciprocity a signal radiated from a distant source and picked up by the antenna under test will appear at the input to the antenna with the same value as if the input and output conditions of the antenna and the distant source were reversed. This simplifies the measurement, since in this way work on the antenna and measurement of the pattern can take place at the same location with the distant source fixed and the signal simply radiated.

With these conditions, rotating the antenna about a vertical axis will provide a vertical field pattern in one plane. Revolving the antenna 30° about its own (normally vertical) axis will place it in a position where a new vertical pattern can be taken.

With the antenna at right angles to a line to the "source," revolution about its own axis will yield a horizontal pattern.

For any other position than that normal to the line to the source, an azimuthal pattern can be obtained for the angle being considered (for instance, the pattern of the variation of the maximum value of a main lobe tilted below the horizontal).

Since it is customary to measure the gain of an antenna in terms of the amount of signal radiated with the desired polarization considered effective, all energy with other polarizations being considered lost for effective use, measurement of this lost energy is also necessary, the amount being accounted for as a decrease in gain. This is usually done by rotating the polarity of the transmitting source and determining the amount of energy received for this condition by the antenna under test.

In the statement of gain for commercial purposes, losses in the feed system and radiating elements must also be accounted for.

Gain is proportioned to aperture, which, for the types of antennas used in telecasting, is the active height of the antenna. Length represents both antenna cost and an overturn load for which the tower must be adequately designed. The efficiency with which the aperture is used becomes an important criterion of antenna design. Gain per wavelength is a yardstick by which this efficiency is indicated. This yardstick must, of course, be used judiciously, since desired characteristics such as null fill and directionalizing must, in turn, be paid for in terms of gain. In general, omnidirectional broadcast antennas currently being built and used have gains per wavelength which vary between 1.05 and 0.80, depending on the amount of null fill.

It is interesting to note that for a uniform current sheet, with all elements of the sheet having equal phase and amplitude, the theoretically maximum gain per wavelength which can be achieved for antennas over two wavelengths is 1.22. With such a value, full nulls would exist throughout the pattern. No commercial antennas now in use attain this ideal value.

Impedance

Transmission-line theory tells us that maximum transfer of power takes place when a load terminating a line has the same impedance as the characteristic impedance of the line. Since the final load in a radiating system is space, it is desirable that the antenna match the impedance of space, or approximately 377 ohms, at the point of radiation.

The ease with which a signal is radiated determines the effective impedance of the antenna at the boundary with space. Thus, a logarithmic horn of the type shown in Fig. 33 flaring outward to a considerable diameter at the mouth expands the wavefront and launches it practically without interference. If the characteristic impedance of the horn (determined by the ratio of D to d) is maintained down to the entrance to the taper, that entrance (input to the antenna) will have an impedance of 377 ohms. Because the impedance throughout the elements is constant and resistive in nature, the antenna is not sensitive to frequency, signals of all frequencies being transferred equally well. This insensitivity to frequency is called "bandwidth," and the horn has nearly the ultimate in bandwidth.

A biconical dipole antenna (Fig. 15a and 15b) with flaring arms, has a similar action and an input impedance of around 300 ohms. This, too, has a large bandwidth. On the other hand a dipole with thin areas is very critical to frequency and so transfers the energy to the radiated field at a maximum rate only at the frequency where the over-all length is $\lambda/2$. At other frequencies considerable reflection occurs and the input impedance changes rapidly. At the resonant frequency the input impedance is about 73 ohms.

The input impedance of a superturnstile antenna (see under Superturnstiles) is about 150 ohms (both batwings together), of a helical antenna 100 ohms and of a resonant fullwave slotted cylinder about 40 ohms.

In each of these cases it will be seen that the antenna has, because of its construction and electrical response, effectively transformed the impedance as seen at the space boundary to some other value. If, in the process, compensation has been made so that the impedance seen by the signal is relatively constant at all frequencies involved, the antenna will have adequate bandwidth. If compensation is not made, the bandwidth will be narrow. The superturnstile, with its broad radiators and compensation afforded by the slot between radiator and pole, is very broadband. A ring or a thin-dipole antenna, on the other hand, is extremely narrow.

If the load terminating a line does not have an impedance equal to the characteristic impedance of the line, some of the power is not transferred but is reflected back down the line. Combination of this energy with that coming up the line sets up "standing waves" similar to those found at sound frequencies in musical instruments or on a vibrating string. The ratio of the maximum to the minimum voltage of such a wave is called the voltage standing-wave ratio (VSWR) and is denoted by the symbol ρ. It is used as a figure of merit to indicate the efficiency of transferal of power.

Another such figure of merit is the ratio of reflected to incident component of voltage at the load or at an impedance discontinuity. This is denoted by the symbol Γ and is called the reflection coefficient.

The values of ρ and Γ are related by the formula

$$\rho = \frac{1 + |\Gamma|}{1 + |\Gamma|}$$

A third effect of an impedance discontinuity and the resulting reflection of power is the possibility of creating an "echo," or repeated picture as viewed by a receiver. If the portion of the signal reflected from a mismatch in the line or antenna is not totally absorbed in the output circuit of the transmitter, it is rereflected toward the antenna. The part of this which reaches the antenna and is radiated appears as a second picture, to the right of the primary one, which may be of such intensity as to be very objectionable.

Where an echo causing mismatch occurs, it is possible to locate approximately the section of line in which the reflection occurs by measuring the distance between the initial picture and the echo on a receiver screen. Since the width of a picture represents 53 μ sec of time, and since a signal can travel 26,150 ft. through a transmission line and return to the starting point in this length of time, the proportion of the picture width (in inches) which the delay (in inches) of the echo represents is the same proportion of 26,150 ft. which the signal traveled before striking the reflecting mismatch. That is,

$$D = 26{,}150 \times \frac{\text{delay of echo beyond initial picture, in.}}{\text{width of receiver screen, in.}}$$

where D is the distance from transmitter to discontinuity.

It has been pointed out that antennas may transform the impedance seen at the space boundary to some other impedance at the input. If, for instance, the D/d ratio of the horn shown in Fig. 33 was changed gradually along its length, there would be a smooth transition to some new impedance looking into the input of the value

$$Z_C = 138 \log \frac{D\,(\text{input})}{d\,(\text{input})}$$

Because the horn is difficult and costly to manufacture, it is customary to use simpler and more abrupt transformations in order to match two unequal impedances. A simple and effective transformer for a narrow band of frequencies is obtained by inserting between the impedances to be matched a quarter-wave section of line having a characteristic impedance equal to the geometric mean of the two impedances. That is,

$$Z_C \text{ (of transformer)} = \sqrt{Z_1 Z_2}$$

Since the length of the transformer is $\lambda/4$ for only one frequency, the bandwidth of the transformation is small. Matches over wider bandwidths can be obtained, however, by using several such transformers end to end (thus approximating the tapered horn). Choice of proper characteristic impedances for the various sections can be made by following standard techniques or by cut and try.

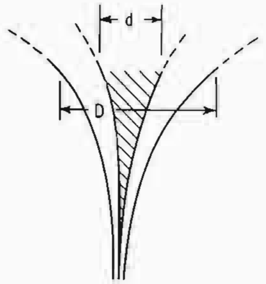


Fig. 33. Logarithmic horn used as ideal broadband radiator.

Another method of impedance matching is to choose a point in the line where the input admittance appears as pure susceptance. Insertion of a lumped susceptance of opposite sign (for instance, a disc of Teflon as capacitive susceptance) will balance that in the line and yield a matched condition. This method is good only for a single frequency.

Impedance matching of an antenna to a line can be accomplished by choosing a point to feed the antenna where the impedance of the antenna appears as the desired value. Off-center feed of a slot, for example, offers a considerable choice of input impedance.

The placement of input to a $\lambda/2$ dipole along a quarter-wave shorted stub offers again a large range of input impedance (see Fig. 34).

Bandwidth

As discussed under Impedance, the range of frequencies over which a circuit maintains a more or less constant impedance is called its impedance bandwidth. Limits of the bandwidth occur when the impedance exceeds some value agreed upon for defining the bandwidth.

Methods of obtaining this bandwidth have been touched upon. Basically they consist of so designing the antenna or intermediate transforming elements that they are not sensitive to frequency change. The horn, through its shape, presents only resistance at the input. The superturnstile

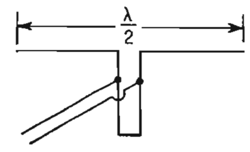


Fig. 34. Impedance matching by selection of point of feed of dipole with shunt stub.

(see under Superturnstiles), by paralleling a parallel-resonant circuit (which becomes capacitive with increase in frequency) with the series-resonant circuit of its radiator (which becomes inductive with increase in frequency), obtains a virtual cancellation of reactance over a considerable frequency range, rendering this antenna one of the most broadband television antennas in general use.

The same principle is applied in the traveling-wave antenna, which, instead of using quarter-wave stubs in parallel with the feed point as in the superturnstile, utilizes a slot whose shape provides the response of a parallel-resonant circuit.

On other antennas, broadbanding stubs and, at times, a series of half-wavelength transformers, spaced at proper intervals apart, are used to obtain impedance bandwidth.

Another interesting method, quite different from the above, is the use of a "power equalizer" to broadband otherwise narrow-band radiators.[13] A bridge diplexer (see Aural and Visual Transmissions) can be effectively used to absorb most of the power reflected from the antenna. Fig. 35 shows east and west radiators being fed 90° out of phase with north and south radiators.

The incoming signal fed from a notch diplexer on filterplexer through a single-line feed enters the visual input of the bridge diplexer and leaves it as two signals 180° out of phase (or + —). After passing through the additional 90° length on the left line, the signal in this line reaches *A* 270° out of phase with that reaching *B*. With equal reflection from *A* and *B*, the reflected signals return to the diplexer.

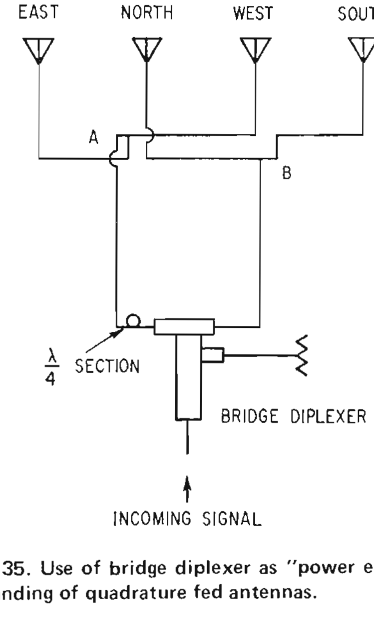


Fig. 35. Use of bridge diplexer as "power equalizer" in broadbanding of quadrature fed antennas.

The 90° section again shifts the phase in line *A*, and the two signals reach the diplexer *in phase*. The diplexer action is such that both reflected signals are now passed out through the aural input to a load which absorbs all the power. Since none return to the transmitter by way of the visual input, there is no standing wave, and the transmitter therefore appears to see an impedance match over the whole channel.

An antenna may have impedance bandwidth, but its radiation pattern may vary with frequency. That is, it may not have pattern bandwidth. This normally occurs because radiating portions of the antenna, being fixed in position mechanically relative to other elements, in effect change this relative spacing as the frequency changes (i.e., in terms of wavelength). The higher the frequencies of operation, the less sensitive antennas are to this as a general rule, because, for a given spread of frequencies (6 MHz for television), the present bandwidth (ratio of operating range, MHz/center frequency of range, MHz) becomes less at high frequencies. Thus, a change of 6 MHz at 600 MHz is only 1 percent, while at 60 MHz is 10 percent.

The traveling-wave antenna, operating normally in the vicinity of 200 MHz, takes care of the problem by incorporating circuit elements which effectively retard the phase of the signal with increase in frequency and advance it with decrease in frequency (see Traveling-wave Antenna). The result is to maintain the wavelength constant at all frequencies of a channel and so in turn to maintain the radiating elements at constant virtual spacing from each other.

Pattern bandwidth is important to the maintenance of video response. Correct relationship of amplitude and phase of signal is important at all frequencies within the channel, within the limits of good engineering practice, particularly in color transmission.

Gain bandwidth is the range of frequencies over which the gain remains constant. This is, of course, closely related to pattern bandwidth. It is particularly important in television, where it is desirable to use a given physical size of antenna over a broad number of channels to obtain approximately the same characteristics at each channel.

Feed Systems

The feed system of a television broadcast antenna is commonly considered that portion of the transmission system having its input at the antenna terminal which is at the top of the vertical run of coaxial transmission line in the tower and its output at the radiating elements.

Most antenna gains in the manufacturers' literature take the losses of the feed system into

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[13] R.W. Masters, A Power-equalizing Network for Antennas, *Proc.* IRE, July 1949, p. 735.

account, which are considered as reduced antenna gain. Therefore, when system losses are calculated, the feed-system loss should be excluded, having already been accounted for.

Types

In the television broadcasting field, three types of feed systems are in wide use. They are the branching, standing-wave, and traveling-wave feed systems. Each meets a need peculiar to its own application. Where frequencies vary from 54 to 890 MHz, where power-handling-capacity requirements vary from 500 to 120,000 watts, where gains vary from 0.5 to 60, and where pattern shapes vary between extreme limits, it is logical that good economics dictates various types of feed systems.

Branching. The branching-type feed system is used in the superturnstile antenna. It is characterized by the progressive subdivision of input signal in a more or less uniform manner, from the input of the antenna to the end seals. A large majority of the antennas using this feed system accomplish the subdivision of power by means of a junction-box assembly into which is plugged the individual radiator feed lines.

Standing Wave. The standing-wave-type feed system is used in slotted-cylinder UHF antennas. For details refer to *Slot Types* on page 349.

Traveling Wave. The traveling-wave feed system operates on the principle of a gradual attenuation of the input signal through radiation resistance as it progresses from the input along the aperture of the antenna. An application of this principle is the helical antenna. Page 362 gives more details. A more recent development is the application of this feed system to a cylindrical-slot antenna known as the traveling-wave antenna described on page 363.

Fig. 36a shows the principle of this feed system using short rod radiators to illustrate the theory. A number of radiators per wavelength uniformly spaced are loosely coupled to a coaxial line. Because of the number of radiators and the relatively slight reflection due to each, the effect is essentially that of a uniform loading. The result is a uniformly attenuated traveling wave in the line. Since a traveling wave has a linear-phrase characteristic, the excitation of each successive radiator will be lagging from the previous one by an amount which depends on the spacing between the radiators and the velocity of propagation in the line. If the radiators are alike, their currents will have the same phase relationship as the excitation. Thus the radiating currents will be successively lagging, and repetition of phase occurs after every guide wavelength.

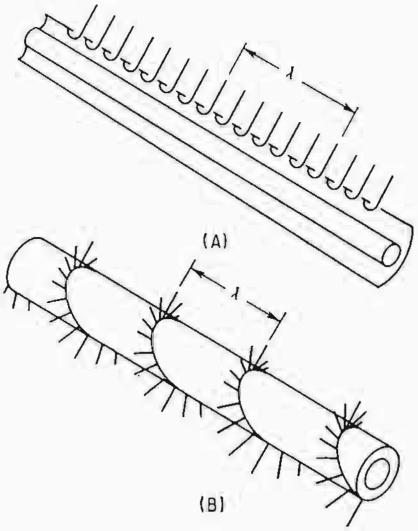

Fig. 36. Basic principles employed in the traveling-wave antenna feed system.

To obtain an omnidrectional pattern the radiators, instead of being in line, can be moved around the periphery to form a "spiral" as shown in Fig. 36b. For a horizontal main beam the pitch of the spiral has to be equal to the guide wavelength in the transmission line. In this arrangement all the radiators in any one vertical plane on one side are in phase and the phase difference between radiators in different planes equals the azimuth angle difference between the planes; that is, the phase rotates around the periphery. The rotating phase produces a rotating field which, because of the relatively small amount by which the magnitude of current changes from layer to layer, produces an omnidirectional pattern.

Aural and Visual Transmissions

For the broadcasting of standard television signals, the video-signal amplitude modulates a separate visual transmitter and the audio-signal frequency modulates a separate aural transmitter, the output of which is generally one-half the peak visual power output of the visual transmitter. To radiate these two separate signals, various techniques can be employed.

Separate antennas. Separate antennas can be used, one to radiate the visual signal, the other to radiate the aural signal. When this procedure is used, a separate transmission line connects the output of the particular transmitter to the input of the respective antenna. Two precautions should be observed: (1) The isolation of the individual antennas must be sufficient to prevent interaction and cross modulation within the systems. (2) The patterns of the individual antennas must be sufficiently alike so that the ratio of the visual signal to the aural signal is neither too large nor

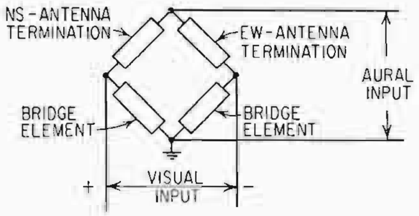

Fig. 37. Bridge diplexer represented as a Wheatstone bridge.

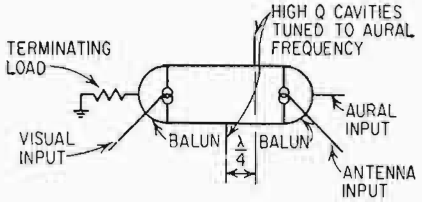

Fig. 39. Notching diplexer schematic.

too small. An example of this kind of installation is the use of the upper half of a superturnstile antenna for visual and the lower half for aural transmission.

Bridge systems. The bridge diplexed system of antenna feed is used in the superturnstile antenna. The complete antenna is fed through a bridge network where the two inputs are in quadrature. The radiating systems are also arranged in a quadrature relationship so that the azimuthal pattern is substantially circular as described under Azimuthal Patterns. The north-south system, which radiates a figure-eight horizontal pattern is constructed in a vertical plane at right angles to the plane of the east-west system, which also radiates a figure-eight pattern with 30 dB or more isolation between the two systems. Each of these radiating systems forms a termination for the two legs of the "Wheatstone-bridge-type diplexer" as shown in Fig. 37. The visual signal is fed into the bridge balanced to ground, and the aural signal is fed in unbalanced to ground.

The superturnstile antenna can be fed with a "ring-T" type of diplexer, which also requires a two-line feed as illustrated in Fig. 38.

Notch diplexer. Where an antenna has a single input, a network for combining the visual and aural signals is required. One type of circuit which accomplishes this function is shown in Fig. 39. The aural signal, divided by means of a balun (*bal*anced to *un*balanced network[14]), is reflected from the cavities tuned to aural frequency. These cavities are arranged so that they present a very low impedance across the line. Because of the quarter-wave separation the aural signal on the lower line in the figure travels an additional half wave to and from the cavity reversing the phase so that the signal enters the balanced antenna terminals instead of returning to the unbalanced aural input. Any aural energy which leaks past the cavities is absorbed in the terminating load.

The balanced visual signal enters the balanced antenna terminals. Any energy in the visual signal which is at the aural frequency is rejected and because of the quarter-wave separation of the cavities is reversed in phase and is absorbed by the terminating load. In order to obtain the proper visual response, a shaping cavity is sometimes associated with each aural cavity.

Filterplexer.[15] A vestigial-sideband filter is a device used with some types of transmitters to absorb the rather small lower sideband energy lying outside the 6-MHz channel. When a notching diplexer is used, it is desirable to combine the visual-sideband filter and the notching diplexer into a single unit.

This is accomplished in a manner similar to the notching diplexer described above. As shown in Fig. 40, two additional pairs of cavities are used on opposite sides to provide reject points in the portion of the lower sideband lying outside the 6-MHz channel. The rejected lower-sideband energy is dissipated in the terminating load.

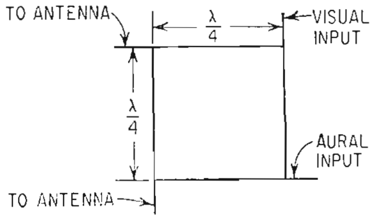

Fig. 38. Ring T diplexer schematic showing inner conductors only.

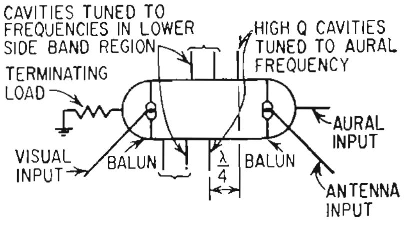

Fig. 40. Schematic of filterplexer.

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[14] Balanced is sometimes referred to as push-pull, and unbalanced as push-push.

[15] Also designated as a Filtrexer.

Isolation using traveling-wave feeds. On an antenna which employs a traveling-wave-type feed, the input power is radiated as the signal proceeds away from the input along the aperture. By the time the signal arrives at the end of the aperture, it should be so low that the reflected energy from the end is quite small. In practical designs this energy is about 20 dB below the input. Therefore, if the visual signal is fed at the center of the aperture, the aural signal can be fed at the ends. The helical antenna described on page 000 uses this method of feed.

Multiple Antennas

In an area where two or more television stations are providing coverage, various advantages accrue to the broadcasters if they enter into what is referred to as a multiple-antenna installation.[16] These advantages include reduced costs of individual tower and better reception, since all receiving antennas can be oriented toward the common source of radiation. Furthermore, the fact that tall towers can be located only in limited areas, owing to air-space restrictions, offers a further incentive for a common installation.

Multiple TV Installations

The most notable multiple television installation is the Empire State tower system. At present there are nine television stations radiating signals from this structure. Three installations (in Minneapolis, Minn.; Havana, Cuba; and Hamilton, Ontario) provide three-station operation with vertically stacked antennas. Many installations provide for two stations with vertically stacked antennas.

Instead of mounting the antennas vertically, some have found it more desirable to mount their antennas on a common platform at substantially the same elevation. Illustrations of this approach can be found in Baltimore, Maryland; Dallas, Texas; Houston, Texas; and Stockton, California. These involve primarily VHF installations. There are also UHF installations in Boston, Massachusetts; Detroit, Michigan; and Washington, D.C.; and Cleveland, Ohio.

AM and TV Installations

There are occasions when an existing AM tower can be adapted for a television antenna. Usually two problems must be faced. First, a portion of the tower must be removed to accommodate the television antenna so as to minimize the detuning effect of the AM system, and second, the wind load of the television antenna over the portion of tower removed and the transmission lines running the full length of the tower is increased. The ability of the tower to withstand this load must be determined. The costs of alterations must be considered in relation to the cost of a new tower.

A further consideration is the need for isolating the television transmission lines from ground in order to mount on the AM tower. This is usually accomplished by the use of insulated hangers for one-quarter wavelength along the tower. This same problem must be faced where it is intended to mount a television tower in the proximity of an AM array. The television tower is insulator-mounted, and the transmission lines are isolated with a quarter-wave run of insulated hangers.

Systems Planning

Many times, the individual aspects of a television installation are meticulously scrutinized, and yet how they work together is given secondary consideration. An exhaustive check list would be almost endless. But a few important items are listed:

1. Detailed study of coverage taking terrain and competitive signals into account
2. Antenna location relative to population centers
3. Antenna vertical pattern design for best coverage
4. Antenna mounting methods
5. Layout of transmission lines
   a. In the vicinity of the tower top
   b. Main tower run
   c. Horizontal run to station
6. Transmitter and associated equipment locations
7. RF filter networks and load locations
8. Station layout
9. Emergency provisions
   a. Emergency antenna
   b. Emergency transmission lines
   c. Standby provisions
   d. RF switching features

A few of these will be discussed in more detail.

Propagation Study

In hilly terrain, especially at higher frequencies, shadow areas will occur which cannot be predicted from FCC curves. A method of predicting is outlined on pages 330.

Antenna Mounting Methods

Most antennas are flange mounted and manufacturers—either in their catalogues or upon request—will furnish mechanical and mounting

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[16] Predicting the Operating Characteristics of Closely Spaced Antennas on the Same Supporting Structure, by Irl T. Newton, Jr., and M.S. Siukola, presented at the 11th Annual NAB Engineering Conference, April 1957.

data for their antennas. Standard mounting bolts are usually furnished with the antenna. If a special double plate design or other design is used in the tower top, the antenna manufacturer should be advised so that the proper bolts can be furnished. If a new antenna is substituted for an old one, an adaptor plate may have to be designed and furnished by the tower manufacturer.

Layout of Transmission Lines

In the vicinity of the tower top. Usually, it is desirable to avoid as many elbows in a system as possible. However, near the tower top, it has been found advisable to have from two to four elbows at the top of the vertical run in order to provide access to the system. It also provides a measure of mechanical flexibility, depending on the horizontal length of line between elbows. This flexibility is very desirable. The amount required is dependent on the movement, due to antenna sway, expected from the lines coming down from overhead.

Where complicated circuitry involving power-dividing Ts, transformers, phasing sections, and cut-over elbows (for an emergency feature) are used, considerable thought should be exercised in planning the hanger supports and line layout in cooperation with the tower designer.

Since mismatches at or near the antenna are the most potent source of echoes, any equipment in this area should be specially optimized to a VSWR value of 1.015 or lower.

Main tower run. Normally, in tower-transmission-line runs composed of 20 ft. sections, the top section is supported with two fixed hangers spaced 10 ft. apart and the sections below on spring hangers located on 10-ft. centers. Care must be applied at installation to locate the transmission-line sections so that the hanger springs do not cross over or rub against the transmission-line flanges. When the spring hangers are installed, they should be stretched according to the chart supplied by the manufacturer. If this is not done properly, it may require an excessive pull to separate the line in hot weather and the line may not be supported adequately by the springs in cold weather. At the base of the tower, clearance must be provided to accommodate the differential expansion of the steel tower and copper transmission line.

Horizontal run to station—The length of the vertical run—which determines the amount of differential expansion between the copper transmission line and the steel tower and the length and size of the horizontal run—which determines the amount the line can bend without damage—must be taken into account. Transmission line manufacturers usually furnish curves or nomographs which provide this information. If the horizontal run is too short, it may be necessary to anchor the line near the transmitter rather than at the station wall which introduced complications. The length of the horizontal run required is an important item in the overall planning.

The horizontal run should have a protective shield from falling ice where such a condition exists.

RF Filter Networks and Load Location

The sideband filter, filterplexer, and similar networks should be located with sufficient clearance so that easy access to all portions for servicing and cleaning is possible. While ceiling mounting conserves floor space, accessibility of all elements should still be a consideration. Since many of these devices use cavities which cannot be pressurized, a clean atmosphere is important, since dust accumulation inside the cavity will eventually cause trouble. Cavities should be arranged so that they are in the same ambient temperature. A difference in height when a high-temperature gradient exists or sun heating of one cavity may result in unbalance. Since hot air is less dense than cooler air, a hot location will reduce the safety factor for voltage breakdowns.

Emergency Provisions

It has always been the desire of the broadcaster to keep the ratio of nonscheduled "off-the-air" time to schedule "on-the-air" time as small as possible—preferably zero. An efficient maintenance procedure is excellent insurance. Emergency facilities can also help to keep this ratio small. A great variety of items are available. A word of caution—do not make the emergency provisions too complex and check their operation periodically.

Emergency Antenna. The simplest emergency-antenna provision is that found in the superturnstile, where, if one portion of the antenna fails, the power going to that half can be absorbed in a load while the other half continues to provide some measure of service with a figure-eight pattern. In various antenna designs the power is distributed to the upper and lower halves through combining networks mounted at the tower top. Simple change-over equipment permits the selection of either the upper or lower half for emergency service. Relatively low-gain antennas have been used mounted on the sides of towers and some inside towers for emergency use. It must be remembered that the tower will distort the antenna pattern.

Emergency transmission line. One extra provision of insurance can be provided by the installation of a spare transmission line so located that it can be inserted in place of the main run with a minimum of change-over connections at the input and output. It is wise to use gas stops at both ends and keep it pressurized.

Standby provisions. How much insurance one wishes to buy in the form of standby equipment can be based on the losses incurred by interrupted service. Where broadcasters have expanded their operations to higher power, the replaced transmitters have been retained for standby use. In some new installations broadcasters have obtained duplicate transmitters and worked them both on alternate schedules. In addition to this excellent emergency feature, a large portion of maintenance work can be scheduled during regular working hours. A standby Diesel generator set, duplicate microwave equipment, duplicate RF networks, and duplicate tower and antenna all contribute to potentially more reliable service.

RF switching features. Perhaps the most common emergency feature is the cutback circuit from transmitter amplifier to driver. This usually is performed quite rapidly using motor-driven RF switches. Where a standby system, including transmitter and RF networks, is available but a common antenna is used, motor-driven RF switches can be inserted to transfer the input of the antenna from the main transmitter to the standby system. Many elaborate cutover and cutback systems have been proposed.

In many switching applications the speed of the motor-driven switch is not required and a manual transfer panel is adequate. To terminate various points in the RF system with a dummy load, it has been found convenient to install a single-pole double-throw switch to break open a line so that the load termination can be made by way of a separate multiposition manual-transfer panel.

TYPES OF ANTENNAS

The development of television was such that Channels 2 through 13 (54- to 216-MHz band) were assigned first and, later, with the demand for more stations, Channels 14 through 83 (470- to 890-MHz band) were assigned. The lower of these two bands, referred to as VHF, resulted in antenna types suited to those frequencies. The higher of these two bands, referred to as UHF, required a type different from those previously developed.

VHF Antenna Types

Even within the VHF band various applications dictated antennas of differing designs for both electrical and mechanical reasons.

Superturnstiles

The first antenna developed for commercial service was the Superturnstile.[17] It consists of a central sectionalized steel pole upon which are mounted the individual radiators, or "batwings." These radiators are mounted in groups of four around the pole in north-south and east-west planes to form a "section," and the sections are stacked one above the other to obtain the desired gain. Fig. 41 illustrates this construction showing a 6-section high-band Channels 7 to 13 antenna.

In this type, each of the radiators is fed separately by its own feed line to whose impedance that of the radiator is carefully matched. The feed lines, in turn, are combined at junction boxes, which perform the dual function of feeding power simultaneously to all feed lines and of transforming the combined impedance of these lines to that of the transmission line which carries the power from the base of the antenna. This latter function is achieved by the use of three-stage transformers immediately below the junction box.

At the base of the antenna at the tower top, a combining network is used when there are more than two junction boxes. These networks accomplish power division between portions of the antenna if so desired. These antennas are manu-

Fig. 41. Six Bay Channel 9 Superturnstile Antenna (JAMPRO Photograph).

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[17] R.W. Masters, The Superturnstile Antenna, *Broadcast News*, January 1946.

factured in various gains from 3 to 12 for Channels 2 to 6 and 6 to 18 for Channels 7 to 13.[18] They can also be obtained for various types of null fill[19] (see under Vertical Patterns) and wind loading. They have also been used in stack and candelabra installations.[20] Antennas can be split by the use of additional junction boxes for emergency use and for other purposes. Elliptical azimuthal pattern can be obtained by changing the power division between the north-south and east-west planes. This antenna can also be used for two channels. A number of them are operating at Channels 4 and 5 and also in various combinations in the Channel 7-13 range. Copper feed lines instead of aluminum are available in areas where salt incrustation occurs but where there is insufficient rain to wash it off. Feed lines in both 3/4-in. and 7/8-in. sizes are available depending upon the power rating required. Special antennas can be built for higher power ratings. This antenna is currently manufactured by General Electric, JAMPRO, and RCA.

Alford Delta-Dipole Antenna

The delta-dipole antenna (see Fig. 42) consists of specially shaped, broadband dipoles mounted on reflecting panels. This special shape, which gives the dipole a delta-wing appearance, increases the effective area of the dipole arms, thereby increasing the bandwidth of the dipole without substantially increasing its resistance to wind pressure. Groups of dipoles and panels are arranged as required, both horizontally and vertically, so as to produce the desired horizontal and vertical radiation patterns.

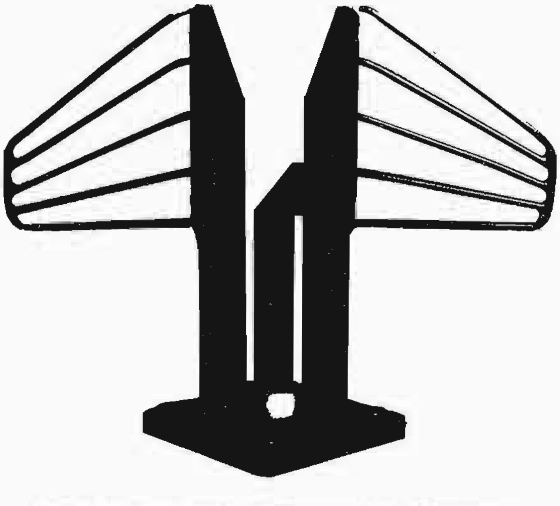

Fig. 42. Delta Dipole Antenna (Alford Photograph).

This antenna lends itself to situations where it is necessary to mount an antenna around a tower or to stack several antennas one above the other. Because of its bandwidth, the delta-dipole also lends itself to situations where it is desirable to combine more than one channel in a single antenna. Both omnidirectional and directional horizontal radiation patterns may be achieved by the proper choice of power division and element phasing between dipoles in any given layer.

Because the distance between the radiating element of the dipole and the reflecting panel is large (of the order of one-quarter wavelength), ice on the reflecting panel has no significant effect on the operation of the antenna, and only parts of the dipole itself require deicing.

AMCI Slotted-ring Antenna

Description. The AMCI slotted-ring antenna is designed for VHF television broadcast transmitting service. It consists of a series of slotted rings mounted on a channel as shown in Fig. 43. The rings are lenticular in cross section with the long axis in the plane of the rings so that the wind resistance of the structure may be as low as possible. Two rods are mounted to the rings, parallel to each other, one along each side of the open portion of the rings to form a continuous slot and to act as a balanced transmission line. Fig. 44 shows a larger portion of the slotted-ring antenna mounted on a supporting mast. In certain instances, the antenna can be mounted directly on the side of a tower.

Each bay consists of two radiating elements ("half bays") arranged one above the other and

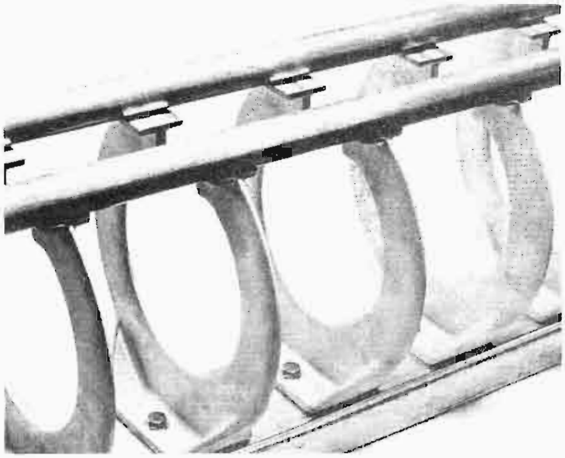

Fig. 43. Portion of a slotted-ring antenna.

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[18] H.H. Westcott, New 50 KW VHF Superturnstiles, *Broadcast News*, May–June, 1953.

[19] Irl T. Newton, Jr., and H.H. Westcott, The New 12BH High Gain Antenna, *Broadcast News*, March–April, 1954.

[20] Matti Siukola, Predicting Performance of Candelabra Antenna by Mathematical Analysis, *Broadcast News*, October, 1957. R.H. Wright and J.V. Hyde, The Hill-Tower Antenna System, *RCA Engr.*, August–September, 1955.

Fig. 44. Portion of a slotted-ring-antenna bay.

fed with a single 3-1/8-in.-diameter rigid coaxial transmission line.

The antenna is provided with a feeding arrangement of a type which enables each bay to handle high power and allows the entire exposed feeder along with every other active part to be deiced. When necessary, tubular sealed heaters are supplied as a part of the antenna for deicing purposes.

Each bay is approximately 3.4 wavelengths long and has an average power gain of approximately 4. As many as five bays can be stacked one above the other to give additional gain, the gain being proportional to the number of bays used.

When several bays are stacked to give a higher gain, they are joined through the use of a rigid coaxial transmission-line harness into a single feed line for the entire array. This type of feed requires only a single transmission line from the transmitter up the tower to the array.

Null fill-in and/or beam tilt, where required, are achieved through the proper selection of line transformers and transmission-line lengths in the coaxial feed lines between the bays.

The horizontal-radiation pattern of the slotted-ring antenna itself is essentially circular, with slight maxima along a diameter which passes through the slot of the antenna and with slight minima at approximately right angles to this diameter as shown in Fig. 45a. Since the potential at the point of attachment to a supporting mast is small, masts of adequate size can be used without substantially affecting the operation of the antenna or its horizontal circularity.

Directional horizontal-radiation patterns are achieved by the addition of pattern-shaping members to the basic antenna. Usually, there are two beam-shaping members connected to each alternate active ring in a directional antenna. The rings provided with these members act differently from simple rings in that a substantial portion of the current which normally flows in a ring is

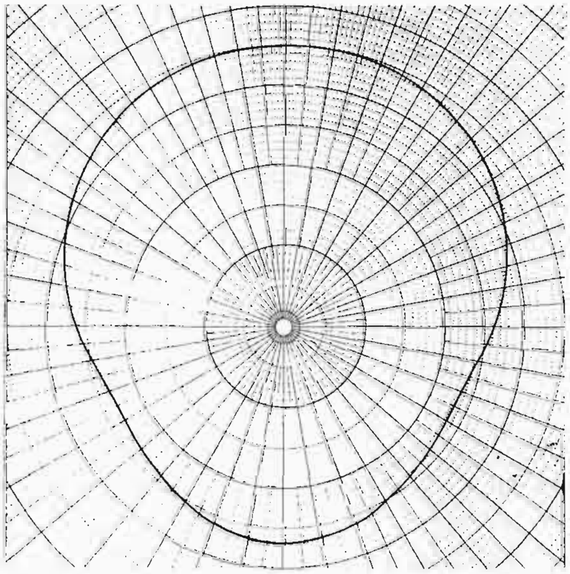


Fig. 45a. Typical omnidirectional horizontal radiation pattern, relative field.

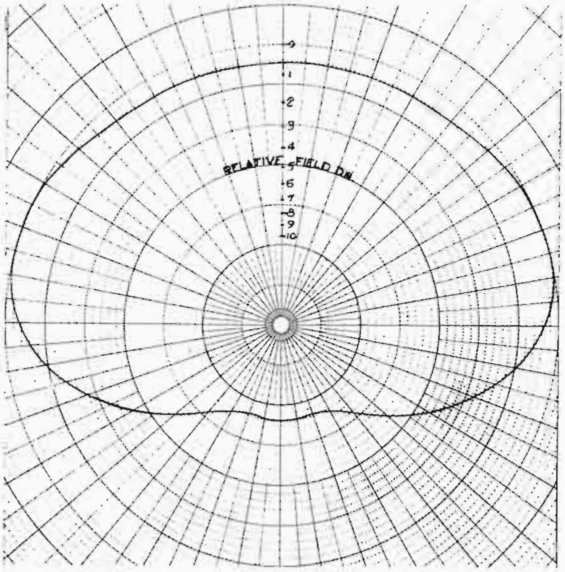
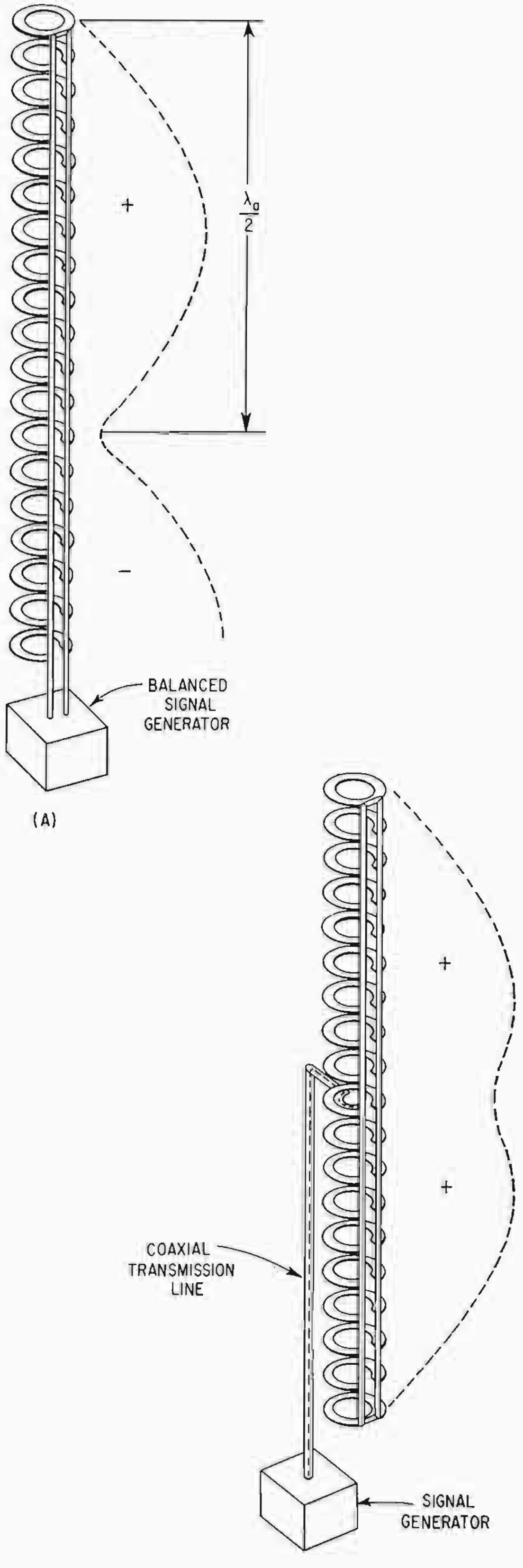


Fig. 45b. Typical directional horizontal radiation pattern, relative field.

directed into the beam-shaping member. The radiation pattern of a directional-antenna bay, then, depends on the configuration of these additional members and on the proportion of modified loops. Fig. 45b shows a typical directional horizontal pattern of a modified slotted-ring antenna.

Theory of operation.[21] The operation of the slotted-ring antenna can best be understood by considering a balanced transmission line shunted by a number of small loops or rings. It is possible by arranging the separation and cross-sectional area of the rings substantially to increase the phase velocity at which a high-frequency wave is propagated along the transmission line. Fig. 46a shows such a loaded transmission line which has been short-circuited at one of its ends and is fed with an RF source at the other. The standing waves which are set up along the line have an apparent wavelength, λa. When the number of rings along the balanced transmission line is of the order of 12 per free-space wavelength and the diameter of each ring is of the order of 0.14 free-space wavelength, the apparent wavelength will be approximately twice the free-space wavelength.

If this same arrangement is fed at the center through a length of transmission line as shown in Fig. 46b and short-circuited at both ends, then a wave propagates from the center feed point toward each of the two short circuits. The reflections from these short-circuited ends set up a standing



(A)

(B)

Fig. 46. (A) Balanced transmission line loaded with shunt rings. (B) unbalanced transmission line loaded with shunt rings.

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[21] A. Alford and H.H. Leach, High-gain Antenna Arrays for Television Broadcast Transmission Using a Slotted Ring Antenna, *IRE Conv. Record,* part 7, pp. 87–94, 1956.

wave, and the difference of potential between the conductors of the balanced transmission line is distributed approximately as shown by the dotted line. The phase of this difference of potential is substantially constant over the entire length of the line.

The potential which exists between the balanced conductors causes circumferential currents to flow in the shunting rings. Since the potential and hence the currents are very nearly cophasal, the overall behavior of the loaded line is similar to that of an array of closely stacked loops. This fact results in a substantial concentration of the power radiated by the rings in the direction of a plane passing through the halfway point along and perpendicular to the balanced conductors.

Construction. Corrosion-resistant aluminum alloys, both wrought and cast, are the primary materials of construction in the AMCI slotted-ring antenna. Stainless-steel screws and bolts are used throughout the antenna. The total weight of a bay is approximately 300 lb. when designed to operate at Channels 7 or 8, with the higher channel bays weighing slightly less.

There are two Teflon seals per bay. The diameter of the inner conductors which pass through these seals is approximately 1-3/4 in. The outer-conductor diameters are approximately 3 in.

The antenna itself is designed to withstand wind velocities exceeding 200 mph and to present a small surface area to the wind. The antenna can be mounted on a standard mast (designed for a wind loading of 50 psf on projected flat surfaces), on special masts (designed for larger wind loadings), or, in certain instances, on the corner of a tower.

GE VHF Helical Antenna General Description

The VHF helical antenna is essentially a coil of uniform pitch wound around a usually round mast section. A left-hand and a right-hand helix are used, joined at the center.

In operation, a radio-frequency wave is established which travels between the helix wire and ground "plane" formed by the mast. The wave thus travels circumferentially around the mast, turn after turn. It progresses axially up or down the mast because of the pitch of the helix.

The antenna is designed to radiate in "side-fire" fashion, that is, the beam maximizes at right angles to the helix axis. In order to have successive turns of the helix work together to give additive side-firing fields, each helix turn has a circumferential length equal to an integral number of wavelengths. The two-wavelength turn is most commonly used because it yields good structural dimensions.

While the wave travels circumferentially around the helix, it radiates power and becomes attenuated. The attenuation rate depends on the spacing of the helix coil from the mast. A value of attenuation of 3 to 6 dB per turn is used, depending on the channel, gain, and bandwidth requirements.

In traveling axially up or down the helix, the radiating wave distributes the radiation over the length of the helix. This results in excitation of a fairly large aperture from a single feed point and so gives a considerable gain per feed point. Nominal values of gain per feed are between 3 and 5 rms over a dipole. This makes it possible to simplify the feed harness because of the fewer number of feed points required for high-gain antennas.

The turn-to-turn phase of the radiating traveling wave determines how well the side-fire beam is formed. This phase varies as the frequency changes from its optimum center value. Over a certain frequency range, there is a mode over which the beam formed is quite uniform in its main characteristics. Outside this range the beam broadens and gradually breaks up. The frequency range over which a certain sized helix can be used depends on its attenuation rate and number of turns. For example, a helix pair giving a gain of 5 per feed forms a good beam over about 6 to 7 percent frequency range. For a gain of 3 per feed, this increases naturally to about 10 percent. The beam-forming bandwidth can be increased further by suitable electrical "loading" of the helix, which alters its phase-velocity versus frequency relationship.

The radiating traveling wave does give very good VSWR characteristics because there is very little resonant energy in the helix. The wave energy reflected from the ends of the helices is down about 40 dB when it returns to the feed, and so it affects the feed impedance very slightly.

In those cases where horizontal directional patterns are desirable, the azimuthal radiation of the helix can be modified. This is usually done by attaching radial or tangential stubs directly to the helix. These stubs are short compared with a wavelength and are nonresonant.

To maintain optimum performance under icing conditions, the helical antennas can be provided with deicing means. The helix itself, being made of copperweld material, is used as the heater. Several hundred amperes of 60-cycle current are caused to flow through the helix from a transformer located at the tower top. A nominal deicing power density of about 2 watts per square inch of helix is used for normal conditions.

High-channel helical antenna, Channels 7 to 13, specific description. These antennas are built in a standard series by General Electric. Gains vary from 4 to 18, from one to four bays being used.

The mast is made from 20-24 in.-diameter steel tubing or piping, varying in thickness from 1/4 to 3/4 in. for different sections.

The helix is made from 0.365-in.-diameter copperweld material. It is supported on insulators made from Teflon or PPO. A low-loss, low-dielectric-constant material is preferred. Height of the insulators is adjustable to accommodate helix-diameter changes needed for on-channel moding.

Feed systems provide either single or two-line feed up to four bays. The standard feed harnesses use 3-1/8-in. EIA-type line as a minimum. The one-bay antenna may use 6-1/8-in. lines to permit full ERP operation from one bay, say with a 100-kw transmitter.

Nominal feed impedance at the helix is about 100 ohms. A quarter wave of 70-ohm line is used to transform this to the 50-ohm EIA standard. An elbow with end-seal mounts through a hole in the mast provides means for attaching and feeding the helix.

Mechanically, the feed harness is so arranged that pieces of harness can be lowered inside the mast after loosening bolts from outside the mast only. Fig. 47 shows a three-bay, high VHF band, helical antenna.

Traveling-wave Antenna

The traveling-wave antenna embodies principles found in the operation of the superturnstile, the slot antenna, and the helix but employs these principles in a manner which results in its being different from any of them.

In form the antenna is a coaxial line, with pairs of slots in the outer conductor spaced at intervals of a quarter wavelength throughout its length. Probes at the center of each slot distort the field within the line to place voltages across the slots. These, in turn, drive currents on the periphery, setting up a radiated field. Attenuation of the signal by withdrawal of a portion of the power at each slot reduces it to a very low value at the upper end of the antenna. There, a special pair of slots, designed to match the line, extracts the remaining portion and radiates it.

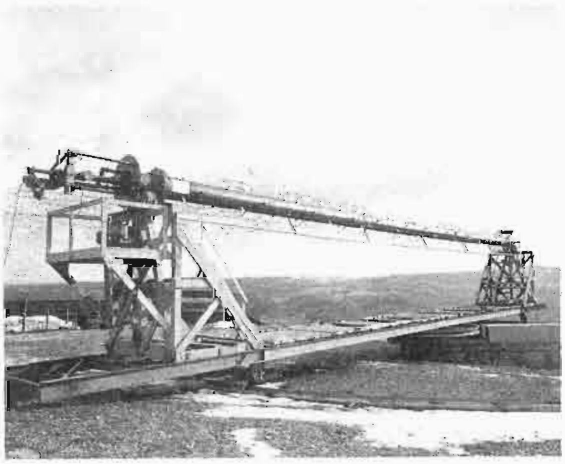

Fig. 47. Three bay, VHF high band Helical Antenna (GE Photograph).

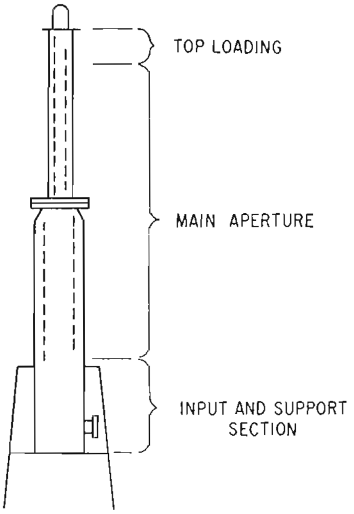

Fig. 48. The traveling-wave antenna-external appearance.

Fig. 48 shows the physical shape of the antenna. The signal, entering through the input section (normally in the buried portion below the tower top), is progressively attenuated as it passes through the main aperture. The portion reaching the top is radiated from the "top-loading" section.

Fig. 49 shows cross sections of the antenna in the three main portions. It will be noted that the

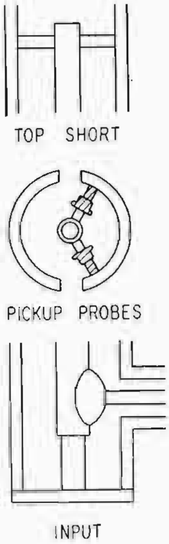

Fig. 49. Cross section of traveling-wave antenna at input, aperture, and top.

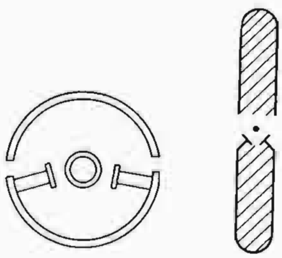

Fig. 50. Cross section of traveling-wave antenna at a slot pair level, showing resemblance to a dipole.

entire inner connector is supported by the base plate of the antenna and can be removed through this base.

Operation of the antenna can be better understood if the section of the aperture having pairs of slots are recognized as being, in effect, dipoles. Fig. 50 shows this similarity.

Successive pairs of slots are alternately in one plane and in another at 90° to it, so that the antenna can be simulated by stacked dipoles with a 90° angle between successive layers.

In a given plane, reversal of the direction of feed every half wavelength (by placing the probes on opposite side of the slots), together with the half-wave change in phase of the signal as it passes along the aperture through this distance, results in all the "dipoles" in that plane being fed in phase. The same action takes place in the other plane except that they are fed 90° out of phase with the first plane owing to their 90° displacement along the antenna. The result is shown in Fig. 51.

Each plane of dipoles radiates essentially a figure-eight pattern. Since the planes are fed in quadrature, addition of the patterns results in a circular pattern, as outlined under Azimuthal Patterns. Because of the circular cross section and the lack of obstructing radiators, the resulting horizontal pattern is almost a true circle, varying from circular by only about 0.5 dB in a typical case.

As slot spacing is actually 90° only for a specific frequency in the channel, variation in frequency across the channel would be expected to result in a progressive lag or lead in the signal as radiated from successive slots inasmuch as the spacing becomes greater than 90° for higher frequencies and less than 90° for lower frequencies. Correction for this effect would obviously be accomplished if, at each slot pair position, another circuit element were added which, with change of frequency, had the opposite effect on the phase.

Such an element is available in the form of a parallel-resonant circuit with resistive loading with its familiar reactance characteristics (Fig. 52). The resistive portion is the radiation resistance.

In the region between 1 and 2 (Fig. 52), increasing frequency results in a lower inductance (higher capacity) while decreasing frequency yields a more inductive circuit. If this circuit is placed across the transmission line at a slot position, the effect will be to cause the voltage at this position to lead the voltage at the preceding slot at high frequencies and to lag it at lower frequencies within the frequency range 1 to 2 (Fig. 52).

By adjustment of the values of inductance and capacity the slope of the response curve can be changed until a compensation is obtained over a considerable frequency range for the apparent change in line length between slot pairs due to frequency change.

The above circuit is obtained by shaping the slots to obtain the required value of inductance and capacity, the length of the slot and the shape of the end portions controlling the former and the width of the slot at the center of the latter.

A further control of the phase at each slot is obtained by the insertion between slots of compensating probes. By means of these, the phase can be made progressively more lagging from top to bottom, bringing about a downward tilt of the main beam if desired.

Omission of particular slot pairs is a method which has been used to obtain special effects such as reduction of signal at a particular angle in the vertical plane to "protect" areas where radiation is undesirable. Such a situation has arisen where important radio-frequency measurements on

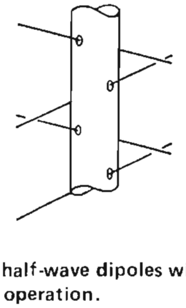

Fig. 51. Stack of half-wave dipoles which traveling-wave antenna resembles in operation.

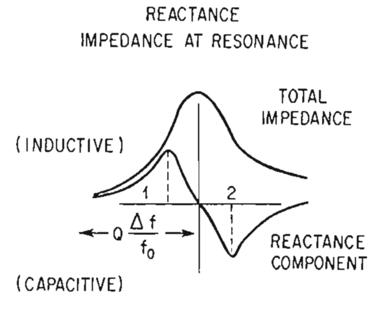

Fig. 52. Universal curve (high-Q parallel-resonant circuit).

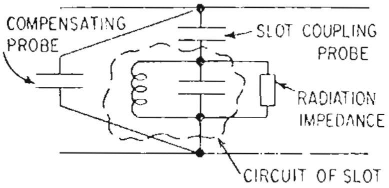

Fig. 53. Equivalent circuit of one slot pair section of traveling-wave antenna.

equipment being manufactured in a particular location would have been disturbed by the reception of television signals.

This equivalent circuit of each layer is shown in Fig. 53.

VHF Zig-Zag Antennas

The general principle is the same as that described under the UHF section on Zig-Zag antennas.

The Empire State Building in New York City has a GE installation on Channel 11 and an RCA installation on Channel 7. The length of the aperture is about four wavelengths in each case. There is also an RCA installation on Channel 9 in the John Hancock Center in Chicago. The length of the aperture in this case is six wavelengths. Another RCA installation is at KCRG which has two six-wavelength panels for a total gain of 12. The gain is about equal to the aperture in wavelengths.

The coupling probes are all set at the same depth. As a result, the same percentage of power arriving at the slot location is picked up and radiated at each slot. The amount of power so radiated is therefore decreased exponentially from the bottom to the top of the antenna, giving the effect of a constantly changing power division except for the elimination of slots necessary for the insertion of flanges, and for the change at the top-loading slots. The result is a smooth vertical pattern without any nulls. The flanges and top loading cause a small ripple in the pattern, but the effect is slight. Fig. 54 shows a typical vertical pattern of a traveling-wave antenna with a gain of 12.

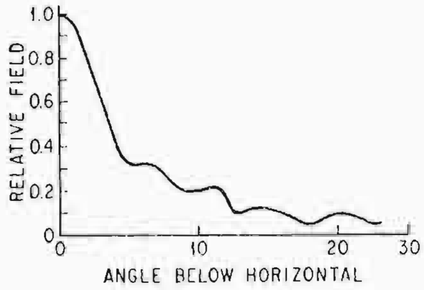

Fig. 54. Vertical field pattern of traveling-wave antenna with gain of 12.

Because the slots are a quarter wave apart, giving an impedance-compensating effect similar to that of insulators similarly spaced in a coaxial transmission line, and because the slots are only lightly coupled into the line, there is almost no reflected energy returning to the input of the antenna. The action of the top loading further reduces the chance of energy reflection. As a result the standing-wave ratio at the input is inherently low, and no input-matching transformers are required to broadband the impedance.

As the antenna is primiarly a large-size transmission line, the power-handling capacity is very high.

The antenna tubing is of steel, hot-dip galvanized. The inner conductor is copper tubing. Hardware is of stainless steel with the exception of the probes, which are of aluminum treated to resist atmospheric corrosion. The slots are covered with polyethylene covers to keep out rain, snow, and ice.

Fig. 55 shows a portion of a traveling-wave antenna being lifted to the test platform for a check of the attenuation and phase velocity. This type of high support is used to ensure that no errors are introduced by reflection from the ground. The shape of the slots employed to obtain the electrical compensation referred to above is shown.

UHF Antennas

There are three general types of antennas in the channel range from 14-70. These are the slotted cylinder types, helical types and panel types.

Slotted cylinder types. These antennas consist of a self-supporting pole using vertical slots as radiating elements. Energy is coupled to the slots

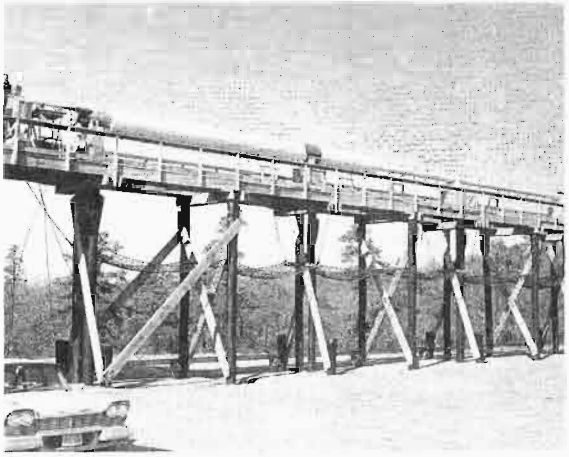

Fig. 55. Impedance Test of high band VHF Traveling Wave Antenna (RCA Photograph).

either conductively, inductively, or capacitatively from the feed system inside the cylinder so that a voltage appears across the slot. This causes currents to travel around the cylinder at right angles to the long slot dimension which generates an RF field which is horizontally polarized. The amount of cross polarization is quite small with this type of antenna. If the path around the cylinder is of such length that the current attenuates appreciably owing to radiation, the circularity is affected. Advantage is taken of this fact in designing directional antennas. To maintain the circularity required, a number of slots simimlarly fed are used at the same level. The antenna has considerable versatility in gain, beam tilt, vertical and horizontal patterns and also in power input ratings.

RCA UHF pylon antenna—gain. These antennas are built with gain values from 6 to 46. Two general types of vertical patterns are used which are designated as filled and shaped (see Fig. 4 and 5). In the filled pattern, there is one slot for each wavelength of height and the gain is approximately equal to the number of wavelengths depending upon the null fill as shown in Fig. 4 where there are 31 slots for 31 wavelengths of height. For the shaped pattern where the end layers radiate less energy—to eliminate the lobes and nulls in the fill area of the pattern—the number of layers must be somewhat higher to achieve the same gain.

Vertical patterns. A positive method of increasing the radiation at angles below the main beam is required since an antenna in which all of the radiators have equal amplitude and phase has complete nulls at periodic intervals as shown on Fig. 56. In a filled pattern, the odd nulls (1, 3, 5, etc.) are filled by power division. The even nulls are filled by the phase differential which occurs when beam tilt is introduced by shifting the feed point at the center of the antenna upwards (see Fig. 4).

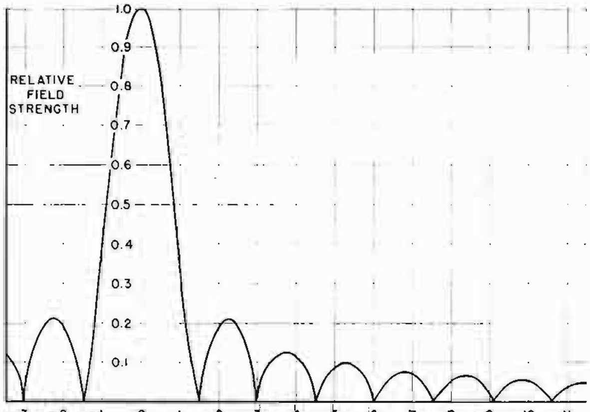

Fig. 56. Vertical pattern of an antenna having uniform distribution for an aperture of 38 wavelengths with sources in phase.

For higher gain null filled antennas, a multistep illumination with special phasing can be used to achieve patterns in which the nulls and peaks are minimized and which have very high aperture efficiencies. A pattern of this type is shown in Fig. 57.

In a shaped pattern, in which the nulls and lobes are practically eliminated, a binomial distribution[22] is used as shown in Fig. 58 which results in a smooth vertical pattern as shown in Fig. 59. By a proper phase distribution[23] as shown in Fig. 60, a smooth vertical pattern as shown in Fig. 61 can be obtained with the required beam tilt. Fairly close correlation between calculated and measured patterns can be achieved.

Horizontal patterns. For an omnidirectional pattern a good circularity (± 1dB or lower) can be achieved by using the proper number of peripheral slots in a given layer. Commonly used directional patterns can easily be obtained by the use of one, two, or three slots which provide patterns as shown in Fig. 62. These patterns are

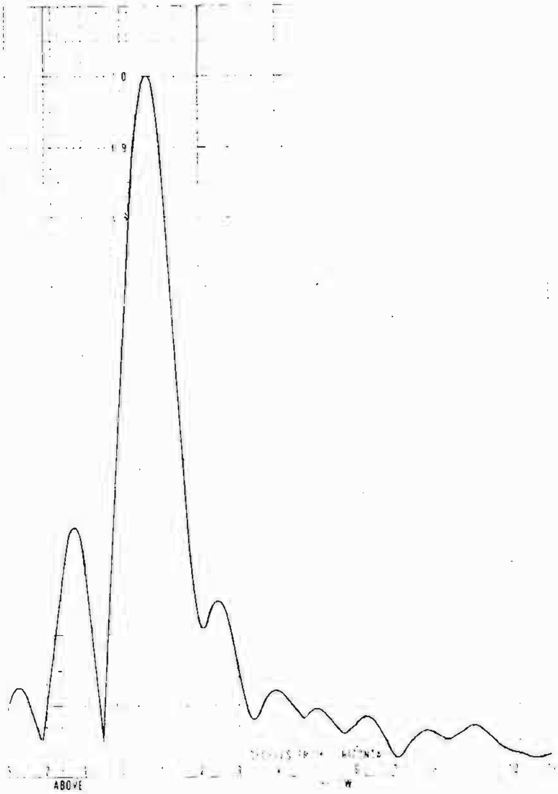

Fig. 57. TFU 50J antenna with a multi-step illumination with a gain of 44.

[22] Kraus, *Antennas* Chapter 4 p. 94.

[23] P.M. Woodward, A method of calculating the field over a plane aperture required to produce a given polar diagram. *Proc. Inst. Elec. Engrs.* London, 1946.

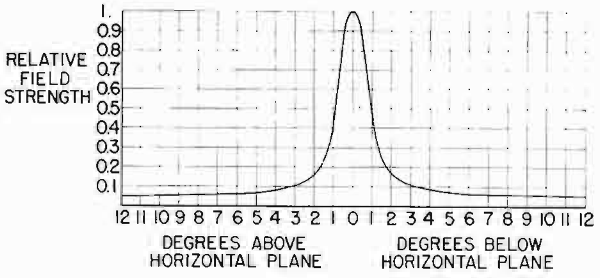

Fig. 58. Binominal distribution.

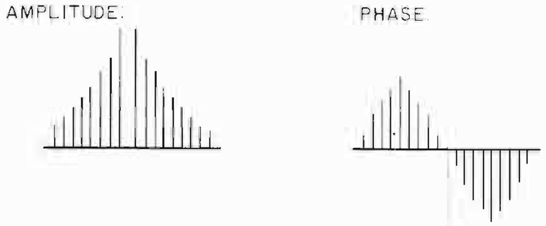

Fig. 59. Vertical pattern resulting from binominal distribution.

produced by currents flowing around the periphery of the antenna and can be calculated using classical methods. A slight variation from the calculated pattern occurs due to the phsyical width of the slot.

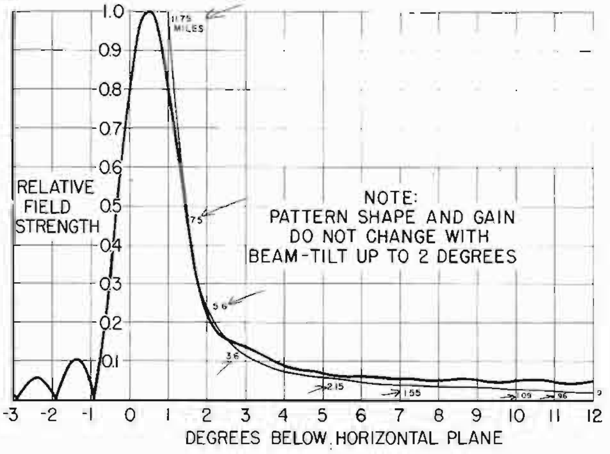

Fig. 60. Amplitude and phase distribution required to achieve a smooth pattern with minimum radiation above the horizon.

Power capability. A cross section of a typical UHF Pylon Antenna is shown in Fig. 63. The copper feed system is a single tube with a feed point near the center. Power is transmitted to the center through the lower portion which functions as a continuation of the transmission line. At the end seal, the power divides and propagates in the space between the copper feed system and the outer galvanized steel tube in a TEM mode. The

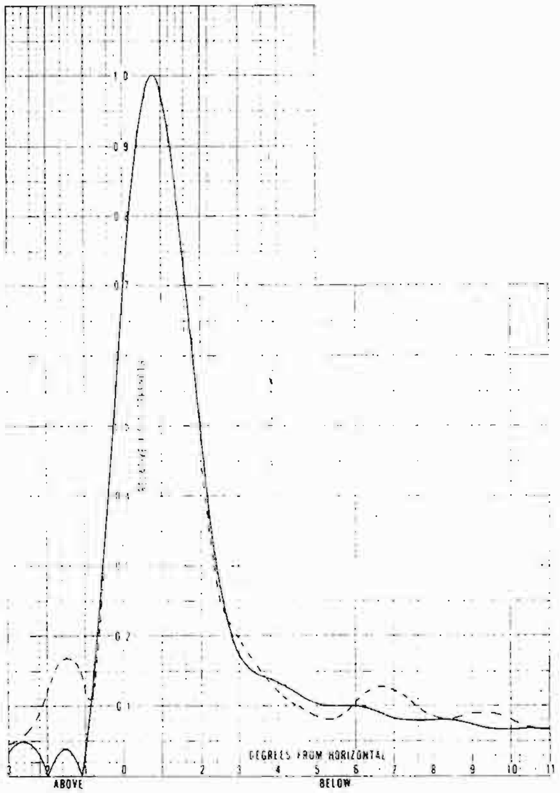

Fig. 61. TFU 35G antenna with calculated and measured values using the shaping techniques described.

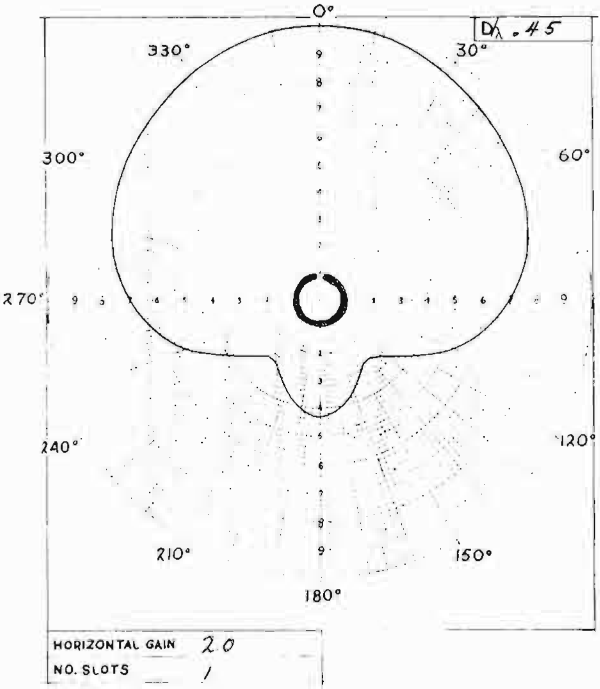

Fig. 62. Horizontal patterns achievable with slotted cylinder antennas using one, two, and three slots.

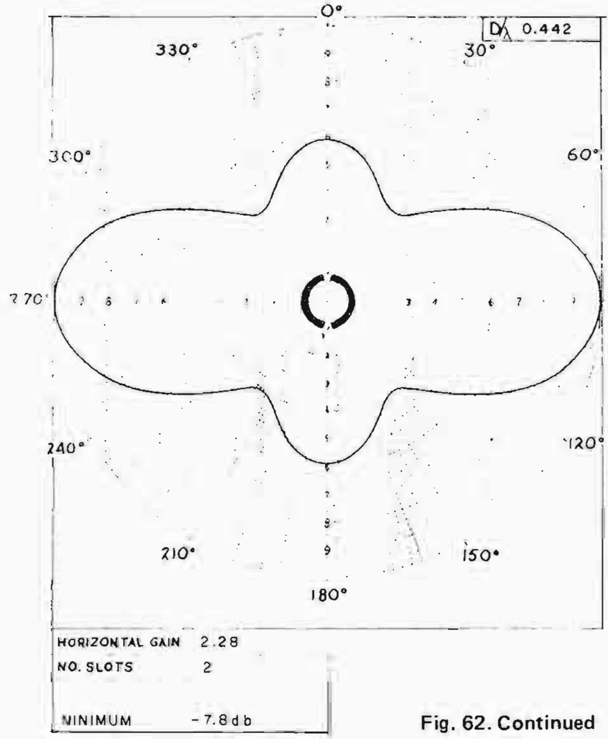

Fig. 62. Continued

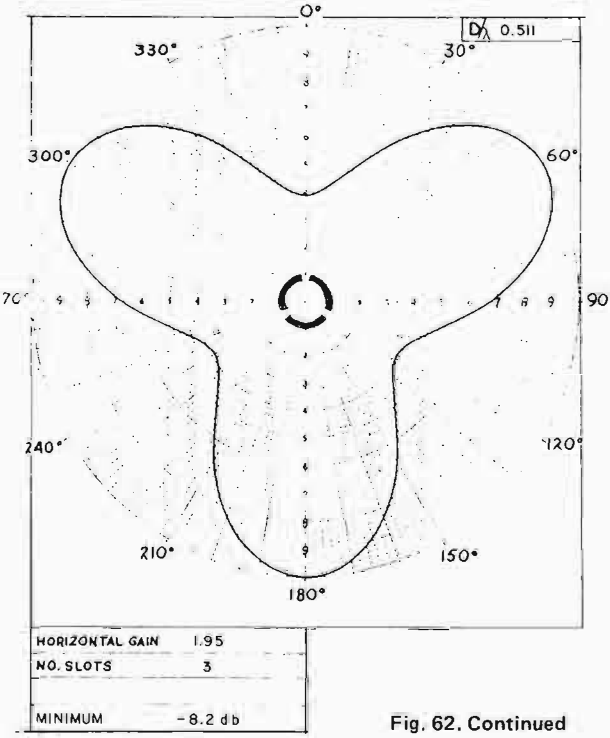

Fig. 62. Continued

energy is capacitatively coupled to the slot through cylindrical couplers placed adjacent to the slot (see Fig. 64). The power rating is determined by the diameter of the feed system.

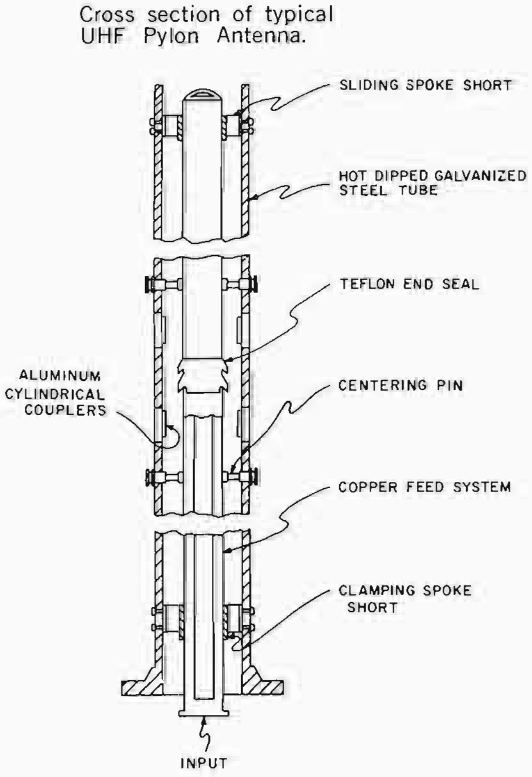

Fig. 63. Cross section of UHF Pylon Antenna.

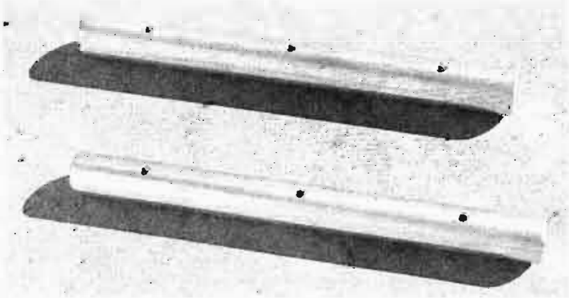

Fig. 64. Cylindrical coupling elements used in slotted cylinder antennas.

A TFU 46K antenna is shown in Fig. 65 as it is being transported to the turntable for pattern test.

Amplex UHF slotted cylinder antenna. Another type of slotted cylinder antenna is built by Ampex

Fig. 65. TFU 46K antenna being moved to the turntable location for pattern test.

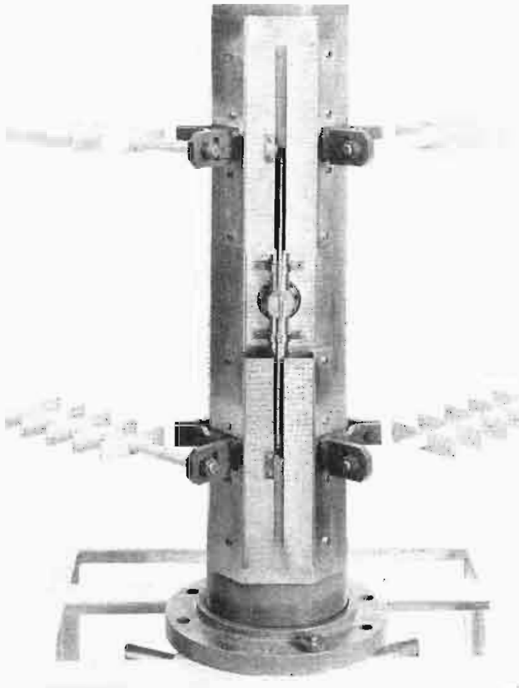

Fig. 66. Ampex Slot-Director UHF antenna. Parasitic directors are used to achieve a variety of patterns including omni-directional.

which is known as the "Slot-Director Antenna." This antenna requires only one slot for approximately one wavelength of height. An omnidirectional pattern of ± 1-1/2 dB as well as a wide variety of directional patterns are achieved by the use of parasitic (nonfed) end fire type "director." These are placed around the cylinder near each slot as shown in the photograph Fig. 66. The design and pointing of these directors determine the type of horizontal pattern achieved.

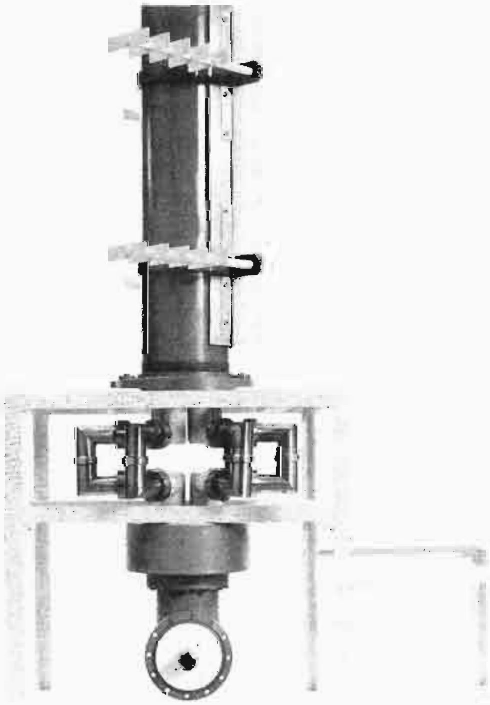

Fig. 67. Branching feed system used with Ampex Slot-Director Antenna.

Since there is only one feed point per layer, a power divider shown on Fig. 67 below the antenna permits feeding several layers with a separate feedline which permits flexibility in feed choices.

Alford Long-Slot UHF Antenna. The long-slot UHF antenna is a high-frequency version of the VHF slotted-ring antenna previously described with the principle difference being that the series of rings utilized in the slotted-ring antenna is replaced with a continuous sheet in the form of a slotted cylinder. The basic long-slot element therefore consists of a single continuous slot in a cylinder having a diameter of approximately 0.14 wavelengths and a length of approximately 1.7 wavelengths. The rms or average gain of each element is approximately 2. These cylinders are stacked one above the other to achieve the vertical gain desired and are supported by a cylindrical mast or by a specially designed truss or, in some instances, directly by the leg of the tower.

As many as 36 elements can be stacked providing vertical gains up to approximately 50 with null-fill. Shaped vertical patterns and/or beam tilt are obtained by varying the magnitude and phase of the signal fed to each element through the use of line transformers and different line lengths in the coaxial feed lines used to interconnect the elements. Fig. 68 shows the computed vertical pattern, based on measured element patterns, of an 18-element long-slot antenna when supplied with 1/2° of beam tilt and with a shaped vertical pattern.

Directional horizontal patterns are achieved by adding directionalizing sheets of "wings" to both sides of the slot. These wings divert a portion of the horizontal current that normally flows around

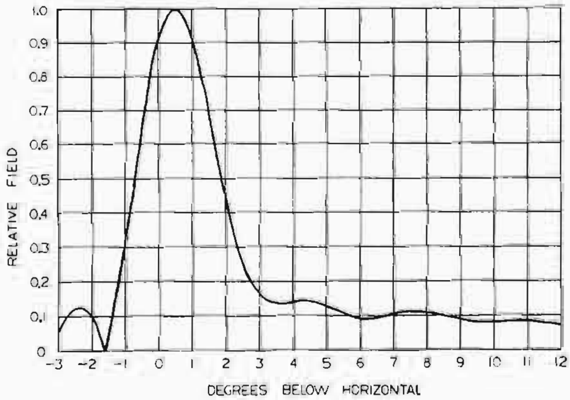

Fig. 68. Vertical field pattern of an Alford 18-element long slot UHF antenna with a gain of 25.

the basic cylinder from one side of the slot to the other. Since this diverted current contributes to the field radiated in the horizontal plane, the horizontal radiation pattern may be controlled by proper choice of wing shape and dimensions. Fig. 69 shows a 16-element directional long-slot antenna. The gain of this antenna in the direction of maximum radiation is 48.8 (16.88 dB).

Each element is covered with a radome to protect the slot from the effects of the weather. Where required, deicers can be supplied consisting of thin, vertical, high-resistance wires molded within each individual radome. These wires, when properly energized with a 60 Hz voltage, prevent the formation of ice on the radome and yet do not interfere with the horizontally polarized, radiated RF signal.

Fig. 69. A 16 element directional long-slot UHF antenna at Station WXTV, New York, N.Y. (Alford Photograph).

G.E. UHF Helical, General Description[24]

The basic operating principle of the UHF helical antenna is as already described under Helical Antennas. The UHF antenna differs from the VHF antenna primarily in its method of feed. The helix is made from 0.247-in-diameter copperweld.

At UHF, the percentage of bandwidth becomes small, and it is feasible to end-feed the vertical array at least up to gains of 30. If matched condition is maintained along the feed as power drops off at the different bays, the beam will tilt with frequency an amount 57.3 F/fo degrees, where fo is the mid-frequency and F is the change in frequency relative to fo. With a gain of 30, a half-power beamwidth of about 1.8° is obtained and a ±1/4° tilt causes no difficulty.

UHF helical antenna, one to six bays. The basic UHF antenna bay has a gain of 5. Its length is varied with channel, so that its gain is constant. These bays are stacked together end to end, up to six.

Each bay is like a coaxial of about 90 ohms Zo, with a capacitive feed probe coupling out power to the helix. The top bay couples out all the power remaining. Impedance match is maintained throughout the feed for optimum impedance bandwidth.

Phasing of the bays relative to one another is done by relative rotation of the bays. (Because the wave travels circumferentially around, the phase varies with azimuth.) Swivel flanges are used to fasten the sections together to make this rotation easy to perform. Rotation of the upper one or two bays can even be done after erection for slight modification of pattern contouring if desired. Fig. 70 shows a typical UHF helical antenna.

Zig Zag Antennas

The zig zag principle was first disclosed by H. Chireix in "L'Onde Electrique" 7, 169, 1928. In 1952 O.M. Woodward used this principle in the design of a unidirectional antenna.[25] During the last five years the antenna has been offered by various manufacturers and is used for both VHF Channels 7-13 and UHF Channels 14-70.

It has two outstanding characteristics. One is, that a single feed point can excite an aperture of about eight wavelengths since the element itself has a dual function of radiator and feed system. It is basically a strip transmission line, but elevated

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[24] *Electronics*, August, 1951, pp. 107–109.

[25] Patent No. 2, 759, 183 issued to O.M. Woodward–RCA.

Fig. 70. GE UHF Helical Antenna.

Fig. 71. Turnstables at Cazenovia Test Site (GE Photograph).

at a sufficient distance above the panel so that a controlled amount of radiation occurs. The radiation as in most traveling wave type antennas decays approximately in an exponential fashion, although this can be controlled by various means. Practically all types use radomes for weather protection.

The other feature is that it lends itself to a great variety of horizontal directional patterns in two ways. The panels facing in various directions can be excited at various amplitudes and phases, and the structure on which they are mounted can have 3, 4, 5, or more sides or have special diamond or other shapes. The panels can also be used for tangential firing around larger structures.

The antenna, as in all traveling wave types, has good impedance characteristics since the energy can be almost completely radiated without reflections by the use of various techniques. The following are descriptions of antennas of various manufacturers.

RCA Zee-Panel

The zip zag antenna is utilized by RCA to provide a variety of antenna systems. The Zee Panel Antenna Fig. 72 employs the basic zig zag element mounted on a panel. A special end-fed radiator at the far end of the element prevents reflections back to the center feed point. A variety of radiation patterns may be achieved with the appropriate arrangement and excitation of these panel radiators. Beam tilt may be obtained in each panel if required. Null fill may be achieved by proper phase and amplitude on each layer in the array and in some special cases in the individual panels.

RCA Vee Zee Panel

The Vee Zee panel antenna[26] shown in Fig. 73 is a Zee Panel antenna modified to achieve a broad horizontal pattern. Good horizontal circularity may be achieved in a special array of panels

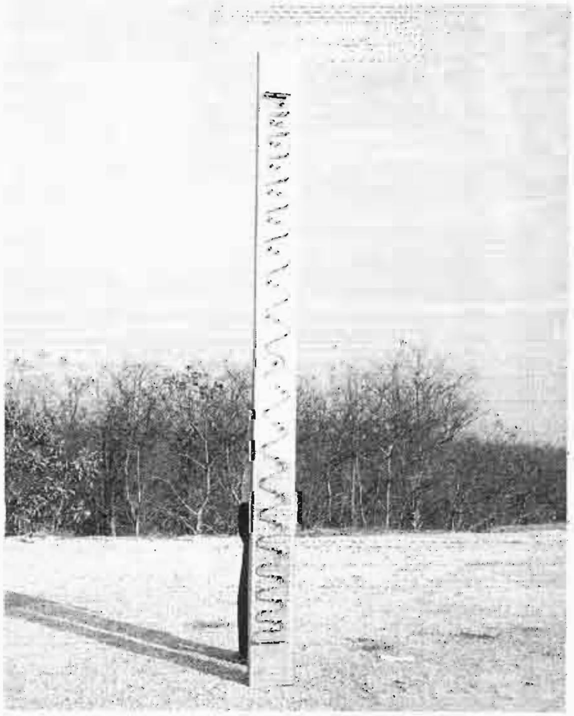

Fig. 72. RCA Zee-Panel.

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[26] U.S. Patent No. 3, 409, 893.

V-Z Panel as a side-mounted antenna–R.N. Clark and A.L. Davidson, *IEEE Transactions on Broadcasting*, January, 1967.

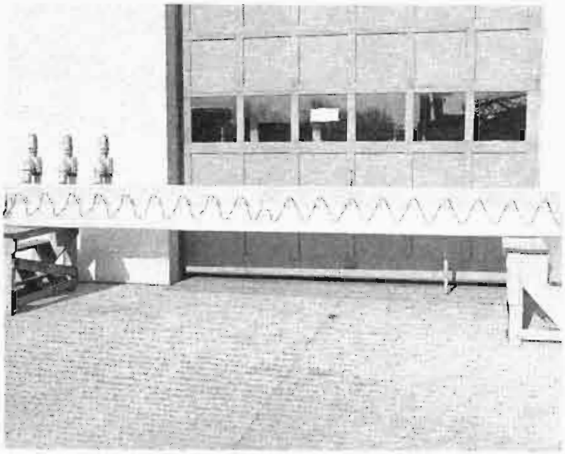

Fig. 73. RCA Vee-Zee Panel for tangential firing around towers.

mounted about a large triangular tower. The Vee Zee panel array is useful where it is desired to locate two or more separate antennas on a single tower.

RCA Polygon Antenna

The polygon antenna is another application of the zig zag antenna. The panels are welded together to form a self-supporting structure. At each layer, the feed points of each panel are electrically connected together with a strip-line network mounted to the supporting structure (see Fig. 74). A variety of horizontal patterns may be achieved with the design of the strip line network. Additional coax feed system lines connect the various layers at the proper amplitude and phase to achieve the vertical patterns desired.

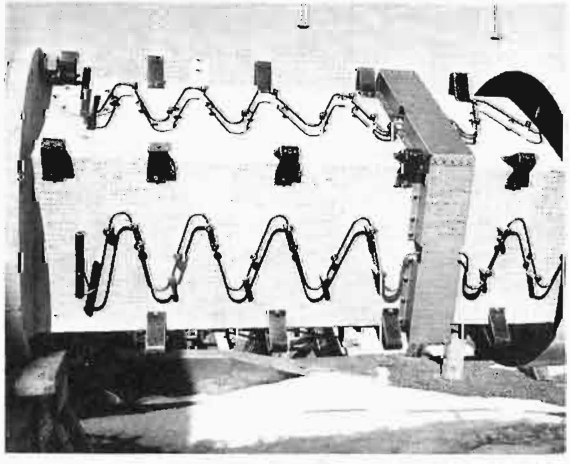

Fig. 74. RCA Polygon Antenna detail showing belt line, shell, and zig-zag construction.

G.E. Zig-Zag Panel Antenna, General Description

A panel consists of two Zig-Zag conductors bent at approximately one-half-wave intervals. The conductors are spaced about one-eighth wavelength from a rectangular mounting panel and fed at their junction at the center of the panel. Each panel is ordinarily about eight wavelengths long.

The radiation pattern of a single panel has a half-power vertical beam width of about 7.5 degrees and a horizontal beam width of about 65°. The shape of the horizontal pattern approximates a cosine-squared function.

The zig-zag panel design forms an excellent building block for directional antenna arrays.[27] Used in an array or as a single section it is often desirable to employ vertical beam contouring and electrical beam tilt for each individual panel to attain high power gain efficiency. A typical Zig-Zag antenna is shown during pattern measurements in Fig. 75.

Beam shaping is attained by using an amplitude and phase distribution over the single panel to suppress the unwanted energy above the main beam and to tilt the main beam to a desired depression angle below the horizontal.

Distributed loading of the radiating element and incremental length changes of the distance between corners are used to control the amplitude and phase distribution of the current along the panel.[28] The feed point impedance may be transformed to a convenient value such as 50 ohms by the use of a special design coupling strap to connect the radiating elements to the feed bushing.[29] Although the usual panel length is about eight wavelengths this length may be decreased to three wavelengths or so for special applications.[30]

JAMPRO UHF Zig Zag Antennas

This antenna consists of a number of panels arranged around a steel supporting tower as shown in the photograph Fig. 76. Each panel may be treated as a separate unit of the antenna. Great flexibility of horizontal and vertical patterns is available. Each panel has an eight-wavelength

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[27] "Directional Zig-Zag Antenna at KERO-TV, Bakersfield, California," K.B. Hoffman and R.E. Fisk. *IEEE Transactions on Broadcasting,* Vol. BC-10, February, 1964.

[28] US Patent No. 3, 369, 246.

[29] US Patent No. 3, 375, 525.

[30] *Empire State Zig-Zag Antenna Installation and Performance,* R.E. Fisk, General Electric Co., presented at the 19th Annual Broadcasting Engineering Conference National Association of Broadcasters, Washington, D.C., 1965.

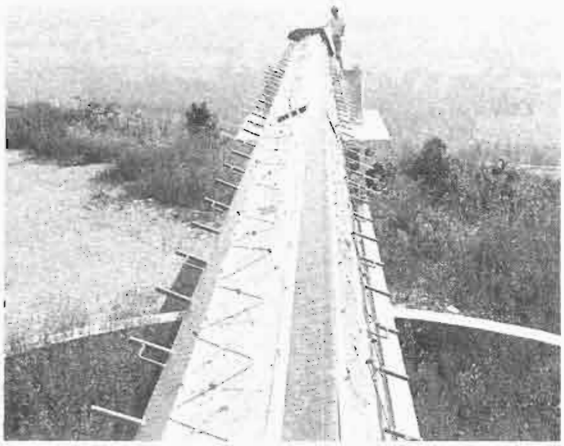

Fig. 75. GE Zig-Zag Antenna.

aperture fed from a single feed point at the center. The radiators are mounted on reinforced Teflon insulators, and grounded at the ends. The vertical pattern, is quite important in high gain antennas, and a computer program provides information for the first and second null fill which is accomplished through controlled power distribution across the entire antenna aperture. Standard UHF omnidirectional antennas have a pattern circularity of ± 2 dB.

ANTENNA TESTS

Before Shipment

Antennas are tested to meet the necessary requirements for impedance and patterns. This is usually done for all prototype antennas but not necessarily on the repeat antennas of the same type before shipment.

Custom antennas are usually impedance tested before shipment. As noted above under Antenna Specifications, the impedance is adjusted by the manufacturer to assure himself that the antenna will meet the 3 percent RF Pulse System Specification. These measurements are made under ideal conditions at the manufacturers plant to be certain that they are not influenced by other objects or the earth. From a Smith Chart Plot a judgment can be made by an experienced engineer to determine the percentage of reflection. It can also be determined by using a computer program as discussed under System Specifications.

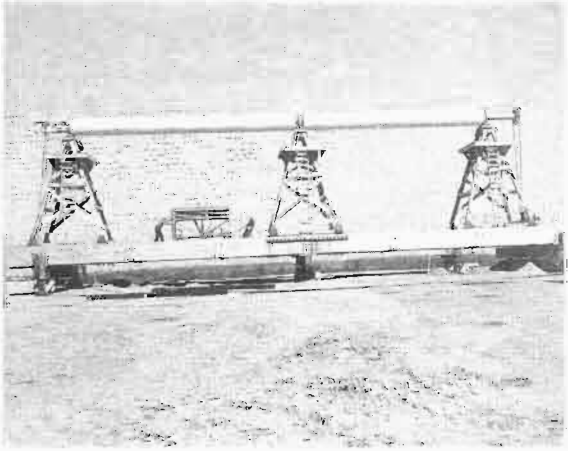

Fig. 76. JAMPRO Zig-Zag Antenna.

Pattern Tests

The object of a pattern test is twofold. One of the objectives is to determine the gain as compared with a dipole for which perhaps a substitution method could be used. The other objective, however, is to determine the amount of radiation at all vertical and horizontal angles which have an influence on the coverage. Both objectives can be accomplished by taking patterns as described under Gain, since the gains can be determined by integrating all the power flow through an imaginary sphere.

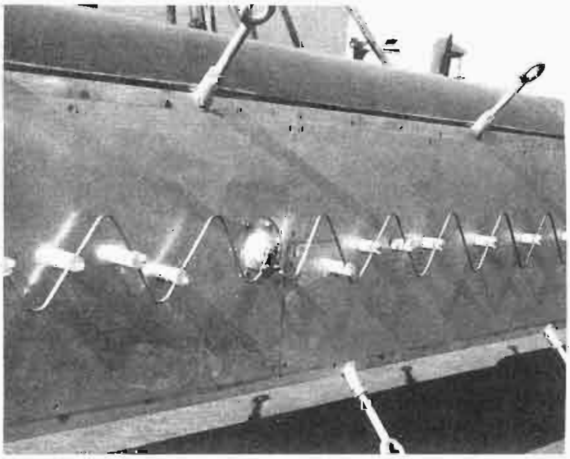

Fig. 77. Channel 32 Polygon Antenna on the 35 ton turntable which will accommodate antennas up to 180 feet in length (RCA Photograph).

To pattern-test the antenna it can be placed upon a wooden turntable which has a speed-controlled motor drive.[31] Fig. 77 shows such a turntable. From the reciprocity theorem it is possible to use the antenna as a receiving antenna as well as a transmitting antenna and obtain the same resulting pattern. This is done for the sake of convenience, since it permits the pattern recorder and the antenna under test to be located

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[31] "RCA Expands Antenna Engineering Facilities," *Broadcast News*, Vol. 128.

at the same point, thus allowing quick analysis of the results. The transmitting dipole is placed in the far field which is 2 a^2/λ in feet where "a" is aperture of the antenna in feet and "λ" is the wavelength in feet. Since the antenna is in a horizontal position on the turntable, the transmitting dipole must be placed in a vertical plane. The received signal is amplified and the patterns drawn out on the recorder. To determine gain all of the energy going through an imaginary sphere with the antenna at its center must be accounted for. Usually the area of interest in a pattern lies from about 3° above the horizontal (+3°) to about 11° below the horizontal (-11°). However, for gain determination, all energy from +90° to -90° must be taken into account. Also since some types of antennas have a degree of unwanted vertically polarized energy in addition to the desired horizontally polarized energy, this factor must also be considered. Ohmic losses in the feed system must also be considered in determining the gain.

After Shipment, before Erection

After the antenna is erected, the difficulties of working on it are greatly compounded. Since few engineers climb, the work must be done entirely by riggers, who do not have the background to do electrical testing. Furthermore, the time during which work can be performed on the antenna is very limited, owing to both scheduled operation and the weather, which frequently prevents work or even climbing. Hence, it is extremely important that tests be made on the ground before erection. Both electrical and mechanical tests should be made.

A thorough mechanical inpsection should be made to see that the required components are in their proper places and securely fastened using the specified fastening materials. The pressurized portions should be pressure-tested for a long enough period to be certain that there are no slow leaks. A loss of over 2 lb. in 24 hr. should be investigated. The fit of major mechanical assemblies should be checked on the ground, since any discrepancies during the rigging operation can become major problems.

Depending upon the antenna type, it is generally good practice to make some electrical measurements on the ground before erection. The primary purpose is to determine if anything has happened to the antenna during the shipping and reassembly process. Hence, it is basically a qualitative test rather than a quantitative one since the ideal conditions at the vendors site may not be duplicated.

The test normally used is an impedance, or VSWR, measurement made every megacycle over the television channel. Closer measurements are not necessary since for a broad-band antenna the impedance varies quite slowly with frequency.

The practice would vary with VHF antennas and UHF antennas. It is usually necessary to be above the ground by about three wavelengths to obtain meaningful measurements. Hence at UHF, a height of 6 ft. is readily achievable. Often the antenna can be tested on the shipping trestles if they are close to this height and made of wood.

For VHF, the heights required above ground are about 15 feet from Channels 7-13, and 35 ft. or so for Channels 2-6. It is manifestly impractical to provide trestles of this height for field tests. Since these antennas often have branching type feed systems, other means can be used. In the case of a Superturnstile Antenna, the E-W system and the N-S system can be separately measured for impedance at a low height by placing the plane of the radiators under measurement in a vertical plane so that the maximum field is parallel to the ground rather than into it. Since the radiators are still quite close to the ground, ideal measurements cannot be obtained and a judgment factor is required. Final touch-up of the impedance after erection can usually be made by using a variable transformer.

It should be noted, however, that the further the variable transformer is from the point in the antenna where the best match across the band exists, the more difficult it is to lower the reflected pulse value. This point is at or near the radiators for a Superturnstile antenna or after the last transformer when broadbanding techniques are used.

The action of the variable transformer is to insert a negative bump to counteract the positive bump (see Fig. 11) due to the remaining mismatch at the antenna. If the negative bump is displaced in time, by too long an intervening transmission line, it can only partially reduce the positive bump. If it is displaced more than a 100 ft. or about 0.1 microsecond it serves no purpose and only introduces a second unwanted bump.

The use of a variable transformer could in the case of a factory assembled antenna eliminate the ground test if a good mechanical inspection is made. For antennas of the Traveling Wave type for Channels 7-13, the construction is extremely rugged and a mechanical inspection only is required. This antenna has a built-in variable transformer.

When impedance measurements are made on antennas at the customer's site, there may be site factors involved such as fences, building materials, towers and other objects in the field. If the readings are of the same order, or if the Smith Chart plot is about the same but displaced, the antenna can be considered to be in good condition. To make any corrections in such a situation could correct the antenna for the site conditions which would not be present at the tower top and hence worsen the impedance. As noted above the check is qualitative to discover possible damage during shipment and not a quantitative compliance test.

The remarks above are also applicable to panel type antennas. Where possible, it is always desirable to ship antennas in one piece even through special permits and shipping arrangements are necessary.

After Erection

Overall Test

See antenna specification considerations under "System Specification Performance after Erection."

Reflectometer Test

In order to protect antenna and line components properly it is mandatory that a reflectometer be used on both visual and aural transmitters to interrupt power when the VSWR exceeds a predetermined value. If an arc occurs in the antenna system, it usualy loads the transmitter so that meter readings may fail to give a warning resulting in major damage to the antenna system.

Hence, before application of power to the antenna system the reflectometers should be checked for proper operation.

INSTALLATION

Advance Planning

The instruction book for a particular antenna usually contains considerable useful information which should be carefully read and followed. There are a number of items, however, common to most antennas which will be discussed.

Preinstallation Procedure

Usually it is advisable to have the manufacturer's serviceman take care of assembly supervision and testing. Some detailed procedure is outlined below.

Antenna Mounting Trestles

Most antennas are impedance-tested on the ground before erection. This is a wise precaution, since any corrective work, if required, is extremely difficult to accomplish once the antenna is at the tower top. The impedance of the antenna is affected by the ground, and trestles are required to obtain adequate clearance. Usually the furnishing of the trestles is the responsibility of the station, although the design is furnished by the manufacturer. They should be on hand when the antenna arrives located on reasonably level ground close enough to the base of the tower so that the antenna can be hoisted directly but far enough away so that assembly work can be done on the antenna without danger of falling objects from the tower while the riggers are working on it. The antenna should be placed so that the tower is not in the radiated field of the antenna, which would affect the impedance during the ground test. This will vary with the type of antenna and the frequency, and the manufacturer's recommendation should be obtained.

Precautions during Unpacking and Assembly

Antennas are usually heavy and appear to be quite rugged. Riggers used to handling heavy, rugged components often overestimate the ruggedness of the antenna, since many of the components can be damaged by rough handling.

If lifting lugs are not provided, the usual practice is to use cable wrapped around the mast with a 2 by 4 "corset" to protect feed lines, slot covers, or other components mounted on the pole. Special oak 2 by 4 lumber should be used for this purpose, since regular lumber crushes, causing damage to components.

Long poles can be given a "set" or internal components damaged if the pole is not properly supported over its entire length when it is lifted from a horizontal position. Strains can be set up under this condition which exceed the maximum wind-load conditions.

To ensure proper handling, a qualified rigger who has a reputation for making successful antenna installations is desirable. Some manufacturers will, if the customer desires, provide a "package" for the tower, line, antenna, and all installation work. This avoids split responsibilities and has many other advantages.

Checking Shipment

It is a wise precaution to check the shipment in detail against packing lists and see that no damage has occurred during shipment. The per-diem rate for a crew of riggers is costly, and any delays due to missing or damaged parts will prove expensive. If there is any damage or shortage, the shipper should be notified immediately.

Pressurized Equipment

Equipment that is normally pressurized should be either stored in a dry place or kept under pressure during storage. The latter will also establish whether any leaks have resulted from shipment.

Assembly

Usually the manufacturer furnishes detailed instruction for the assembly which should be carefully followed.

Special tools are sometimes furnished or called for in certain operations which should be used.

Since the antenna is primarily a piece of electrical equipment, cleanliness at points of electrical contact is mandatory.

Electrolysis can occur if proper hardware specified is not used.

Forcing parts into place will usually result in future difficulties. The reason should be investigated.

All hardware should be tight and secure.

If anything does not appear to be correct, consult the manufacturer rather than take a chance.

If any field welding is required, certified welders should be used, since failure could result in loss of human life.

Tests before Erection

It is extremely important that certain tests both mechanical and electrical be performed before the antenna is erected, since the difficulties of working on it after erection are greatly compounded. These tests are described under After Shipment, before Erection.

Erection

The erection procedure should be left in the hands of a qualified rigger. It is highly desirable to erect the antenna in one piece when this is feasible. If not, the rigger must be thoroughly instructed in the assembly procedure. The orientation of the antenna should be carefully established and well marked so that there is no misunderstanding.

In some antennas when transmission lines pass through the top plate of the tower, orientation is doubly important.

Vertical Alignment

For flange mounting triangularly shaped stainless steel shims should be used fitted between the mounting bolts. Vertical alignment is best checked with transits from several directions. Allowance must be made for wind deflection and sun benching. Accurate vertical alignment is especially important at UHF, where beamwidths are much narrower owing to the use of higher gain antennas.

Tests before Application of Power

These tests are important to ensure that the over-all requirements are met and also to be certain that the system is ready to receive power. Much damage can be done if there are loose or open connections or if the reflectometer circuits in the transmitter are not properly adjusted.

MAINTENANCE

Daily Operation

A drop in gas pressure (in excess of 2 lb. in 24 hr.), an increase in VSWR as indicated by the reflectometer, or the appearance of an echo on the monitor indicates an unusual condition in the antenna system.

Gas leaks can usually be located by sectionalizing parts of the system. An increase in VSWR may denote icing or a change or failure of some part of the system. Power should be reduced when the VSWR rises, since the power-handling capability is inversely proportional to the standing-wave ratio.

The appearance of an echo is a symptom of some change in the system which should be investigated. New pulse techniques will make the location of faults much simpler.

Semiannually

A qualified rigger who is thoroughly familiar with all the aspects of the line and antenna should inspect the system. He should inspect for signs of corrosion, loose clamps or hardware, condition of slot covers, need for paint, physical damage, etc., as the particular antenna requires.

In superturnstile antennas it is advisable to take resistance readings between the inner and outer conductor for each side of the line. Any significant change from the initial readings should be investigated.

As a general guideline, no work should be performed on an antenna while power is on. In the case of a multiple antenna system where antennas are at the same level, the power should be off for all antennas on the platform.

RF fields from UHF antennas are particularly dangerous for two reasons: due to the shorter wavelength, local heating in the body is more likely to occur without an awareness that it is happening and could have serious results. Also, since a maximum power of five megawatts can be radiated, UHF stations are now approaching this value which is 16 times as high as for the Channel 7-13 range, and 50 times as high as for the Channel 2-6 range.