RADIO COMPONENT HANDBOOK

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FOREWORD

The primary aim of this handbook is to provide radio engineers, technicians and other users of radio components with reference data which will fill the gap between the formal text book and the general handbook.

The information has been grouped by components and for convenience, as far as possible, has been divided into three parts—design, application and specification. Derivations of design equations have generally been omitted since these belong in a text book and not a handbook. Our main objective has been to present only essential information—written and compiled by a group of engineers actively employed in the design, application and specification of component parts—which will be of use to the practising engineer.

Realizing that the usefulness of the handbook depends, to a large extent, on its availability (low cost) several leading manufacturers of radio components were approached for financial assistance as sponsors. As engineers we reserved the right to present our material from an unbiased viewpoint, freely pointing out the disadvantages along with the advantages of a particular design. It was definitely understood that the contents would in no way be influenced by the participation of sponsors.

We therefore wish at this time to express our sincere appreciation to the following sponsors, who, through their unselfish efforts have made the publication of the handbook possible at a cost within the reach of all.

The Staff.

Cheltenham, Penna.
May, 1948.

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General Design

The design of radio equipment requires a knowledge not only of basic radio fundamentals, but a thorough understanding of where and under what conditions the equipment must operate. On the knowledge of these operating conditions depends, to a large extent, the success of the equipment. While it is true that circuit design is of great importance, since the equipment must perform satisfactorily, it is also true that there are other factors of equal importance.

Weather and climatic conditions under which it might be necessary to operate must be studied. Since this is an important factor to be considered an attempt should be made to determine what variations can be expected. Fig. 1-1 shows the probable variations in temperature, humidity and altitude for different classes of radio equipment.

Electrical Requirements

Electrical performance depends to a large extent on the type and end use of a unit. Local operating conditions of course make it impossible to definitely establish specific values of sensitivity, selectivity, fidelity and power output but in general the chart (Fig. 1-2) can be used as a guide.

Sensitivity

Sensitivity is limited by noise—internal, due to thermal agitation in the antenna circuit and shot noise originating in the amplifier tubes; external, due to atmospherics and electrical (man-made) disturbance. Any increase in sensitivity beyond the noise limit is useless since noise and signal would be increased simultaneously, their ratio remaining unchanged.

Specification	Communications		Entertainment	
	Airborne	Ground	Auto	Home
Temperature	-60 to +75°C	-40 +50°C	-40 +50°C	0 +50°C
Humidity	95%	95%	95%	95%
Altitude	50,000 ft.	5000 ft.	5000 ft.	5000 ft.

Variations in Climatic Conditions for Various Types of Equipment.

Fig. 1-1

Specifications	Communications	Entertainment		
		Auto	Small	Large
Sensitivity	1-50 uv	1-20 uv	20-200 uv	3-20 uv
Selectivity	200-3500 cycles	7-10 KC	7-15 KC	7-12 KC
Fidelity	60 cycle-5 KC	80-5000	200-3500	70-8500
Power Output	100 mw-5 watts	1-5 watts	1 watt	5-20 watts

Suggested Limits: Characteristic vs. Type Receiver.

Fig. 1-2

General continued

Except in electrically quiet neighborhoods there is little advantage in a home radio having much greater than 15 to 25 microvolts sensitivity. In automobile receivers a good signal-to-noise ratio is required because this type of receiver must operate with an antenna of small effective height and consequently in a great many cases with little signal input. For this reason auto receivers are designed with a high antenna stage gain and usually with an r-f stage to improve the signal-to-noise ratio by providing additional amplification before the signal reaches the converter.

Since shot noise varies as the square root of the plate current it is desirable to keep the ratio of transconductance to plate current large. Incidentally, the ratio of conversion conductance to plate current is less in converters than in tubes operating as amplifiers.

Selectivity

The degree to which a receiver selects one of several simultaneously applied signals is a measure of selectivity. A ratio of 30 db is considered adequate for most applications and is dependent mainly upon the selectivity of the i-f amplifier.

Spurious Response

Sensitivity to spurious responses—image, direct i-f pickup, harmonic whistles, etc.—is dependent upon both the "head-end" and i-f selectivity as well as other factors such as shielding and harmonic content of the various signals throughout the unit.

Fidelity and Power Output

Fidelity and power output requirements as shown in Fig. 1-2 depend more on the price range of the unit rather than the actual requirements dictated by operating conditions. Since these depend on market and other considerations, rather than engineering design requirements, there is no need for further discussion.

Mechanical Design

Normally the mechanical design engineer supervises the work of the equipment layout; however, the design of radio equipment is largely electrical and therefore the electrical design engineer should actively participate in the work. It is surprising to find in the radio engineering profession so many well qualified electrical designers with such a meagre knowledge of metals and their application in radio. While it is true that most radio engineers find such knowledge practically non-essential, it is nevertheless an asset to be able to appreciate the problems and be in a position to discuss them intelligently. Such understanding leads to better co-operation and often results in an improved design because of possible compromises that can be made.

General continued

General Considerations

A metal or alloy is made up of a large number of minute crystals arranged at random. In the process of manufacture the rate of cooling of the metal determines to a large extent the size of the crystals formed (slow cooling results in large crystals and generally a weak material). On the other hand, rapid cooling is likely to produce a less ductile material.

Cold working a metal will increase its hardness and strength at the expense of ductility. This can be easily demonstrated by bending a piece of soft metal with the hands and then trying to straighten it out again. While it bends easily, it is very difficult to straighten. The bending (working) distorts the crystalline structure and in some manner produces a structural change which increases its hardness. Once the metal has been hardened by cold working, the crystals remain in their distorted condition until the metal is heated to a high temperature (annealed). Thus the crystals are relaxed and regain their original position. Hot working is a combination of annealing and cold working wherein the grain size is decreased but the crystals retain their symmetry and no strain is apparent. This results in some hardening and strengthening without loss of ductility.

Table 1-7 has been prepared to show at a glance the characteristics of those metals commonly used in the majority of present-day designs. For convenience of discussion the metals and their alloys have been divided into two groups; ferrous and non-ferrous.

Non-Ferrous Metals

Copper, aluminum, magnesium, zinc and their alloys are the most commonly used non-ferrous metals in radio design; we will therefore confine our discussion to these metals only.

Copper with a tensile strength of 30,000 to 65,000 psi, depending upon the treatment to which it has been subjected, is fairly free from corrosive effects. In dry atmospheres a thin film of cuprous oxide and in moist environments a green basic carbonate forms, both of which are protective in nature. As it is an excellent conductor of electricity and readily worked, it finds many uses in radio such as shields, wire and even castings (if properly alloyed with other metals). Alloyed with zinc, it is known as brass and has excellent mechanical

Accelerating Force (g) versus Vibration Amplitude and Frequency

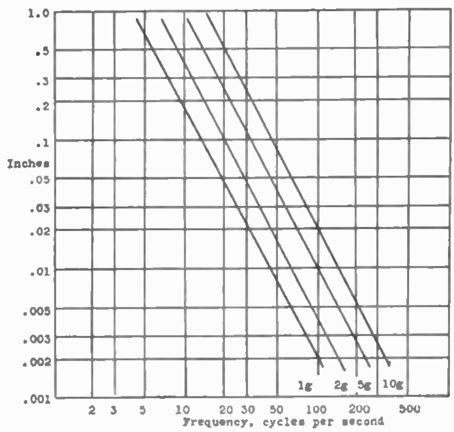


Fig. 1-3

General continued

properties as well as good workability. Alloyed with tin, it is known as bronze. Like brass its properties depend on the particular alloy and its treatment. The addition of phosphorus results in the well known phosphor-bronze which is noted for high tensile strength, elasticity, fatigue resistance and the ease with which it can be worked.
which it can be worked.

Aluminum and magnesium are both important because of their light weight, toughness and high electrical conductivity. Some of their alloys are comparable in strength with mild steel, yet they weigh approximately one-third as much.

Zinc is primarily used as a coating for other metals although it can be rolled, extruded or cast satisfactorily. It is principally used for coil or tube shields or as an alloy with aluminum and copper it is ideally suited for die-cast parts.

Ferrous Metals

A wide variety of steel compositions are available for design purposes; in most applications, however, it is satisfactory to specify ordinary carbon steel because of its excellent mechanical properties. The carbon content of a steel is extremely important; in fact the Society of Automotive Engineers has standardized a method of classification in order to assist in identifying the various classes. Each type of steel has been assigned a series of four digits; the first for carbon is 1, the second digit represents the type (0 for plain, 1 for free cutting etc.) and the last two digits indicate the carbon content in hundredths of one percent. Thus SAE1010 is plain carbon steel having a carbon content of approximately 0.010 percent. Steel alloys (for example, silicon electrical steel for transformer laminations) are only specified where special characteristics are required.

Chasses and other metal parts for radio equipment are generally fabricated from steel, although aluminum is widely used for airborne equipment where weight is a factor. As previously mentioned, there are many grades of steel available and it might seem difficult to choose the correct type. The requirements however, are fairly well defined; that is, a metal is required that has a good surface for finishing, is capable of being easily formed and is low in cost. Many designers specify half-hard cold rolled "automobile body" steel. This has an excellent finish and is not too hard for working. In general, cold rolled steel is specified rather than hot rolled because the former takes a smoother finish or plating. Very few designers specify the actual composition of the metal, but they do specify what it will be used for and leave the details as to composition etc. to the supplier.

While aluminum, magnesium, brass, bronze and copper are specified in the B & S gage, steel is specified in the USS gage. The gage or thickness varies of course with the size and end use of the part to be fabricated. In general, small parts or chasses use 0.038" material, medium sized 0.05" and the larger parts 0.062". This of course varies with the actual design of the part. For example, if the part has large

General continued

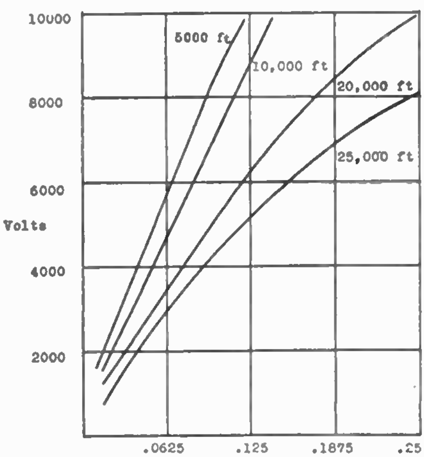
cutouts, which would obviously weaken the unit, then it would appear that a heavier gage material should be specified than if the cutouts were small. Actually this is not always the case; it may be much more economical to fold and weld the corners or add strengthening ribs at the weak spots rather than use a heavier material. While it is true such designs necessitate extra operations, which add to the piece price, nevertheless the tools for blanking and forming the lighter material are not quite as expensive and will produce more parts before wearing out.

No hard and fast rules are available with which to make this decision, as each design must be considered individually. An experienced cost estimator, in collaboration with a qualified tool designer and a representative of the purchasing department should assist in making such decisions. Where the design is quite similar to a previously produced part the mechanical design engineer can of course rely on his past experience for the answer.

Riveting is the most common method of assembling a unit, although spotwelding is often employed where the parts to be joined are approximately equal in thickness. Spotwelding of two parts that differ appreciably in thickness is not recommended. When specifying spotwelds it is important that adequate space be available for performing the operation. Inaccessible spotwelds often require special jigs or fixtures and require additional time which defeats the main purpose, that is, speed in production and decreased cost. Dowels, stamped in the part at the same time the original stamping operation is performed, often can be used in place of holding fixtures, thereby saving both time and equipment.

There is no set rule for determining the minimum number of spotwelds required. This is usually left to the judgment of the designer, but it should be clearly specified because of the cost involved. Flanges to be spotwelded should be at least one-half inch wide to avoid coming too close to the edge of the material.

Sharp corners on brackets, etc., are to be avoided because of the danger of injury to production personnel. Some designers cut the corners at a 45° angle, which is a compromise between safety and cost. A small radius usually increases



AIR GAP BREAKDOWN VOLTAGE vs ALTITUDE

Fig. 1-4

General continued

the tool cost while cutting the corners at a 45° angle is relatively inexpensive.

The matter of tolerances is probably one of the most misused details of mechanical design. Because it is practically impossible to fabricate a part in production quantities to exact dimensions, it is necessary to specify allowable limits or tolerances. This can often be in the form of a general statement, as for example, "All fractional dimensions are $\pm 1/64''$, all decimal dimensions $\pm 0.005''$, all angles $\pm 1°$ unless otherwise specified". The assignment of general limits depends upon the function of the part and the interchangeability required.

Tolerances should permit ready interchangeability of production parts with a minimum loss in time due to fitting, again keeping in mind that narrow limits are usually costly. If possible the tolerances should be specified in the direction which permits reworking the part should it be outside limits.

A few items of definite importance but often not considered in the original design will now be discussed. Sockets should be oriented in such a manner that leads are short and as far as possible accessible for easy wiring. If long leads are necessary provisions should be made for "dressing" them in such a manner that they do not cause electrical trouble. Small flexible "dress" lugs strategically located on the chassis or other parts are commonly used for this purpose since they have been proven to be worth while in reducing troubles during testing and throughout the life of the unit. Another important, yet often neglected, factor is the time required for various production operations. If parts are inaccessible and wiring is extremely difficult, it not only costs more per unit to produce, but the total volume of production per day is decreased.

Another item of importance, especially in small receivers, is to provide adequate ventilation. This may well influence the overall layout and therefore should be considered early. It should be remembered also that whatever provisions are made to provide satisfactory ventilation, they must not violate the requirements of the Underwriters' Laboratories.

These seemingly small details are mentioned because they are important in the overall picture and should be provided for in the mechanical design.

Shock Mountings

In radio equipment design it is often necessary to provide an isolating medium between certain parts to prevent microphonism. Sometimes it is only necessary to isolate a single stage or a single part, as for example, the variable tuning capacitor. In general, however, the entire unit is isolated from its cabinet or case. Adequate mountings spaced well apart will go a long way in reducing vibration effects. Ribs, flanges, embossings and welded sections as strengthening for the chassis where large parts are mounted are also highly recommended; they permit making the chassis from a lighter gage material.

General continued

The effects of vibration can be minimized by the use of materials such as rubber, cork and even steel (springs). Rubber becomes harder as the load increases, cork becomes softer under similar conditions and steel springs deflect linearly with load.

The most promising of these appears to be rubber (for our specific applications) since it provides a fair degree of isolation under normal conditions, and when subjected to a severe shock the deflection is not greatly magnified. In other words, it behaves somewhat as a limiter stage in an FM type receiver. Similarly, cork can be likened to a square law amplifier, while springs behave as a linear amplifier since the greater the load the greater the deflection. Rubber may be used either in shear or compression depending upon the load, the required efficiency and the physical space available. It is generally used in compression (grommets) in most home radio applications since it requires little physical space. While the efficiency is not as high as rubber-in-shear it is satisfactory for most purposes.

Rubber will bulge when in compression so allowances must be made for this in the design. This presents no problem with the use of rubber grommets since allowances must be made for clearances in assembly which ordinarily will take care of any bulge effect.

Finish Considerations

The specification of finish or protective coating on metal parts depends upon their function, what climatic conditions prevail, and to what degree protection from corrosion is desired. It is practically impossible to apply a finish to a component which will withstand a severe salt spray without some evidence of discoloration or other deleterious effects, so unless these interfere with the actual operation of the part, either mechanically or electrically, it is common sense to tolerate them. The following discussion is based on this premise.

Table 1-6 shows most of the commonly used electroplated and chemical finishes; the extent of protection each affords together with

ACTUAL COST

MATERIAL	LABOR	OVERHEAD
Raw stock	Production	Administration
Semi-finished	Supervision	General Office
Finished	Packing	Engineering
	Shipping	Planning
	Inspection	Purchasing
	Testing	Expediting
		Maintenance
		Advertising
		Selling

SOME FACTORS INVOLVED IN COST.
Fig. 1-5

General continued

recommended thickness has been given. The effect of galvanic corrosion caused by electro-chemical action has not been considered.

Galvanic effect (similar to the generation of current in an ordinary dry cell battery) increases the corrosive action over its normal rate. The metal which is attacked is called the anode while the metal which is protected is called the cathode. These in conjunction with moisture complete the galvanic couple or cell. The extent of the reaction or corrosion when two dissimilar metals contact one another in the presence of an aqueous solution may be determined from the position of the two metals in the galvanic series and the relative areas of each metal.

It should be noted that the various metals are arranged in groups within the series. Metals within the same group are relatively free from corrosion when in contact with one another unless the areas of the two metals are substantially different. The ratio of the areas is nearly proportional to the intensity of the corrosion if the area of the more noble (cathodic) metal is much larger than that of the less noble (anodic). It is therefore wise to avoid couples wherein a metal that is low in the series (copper for instance) has a much greater exposed area than that of a higher metal (such as aluminum) because corrosion will be accelerated since the anodic metal, which is always attacked, is small.

The following general rules should be followed to decrease the effects of galvanic corrosion:

1. Do not join metals far apart in the galvanic series, especially with threaded fastenings.
2. Designs should use the less noble metals for the large areas, with all small fastenings of a more noble material.
3. Whenever practical insulate the dissimilar metals by coating both the anodic and cathodic elements. This increases the resistance between the couple and results in less current flow (less corrosion).

Plating on Steel

Parts made of steel are usually electroplated with cadmium or zinc. If the surface is to be painted (no electrical contact required) zinc is ordinarily used and supplemented by a phosphate treatment. When the part requires no painting, a chromate finish is sometimes applied. The chromate acts as a protection to the underlying plating and will usually withstand at least 200 hours of salt spray before any corrosion products appear. When a chromate finish is applied over cadmium or zinc the initial finish need not exceed a thickness of 0.0002".

In applications where steel is in contact with aluminum, cadmium is recommended instead of zinc. Both are anodic toward steel and therefore give galvanic protection to any exposed base metal. This is very desirable because small breaks in the plating caused by staking operations or scratches do not seriously impair the coating. A disadvantage to cadmium plating is its tendency to grow "whiskers" when in contact with phenolic materials having traces of free organic acids.

General continued

Nickel is rather unsatisfactory on steel because it is more noble and quite porous unless a very heavy coating is applied.

Finish for Aluminum

Anodizing, which produces a very hard layer of aluminum oxide by electrolytic means, is extremely corrosion resistant; its main disadvantage lies in the fact that it is an insulator and therefore cannot be used where a good electrical contact is required.

A chemical oxide finish, on the other hand, does not impair the electrical conductivity and when properly applied will withstand over 200 hours salt spray without aluminum corrosion products being formed. Unfortunately this finish is not very durable and is easily damaged by scratching. It makes an excellent base for the application of organic coatings, however, and is therefore extensively used when the exterior surface is to be painted.

Organic Coatings

Before any of the commonly used organic coatings such as paint, enamel or lacquer can be applied to a part, the surface must be prepared. Several methods which result in a fine etch (permitting the organic coating to grip the surface) are recommended; Bonderize for zinc, Parkerize or Bonderize for steel, Lithoform on hot galvanized parts and chemical oxide chromodizing or phosphatizing on aluminum.

Underwriters' Considerations

Certain requirements have been set down by the Underwriters' Laboratories, Inc., which when followed make the operation of a radio appliance fairly safe from a shock or fire hazard standpoint. Since these requirements have a bearing on the mechanical design of the equipment a brief summary of the applicable points will be given.

All live or current-carrying parts which involve shock or fire hazard other than cords or cables shall be suitably protected. The enclosure shall be substantially constructed and in the case of metal enclosures shall be suitably corrosion resistant. Metals of at least 0.015" in thickness, asbestos of at least 1/32" or molded phenolic of 1/8" may be used for the enclosure, provided the part has adequate mechanical strength.

In the case of parts conductively coupled to the power line through less than 120,000 ohms impedance, the part or parts must not be exposed within three times the minor axis of irregular holes or within three times the diameter of holes larger than 1/4". When the current exceeds five milliamperes with a 1500 ohm load, parts connected to secondary circuits of over 24 volts are also considered shock hazards and must be protected with suitable barriers or enclosures.

Openings are permitted for ventilation if protected by a fine mesh metal screen. Openings may be provided for cables or other conductors if they are small in size and few in number. Circuit adjustment holes are allowable if their diameters are less than 9/32" and the ad-

General continued

justment screws are not more than 1/4" behind the openings. Openings may be provided for manufacturing purposes if they do not exceed 3/16" diameter or equivalent area. Slots having a width of 1/16" or less are excepted.

For complete information see the latest edition of "Requirements for Power Operated Radio Receiving Appliances" published by the Underwriters' Laboratories, Inc., New York.

Costs

Designing for minimum cost, keeping in mind the maintenance of a high standard of quality requires considerable experience and ingenuity. There are three general items to be considered when analyzing the cost of a product; (1) material, (2) labor and (3) burden. These may be subdivided according to the complexity of the product being produced. Fig. 1-5 shows a summary of the factors involved.

Materials and Design

In the design of radio equipment, as in the design of most products, there should be a reason for everything. FACTS are all important. With this axiom in mind the designer should question each step in the design of a new product.

Mechanical

The end use of the part is a logical place to begin when selecting a material specification. If the part is purely mechanical and will in no way affect the electrical performance, as for example a dial scale bracket, then such properties as permeability and conductivity need not be considered. Here the designer is mainly concerned with rigidity and strength, so it is only necessary to consider such things as thickness, elasticity, ease of working etc. The thickness of the metal of course varies with the function and design of the part. Often it is possible to specify a thinner metal if the design is such that strengthening ribs or flanges can be added at strategic points. Tool costs are usually somewhat lower if thin metal can be used, although the additional cost of strengthening ribs or flanges may outweigh the savings in material. Each case should be considered as a separate problem if the minimum cost is to be obtained.

Another factor—tolerances—must be considered when cost is being studied. If wide tolerances bring about complications in assembly, it becomes very questionable as to whether an overall saving will be made. Tolerances should be as liberal as possible, but only to the point which will permit complete interchangeability of production parts. In general, close tolerances are not too expensive, (considering the overall design); obviously the original tool cost is higher but the fact that the cost is spread over a large number of units makes it of little consequence when compared to the ease of assembly and resultant saving in time. It must be remembered that labor costs are relatively high and any saving in man-hours is well worth while.

General continued

When sub-assemblies are purchased from an outside source consideration must be given to the physical shape of the part because this will affect the method or ease of packing. Sections which protrude beyond the main body of the part are definitely a problem. It is sometimes worth while to omit a shaft or bracket from a sub-assembly and assemble it on the final production line in order to simplify the packing for the parts supplier.

Choice of rivets versus spotwelds seems like a very minor matter but the decision should not be made without consideration of several factors. Perhaps one or the other will show definite advantages because the parts to be fastened together will not have to be moved from one department to another. There is also the possibility that if the parts are to be riveted a special size of rivet will be required, which will necessitate an additional machine and operator. In the case of spot-welding the number of welds should definitely be specified since each weld represents an appreciable part of a cent of cost.

Savings are also effected in the mounting of parts by including a locating dowel for positioning purposes which at the same time can replace one of the mounting screws. The use of embossings in place of spacers and punch-formed holes for mounting screws should also be investigated if the quantity to be produced is large enough to warrant the extra tooling. The operator would not have to handle the extra parts (spacers, nuts or lockwashers) and the assembly is greatly simplified. Either self-tapping or regular drive screws can be employed or the punch-formed hole may be tapped if it is necessary to specify a regular machine screw. Along these lines it is often feasible to throw up tabs or small brackets from the main chassis thus eliminating the need for separate parts. These brackets should be designed in such a manner that no extra operations are required in forming the part. In other words if the bracket or tab can be formed during the same operation that forms the main chassis then worthwhile savings are possible, otherwise it might be advisable to continue with separate parts either riveted, screwed or spotwelded into position.

Another source of savings is where a part can be designed to be used on several models or in several places on the same model. Omit whenever possible the need for right and left hand parts because invariably a production operator will pick up the wrong part. Such parts are difficult to keep separated in the stock room and the carrying of an extra item, considering the drawings, part numbers and records involved, amounts to additional overhead expense which can often be eliminated.

Still another way of decreasing costs is to design the product in such a way that a minimum number of different machines and tools are required. Extra machines require additional setup time and maintenance as well as man hours to produce; both of these add to the piece price of the unit. The savings through Standardization is of course well known to every engineer and the advantages of eliminating "special" components needs little discussion since it is so obvious that the supplier

General continued

can reduce his cost by larger production, and the manufacturer by the elimination of extra drawings, ordering and stocking.

The above mentioned possibilities for savings represent, of course, only a few of the total number to be found in almost any design. The main idea in pointing these out is to give an example by which the designer can pattern his work.

Electrical

Savings in the electrical design of a radio can be appreciable if the development has been well planned and carefully carried to completion. Due to the many available circuit combinations it is impractical to discuss all possible sources of savings; it is hoped, however, that the examples given will be sufficiently representative and illustrative to show the general method of procedure.

Usually the first consideration in attempting to design for electrical savings is the choice of tube types. Here, as in practically all other instances, up-to-date tube costs are required. In general, using tube types included on the manufacturer's preferred list will result in worthwhile savings, although there are of course exceptions to this rule.

Because of the wide range of frequencies involved in the design of a radio, many grades of insulation or dielectric are required to obtain good performance. Because of this fact it is very easy to specify a higher grade than necessary; therefore all applications should be studied in order to determine the lowest priced material which will give satisfaction. Many times a leakage problem exists which can be solved by impregnating a relatively low cost insulating material in a suitable wax or other non-hygroscopic material, thereby making a saving even though the impregnation necessitates an additional operation. Of course in our anxiety to reduce costs the fact that insulators must have good mechanical properties should not be forgotten; it is necessary therefore to consider these characteristics as well as power factor or electrical losses.

Resistors and capacitors, because of the quantities usually involved, are nearly always a possible source of savings. Here it is important that the wattage, voltage, capacity or resistance ratings be correct. It must be remembered that power line voltages are seldom the same in any two localities and for this reason allowances must be made to provide for such variations. The tolerances too are particularly important; they should be as liberal as possible and yet be consistent with good performance.

The audio and power circuits present unusual opportunities for economical design. Temperature rise in power transformers can be decreased by careful placement of parts to provide good ventilation with a consequent savings in both iron and copper. Filtering with relatively inexpensive R-C circuits instead of additional high voltage capacitors, bucking of hum in the speaker, and the careful location of components and "dressing" of leads should all be investigated. Elabo-

General continued

rate audio systems can often be dispensed with by the proper choice of speaker response characteristics.

Probably of more importance than any other single item associated with the electrical design is the layout of parts and wiring. Convenience in wiring through the use of just the correct number of wiring panels, and ease of assembly are of paramount importance because they both directly affect the labor costs. When too many leads or wires must be soldered to a single terminal panel, the efficiency of the wireman is decreased, the joint tends to become sloppy and the possibility of poor soldering increases, not to mention the fact that excess solder is likely to become lodged in some inaccessible spot and might later cause trouble. It is usually possible to show a savings in the overall picture by including additional wiring panels to prevent such overloading. A design in which the parts are poorly placed and the wiring is inaccessible not only is difficult to produce but is equally difficult to test or repair. Testing and repair require skilled labor which

TYPICAL PERFORMANCE DATA SHEETS

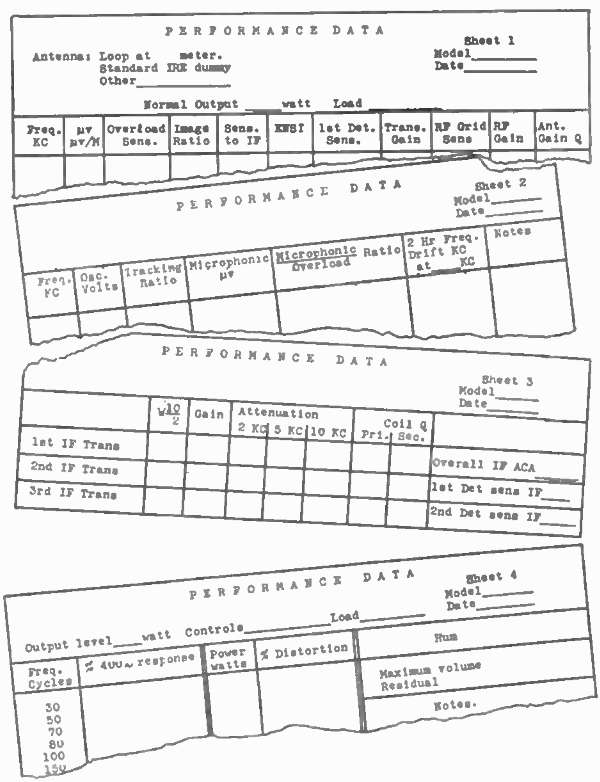


Fig. 1-6

General continued

is relatively expensive, in fact it is sometimes advantageous to include test jacks or clips in the design in order to shorten the testing or repair time. The additional parts may appear to be an unnecessary expense but in many cases there will be a substantial labor saving and therefore the possibility should be investigated.

Because of the numerous new developments in materials and methods of fabricating parts, past experience can not always be relied upon. For this reason in the electrical design, as in the mechanical design, a careful cost analysis is the key to savings.

Measurements

Typical Test Data Sheets used during the development of a radio receiver are shown in Fig. 1-6. Many of these tests may seem unwarranted because the information can be calculated from other data. For instance, knowing the second detector sensitivity, the i-f gain per stage, and the translation gain of a superheterodyne, it should be possible to calculate the first detector sensitivity. To the uninitiated it might be surprising that the measured and calculated values do not agree. If the measurements have been correctly made, the difference is usually due to overall degeneration or regeneration. These two effects can become very troublesome during production, so it is to the designer's advantage to know their magnitude and origin. A discussion of these points together with sample curves will be given as each measurement is described.

Normal Operating Conditions

In order that the receiver characteristics may be more readily interpreted and compared it is important that measurements be made under so-called Normal Test or Operating Conditions. Fig. 1-7 gives these conditions in a convenient usable form. Note that certain tests should be made at high and low power line or battery supply voltages. This is necessary to determine whether extremes in power supply voltage will cause unstable operation such as blocking, oscillation, oscillator stoppage, microphonics etc., to mention a few. Also note that both high and low transconductance tubes should be tested for the same reasons.

Single Stage Measurements

A logical beginning would be to start with the audio amplifier, work back through the second detector or discriminator, the i-f amplifier, converter-oscillator and the r-f stage. As each independent section is found satisfactory, it is combined with the preceding section until the entire receiver is operating as a single unit. Since these measurements are fairly well standardized only those that require special precautions will be discussed.

NORMAL TEST AND OPERATING CONDITIONS

TYPE RECEIVER	LINE POWER AC, AC-DC	BATTERY POWER STORAGE	BATTERY POWER DRY CELL
Normal Power Input	117v	6.6v	1.35v
Limits Power Input	106-128v	5.8-7.8	1.1-1.6
Normal Test Output	When power output capability exceeds 1 watt use 0.5 watt. When power output exceeds 0.1 watt but is less than 1 watt use 0.05 watt (50 milliwatt).		
Power Output	Watts (RMS) at 10% harmonic distortion.		
Tubes	Tubes should have center characteristics for those parameters which affect performance. Check operation at limits of power input with high and low tubes.		
Sensitivity Normal Maximum output	Minimum input of r.f carrier with 400 cycles 30% modulation to give normal output. Minimum input of r.f carrier with 400 cycles 80% modulation to give maximum (10% distortion) output.		
Selectivity	R. F. carrier 400 cycle 30% modulation.		
Image Response	R. F. carrier 400 cycle 30% modulation.		
Fidelity	R. F. carrier 30-10,000 cycles 30% modulation. Measure curve at center of r-f band unless selectivity appreciably attenuates side bands in which case measure at ends of band.		

Fig. 1-7

Audio Amplifier

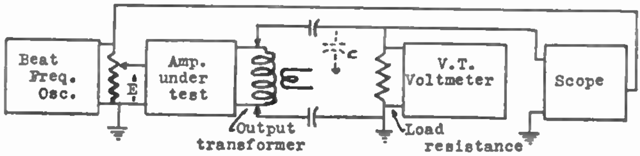
Fig. 1-8 shows a typical set-up for the measurement of audio amplifier characteristics. The output coupling capacitors (at least 10 mfd) should have a minimum of capacitance to ground. With a single-ended amplifier as shown only the capacitor in the high side (plate lead) would cause an erroneous reading; however, if a push-pull amplifier were being measured both capacitors would affect the results if there were any appreciable capacity to ground. This would attenuate the high audio frequencies as shown.

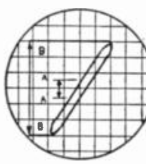
At audio frequencies most ground connections are effective, nevertheless it is good practice to ground the amplifier and the measuring equipment at one point thereby eliminating a possible source of error due to ground currents between the parts. A typical input-output curve is shown; if the input voltage is measured simultaneously with the output voltage the gain of the amplifier may be determined and an indication of when the peak input voltage equals or exceeds the normal amplifier bias is obtained. By using an oscilloscope as a monitor, experience is obtained in correlating distortion and waveform.

The fidelity curve is plotted in percent of 400 cycle response versus frequency as shown. It is possible to have a perfectly flat amplitude versus frequency characteristic and yet on a listening test the fidelity may be objectionable due to phase shift or intermodulation products in the amplifier. As a simple means of checking this, an oscilloscope may be employed. Proper adjustment of the amplitudes of the input and output voltages should result in a straight line or narrow ellipse on the scope screen. The phase angle can be approximated by measuring the distance AA and BB on the screen as shown and calculating the ratio between them. Checks should be made at several points throughout the range.

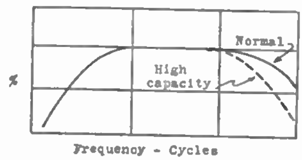
General continued

Audio Frequency Measurement Considerations





Determination of phase distortion with oscilloscope connected as shown in schematic.
Phase angle
$\sin \Theta = \pm \frac{AA}{BB}$



Effect of high capacity to ground from output coupling capacitor shown as C in schematic.

Fig. 1-8

Second Detector

In checking the second detector if the maximum output previously measured on the audio amplifier is not reached, obviously the overload characteristic of the detector is not satisfactory. Fig 1-9 shows a typical curve of percent distortion versus modulation as measured correctly and incorrectly. By keeping constant output at the normal test level, the percent distortion curve remains essentially flat up to the point where the detector is incapable of handling signals of higher percentage modulation. When the output is not maintained at a constant level but allowed to increase with percent modulation the audio power output will increase as a function of the modulation percentage and overloading will occur in the final amplifier stage, with increased distortion.

FM Discriminator and Limiter Stage

FM receivers require a different type of second detector than AM receivers and therefore the measurements described above do not apply. The important characteristics of a discriminator include sensitivity, linearity and fidelity. Because of the difficulty in simulating actual working conditions, measurements are usually made with the limiter or preceding amplifier functioning in a normal manner.

By inserting a separate audio signal to amplitude modulate the FM signal generator, the discriminator curve as indicated by an oscilloscope will be filled-in as shown by the dotted lines in Fig. 1-10. Most generators are provided with such a connection. The 60 cycle power line fed through a tapped transformer is ideal for this purpose and will assist materially in making the proper adjustments and obtaining a balanced output. The curve shown requires the scope be synchronized from the FM signal generator.

General continued

I. F. Amplifier

The technique of i-f amplifier measurements is an important part in the series of checks made on a receiver. Due to the relatively high order of amplification and selectivity involved, the effects of regeneration and degeneration are very likely to cause considerable trouble in the proper evaluation of the amplifier. It is therefore imperative that these measurements be made with extreme care. This is particularly true when two or more stages are being measured in cascade.

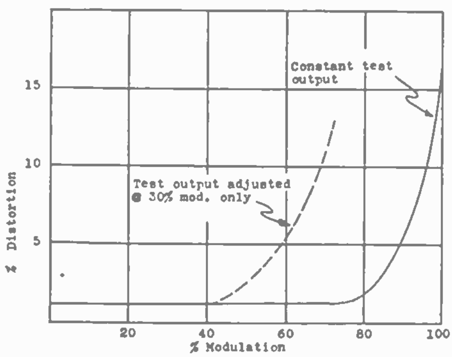
Before making any measurements the stage under consideration is thoroughly isolated from the effects of the other sections of the receiver. For instance, if due to extraneous pickup a signal is introduced into the second detector circuit, an AVC voltage may be developed which might feed back to the grid of the i-f stage being measured. This obviously would not represent normal operation and must be prevented. A common method of rendering the second detector insensitive to such pickup is to shunt a bypass capacitor (0.05 mfd) across the diode.

An exception to this procedure is where the i-f stage feeds a diode. Here the tube voltmeter would not simulate actual operation so it is customary to have the diode connected and operating during the measurement. The AVC however, should be disconnected by returning the i-f grid through a decoupling resistor and capacitor to –B. The input of the preceding stage should also be shorted in the same manner as when the second detector was being measured.

Converter or First Detector

It should be pointed out that converter gain as conventionally measured does not always represent normal operation, particularly where coupling exists between the oscillator and r-f circuits. This is because the signal generator shorts the r-f circuit and therefore does not present the same impedance input to the stage being measured as would normally be present if the r-f or antenna stage were connected. A check of selectivity will then indicate whether the discrepancy is due to regeneration, degeneration, or the fact that the signal generator has changed the circuit operation to such an extent that the converter gain is modified.

DETECTOR DISTORTION CHARACTERISTIC—



Showing measurement error due to overload caused by not maintaining normal test output. The output normally increases with percent modulation and therefore level must be compensated to prevent overloading.

Fig. 1-9

General continued

Should the converter grid sensitivity measure quite different from the calculated sensitivity as obtained by multiplying the individual stage gains together, it would be well to investigate the reason. Usually a small amount of regeneration or degeneration will exist and is to be expected; however, if it amounts to more than 10 or 15 percent it will likely prove serious under certain operating conditions. Particular care should be taken in connecting the equipment to avoid extraneous coupling between the signal generator input and the vacuum tube voltmeter. Leads should be short and direct. Clip leads if used should be arranged to maintain constant circuit capacity.

Oscillator Measurements

In addition to measuring the oscillator voltage appearing across the grid-leak, the frequency drift, pull-in effect, radiation and tracking or alignment should be checked.

Oscillator pull-in is usually not troublesome if the receiver has been properly designed; if it exists, sensitivity measurements cannot be relied upon. A simple check consists of adjusting the converter padding capacitor and noting whether the oscillator frequency changes. If the oscillator frequency shifts with tuning of the converter grid circuit, sensitivity measurements are likely to be poor unless both oscillator and converter circuits are tuned by simultaneously "rolling" the gang and adjusting the converter grid tuning. Obviously such a procedure is impractical for factory testing and should be corrected.

Overall Measurements

Although the individual stage characteristics are found satisfactory there is a good possibility that the overall receiver will not meet with approval. For example, the sensitivity and selectivity calculated from the single-stage data will often not agree with the overall measurements. AVC action may seriously impair the performance, or spurious responses may be troublesome. Needless to say these shortcomings may be greatly exaggerated if the measurement technique is faulty.

Discriminator-Limiter Measurement Considerations

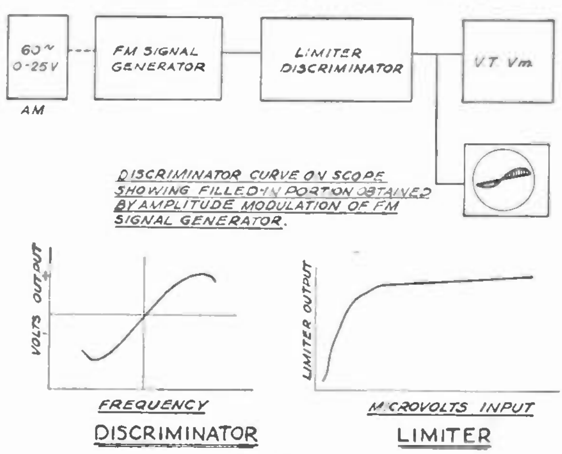


Fig. 1-10

Sensitivity

The overall sensitivity should be compared to previ-

General continued

ous measurements. The first detector or converter grid sensitivity times the r-f and antenna stage gains would normally compare with the measured overall sensitivity; however, this is not always true because the measured converter sensitivity does not always simulate actual operation. The presence of the generator may disturb the coupling between the oscillator and the converter grid, thereby changing converter transconductance.

This is only one reason why the sensitivities do not always check. Regeneration or degeneration might also be the cause and can be checked by comparing selectivity measurements. Calculation of the image response from the r-f selectivity curve as compared with the overall measurement of the same will also indicate whether an appreciable amount of regeneration or degeneration is present.

An appreciable error will sometimes result if a strong signal is used in tuning the receiver, because of the AVC system. For this reason adjustments should be made with a minimum of signal input to avoid possible overload or detuning effects.

Unusual discontinuities in the sensitivity often are the result of improper bypassing or ground connections. It is important that the low potential side of the signal generator be connected to the low potential receiver input and not to any particularly convenient point on the chassis. This is especially true at high frequencies where ground returns are critical. The connecting cable or leads and the dummy antenna should be kept well away from parts of the receiver which might cause feedback.

Selectivity.

The selectivity curve should be approximately equal on each side of resonance if the single stage selectivity curves are symmetrical. Should this not be the case it is well to investigate the cause. One likely source of trouble with loop receivers is magnetic coupling between the loop and an i-f or even an r-f stage. The simple expedient of reversing the loop antenna will sometimes correct this, although it may introduce some other equally bad effect. Should reversing the loop antenna be found desirable, it would be wise to repeat all measurements made thus far.

Another cause for unsymmetrical curves is caused by an appreciable amount of frequency modulation in the r-f signal generator. This is especially true when measuring highly selective receivers because as the signal generator is detuned from resonance during the selectivity measurement any change in impressed frequency will result in a change in voltage at the detector due to the slope of the selectivity curve. The detector is therefore not able to differentiate between frequency modulation of the signal generator or a change in amplitude modulation. Frequency modulation will appear as an additional amplitude modulation on one side of the selectivity curve thereby creating unsymmetry. The use of an unmodulated signal generator with means for indicating carrier strength, such as a microammeter in series with

General continued

the diode load, will eliminate this source of error.

Fidelity

Fidelity curves should be made with the tone controls adjusted to their extremes, and if the volume control is part of a compensation network, an additional curve should be taken at the point of maximum compensation. Care should be taken to prevent overloading the receiver if abnormal peaks are encountered.

Spurious Responses

A spurious response occurs at the harmonics of the intermediate frequency and is known as the Harmonic Tweet or Whistle. Ordinarily only the second harmonic is objectionable. Any feedback from the second detector or i-f amplifier is likely to exaggerate the effect and therefore care should be taken to keep all leads well away from this portion of the receiver.

Combination AM-FM Receivers

Combination AM-FM receivers are usually considered as two separate receivers for measurement purposes and their data and curves are plotted separately.

Field Testing

Although fairly complete measurements can be made on a radio receiver it is very difficult to evaluate the performance without an actual listening test. When possible a comparison should be made between new designs and a representative sample of previous designs. Listening tests should be made under as near normal living room conditions as are practicable, particularly if tonal fidelity is being checked. Unusually high electrical or aural background noise tends to mask the program and makes it difficult to listen critically for purposes of test or comparison. The listening room should be furnished as a typical living room with rugs ,drapes, tables, overstuffed furniture, floor lamps etc. One or two "tea wagons" should also be provided for measuring equipment. In addition to the normal living room furniture a supply of folding camp chairs often is useful, especially when a demonstration is to be given.

Testing Procedure

The receiver is set up along with other previous designs and each performance characteristic such as sensitivity, selectivity, fidelity, mechanical operation etc., is carefully compared under all conditions of operation. To facilitate making comparisons, switches are inserted in the speaker circuits so that quick shifting between units is possible. Switching the speakers on and off also permits setting the volume more accurately and eliminates any chance for error in this respect. Another precaution in comparing models is to make sure the physical location of one receiver is not more favorable than the other. It is good practice

General continued

to interchange the receiver location during sensitivity tests to check for such conditions. This is particularly noticeable on receivers having a loop antenna system.

Particular attention should be given to detect any inter-action or spurious responses between receivers; often what appears to be bad whistle interference may be traced to oscillator radiation from the comparison receiver. Checking fidelity is also quite difficult and unless the volume levels of all receivers are equal the conclusions are likely to be misleading. Volume should be adjusted on the basis of the middle frequency response and checks made at three levels; low, medium and high output. The observer should be as nearly as possible equi-distant and preferably directly in front of the speakers. Checks are also made off to the sides to determine whether the spatial distribution of the sound is satisfactory.

Tests are made at normal, high and low line voltages for stability, ease of tuning (freedom from regeneration), spurious signal response, sensitivity, selectivity and finally hum, distortion and pleasing tone.

During the field test it is of paramount importance to recheck observations frequently—the type of program plays a very important part in judging the quality of performance.

Conversion Factors

To convert	Multiply by
ELECTRICAL	
Amperes to microamperes	1,000,000,000.
Amperes to milliamperes	1,000.
Cycles to kilocycles	0.001
Farads to micromicrofarads	1,000,000,000,000.
Farads to microfarads	1,000,000.
Henrys to microhenries	1,000,000.
Henrys to millihenrys	1,000.
Mhos to micromhos	1,000,000.
Microvolts to volts	.000,001
Millivolts to volts	.001
Microwatts to watts	.000,001
Milliwatts to watts	.001
Volts to microvolts	1,000,000.
Volts to millivolts	1,000.
Watts to milliwatts	1,000.
Watts to kilowatts	.001
Watts to horse power	.001341
Watts to foot-pounds per minute	44.25
Watts to kilogram-meters per second	.1020
ENERGY	
B.T.U. to foot-pounds	778.
B.T.U. to joules	1,055.
Foot-pounds to B.T.U.	.001285
Joules to B.T.U.	.00947
Joules to ergs	10,000,000.
Watt-hours to B.T.U.	3.4126
Gram calories to joules	4.186
LENGTH	
Centimeters to inches	.3937
Inches to centimeters	2.54
Inches to mils	1,000.
Meters to feet	3.2808
Meters to inches	39.3701
Miles to kilometers	1.6093
AREA	
Circular mils to square inches	.000,000,7854
Circular mils to square mils	.7854
Square centimeters to sqaare inches	.155
Square inches to square centimeters	6.4516
POWER	
Foot-pounds per minute to horse power	.000,0303
Foot-pounds per minute to watts	.0226
Horse power to foot-pounds per minute	33,000.
Horse power to watts	746.
MISCELLANEOUS	
Kilograms to pounds	2.305
Pounds to kilograms	.4536
Ohms per 100 feet to ohms per kilometer	3.2808
Degree centigrade to fahrenheit	1.8 plus 32
Degree fahrenheit to centigrade	°F—32 x .5556

Table 1-1

Percent Relative Humidity

Dry Bulb °C	Wet and dry bulb thermometer readings in degrees centigrade Difference between wet and dry bulbs in degrees centigrade																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	20	25
20	9	82	74	66	58	51	44	36	30	23	17	11					
22	92	81	75	68	60	53	46	40	34	27	21	16	11				
24	92	85	77	70	63	56	49	43	37	31	26	21	14				
26	9.	85	77	71	64	57	51	45	9	34	28	23	18	13			
28	9.	85	78	72	65	59	53	47	42	37	31	26	21	17	13		
30	93	86	80	73	67	61	55	50	44	39	34	30	24				
32	93	86	80	74	68	62	56	5	45	40	36	32	27	23			
34	93	87	80	74	69	63	58	5.	47	42	38	34	30	26	22		
36	93	8.	8	5	0	64	59	54	50	45	41	6	32	28	24		
38	93	87	8	c	0	65	60	55	50	46	4	37	34	30	26		
40	94	88	82	76	71	66	6	57	52	48	44	40	36	32	29	13	
42	94	88	8.	77	72	67	62	58	53	49	45	4	38	34	31	17	
44	94	88	83	77	3	68	63	59	54	50	47	43	39	36	32	17	
46	94	89	83	78	73	68	64	60	55	52	48	44	41	37	34	19	
48	94	89	84	78	4	69	65	6	56	53	49	45	42	39	35	21	
50	94	89	84	79	75	70	65	62	57	54	50	47	43	40	37	23	
52	94	89	84	79	75	70	66	62	58	55	51	48	44	41	38	25	
54	95	90	85	80	76	71	67	63	59	56	52	49	45	42	39	26	15
56	95	90	8	80	76	72	68	64	60	57	53	50	46	43	40	27	17
58	95	90	85	80	77	72	68	64	61	57	54	51	47	44	42	29	18
60	95	90	86	8	77	73	69	65	62	58	55	52	48	45	43	30	19
62	95	9	86	81	78	73	69	66	62	59	56	53	49	46	43	31	21
64	95	9	86	82	78	74	70	66	63	59	56	53	50	47	44	32	22
66	95	91	86	82	78	74	70	67	64	60	57	54	51	48	45	33	23
68	95	9	87	82	79	75	71	67	64	61	58	55	52	49	46	34	24
70	9c	6	87	83	79	75	7	68	65	61	58	55	52	50	47	35	25

Table 1-4

Drill Sizes—Clearance & Tapping

Number	Diameter (mils)	Clearance screw	Tapping*
1	228.00	—	—
2	221.0	12-24	—
3	213.0	—	14-24
4	209.0	12-20	—
5	205.5	—	—
6	204.0	—	—
7	201.0	—	—
8	199.0	—	—
9	196.0	—	—
10	193.5	10-32	—
11	191.0	10-24	—
12	189.0	—	—
13	185.0	—	—
14	182.0	—	—
15	180.0	—	—
16	177.0	—	12-24
17	173.0	—	—
18	169.5	8-32	—
19	166.0	—	12-20
20	161.0	—	—
21	159.0	—	10-32
22	157.0	—	—
23	154.0	—	—
24	152.0	—	—
25	149.5	—	10-24
26	147.0	—	—
27	144.0	—	—
28	140.5	6-32	—
29	136.0	—	8-32
30	128.5	—	—
31	120.0	—	—
32	116.0	—	—
33	113.0	4-36 4-40	—
34	111.0	—	—
35	110.0	—	6-32
36	106.5	—	—
37	104.0	—	—
38	101.5	—	—
39	99.5	3-48	—
40	98.0	—	—
41	96.0	—	—
42	93.5	—	4-36 4-40
43	89.0	2-56	—
44	86.0	—	—
45	82.0	—	3-48
46	81.0	—	—
47	78.5	—	—
48	76.0	—	—
49	73.0	—	2-56
50	70.0	—	—

* Use size larger for bakelite.

Table 1-2

Comparative Table of Gages Common in Radio Design

Dimensions in decimal parts of an inch

Gage No.	Revised* US Standard	B & S** American	Steel	Aluminum	Brass	Copper
			Weights per square foot (Lbs.)			
10	.1345	.102	5.487	1.44	4.490	4.725
11	.1196	.091	4.879	1.28	3.997	4.206
12	.1046	.081	4.267	1.14	3.560	3.747
13	.0897	.072	3.659	1.01	3.173	3.338
14	.0749	.064	3.055	.903	2.825	2.972
15	.0673	.057	2.746	.804	2.516	2.648
16	.0598	.051	2.440	.716	2.238	2.355
17	.0538	.045	2.195	.638	1.996	2.100
18	.0478	.040	1.95	.568	1.776	1.869
19	.0418	.036	1.705	.506	1.582	1.665
20	.0359	.032	1.465	.450	1.410	1.484
21	.0329	.028	1.342	.401	1.256	1.321
22	.0299	.025	1.220	.357	1.119	1.178
23	.0269	.023	1.097	.318	.996	1.048
24	.0239	.020	.975	.283	.886	.932
25	.0209	.018	.8526	.252	.789	.830
26	.0179	.016	.730	.225	.701	.737
27	.0164	.014	.669	.200	.626	.658
28	.0149	.0125	.608	.178	.555	.584
29	.0135	.011	.551	.159	.498	.524
30	.0120	.010	.4895	.141	.441	.464
31	.0109	.009	.4446	.126	.392	.413
32	.0102	.008	.4161	.113	.353	.371
33	.0094	.007	.3835	.100	.313	.329
34	.0086	.0063	.3509	.088	.278	.292
35	.0078	.0056	.3181	.079	.247	.260

* Use U. S. Standard for steel. Variations are to be expected in practice.

** Use B & S for brass, copper and aluminum.

Table 1-3

Galvanic Series

CORRODED END (Anodic, or least noble)

Magnesium
Magnesium alloys

Zinc

Aluminum 2S

Cadmium

Aluminum 17 ST

Steel or iron
Cast iron

Chromium iron (active)

Ni resist

18 8 Stainless (active)
18 8 3 Stainless (active)

Lead tin solders
Lead
Tin

Nickel (active)
Inconel (active)

Brasses
Copper
Bronzes
Copper nickel alloys
Monel

Silver solder

Nickel (passive)
Inconel (passive)

Chromium iron (passive)
18 8 Stainless (passive)
18 8 3 Stainless (passive)

Silver

Graphite
Gold
Platinum

PROTECTED END (Cathodic or most noble)

Table 1-5

Commonly Used Finishes

ELECTROPLATED				
TYPE	PROTECTION (Exposure)	THICKNESS in inches	SALT SPRAY Hours	REMARKS
Cadmium	Mild	0.0002	50	On steel
Cadmium	Severe	0.0005	100	All specs.
Cadmium	Very Severe	0.001	200+	Unusual conditions
Zinc	Mild	0.0002	35	No paint or solder
Zinc	Severe	0.0005	100	Can be painted
Zinc	Very Severe	0.0008	150	Unusual conditions
Zinc ox black	Mild	0.0002	35	Deposit 0.0002" before oxidizing
Silver	None	0.00015		Low resistance
Silver	None	0.0003		Low electrical resistance. Can be soldered.
Nickel	Severe	0.0014	50	On steel
Nickel	Severe	0.0003		On brass
Black Ni	Severe	Zn or Cd 1st	50	Rust resistant
White Ni	Severe	0.0012	50	On brass
Copper (flash)	None	0.00008		Undercoat for nickel
Copper	Mild	0.0002		On steel
Anodized (aluminum)	Severe	As required		Excellent salt spray
Black anodize	Severe	As required		Tough black finish
CHEMICAL (Not electroplated)				
Bonderite	Treatment for zinc to improve paint adhesion.			
Lithoform	On hot galvanizing to improve paint adhesion.			
Bonderizing	On steel before applying paint.			
Parkerize	On steel before applying paint.			
Cronak	For additional protection on zinc.			
Sherardize	Zinc iron alloy coating by cementation.			

Table 1-6

Properties of Some Metals and Alloys

MECHANICAL					PHYSICAL			
MATERIAL	FORM	STRENGTH Yield 1000 PSI	STRENGTH Tensile 1000 PSI	HARDNESS Brinell	SPECIFIC GRAVITY	COEFF. LINEAR EXPANSION $10^{6}/''/°F$	ELECT. RESIST. Ohm/cmf	ELASTICITY MODULUS 10^{-6} PSI
Alcoa 2S	Cold rolled	21	24	44	2.72	13.8	17.6	10.3
Alclad 24S	Annealed	41	62		2.77	13.0		10.3
Copper	Annealed	10	31.8	30	8.92	9.8	10.4	16
	Cold rolled	48	60	120	8.92	9.8	10.4	16
Brass (High)	Cold rolled	75	86	180	8.47	11.2	40	14
Phosphor bronze	Cold rolled	75	100	210	8.86	9.9	57	15
Zinc	Cold rolled	21	36	40	7.15	16.5	36	12.4
Carbon steel SAE 1020	Annealed	40	58	130	7.86	6.7	60	29
	Cold rolled	75	81	146	7.86	6.7	60	29
Stainless steel 309	Annealed	50	100	165	7.90	8.3	470	29
	Cold rolled	110	150	275	7.90	8.3	470	29
Invar	Annealed	42	70	130	8.09	0.6	480	21
Silver	Cold rolled	40	51	90	10.5	10.6	9.5	10.3
Magnesium	Cast	12	28	48	1.83	15.5	69	6.25
Dowmetal H	Rolled		25	33				

Table 1-7

Hardware Commonly Used in Radio Design

SCREWS

Class 2 Fit.

SIZE	THREAD	MAX. HEAD DIA. Round	MAX. HEAD DIA. Oval bind.	MAX. HEAD THK Round	MAX. HEAD THK Oval B.	MAX. SLOT WIDTH Round	MAX. SLOT WIDTH Oval B.	MAX. SLOT DEPTH Round	MAX. SLOT DEPTH Oval B.
2	56	.162	.194	.070	.050	.036	.030	.048	.032
4	40	.211	.252	.086	.063	.040	.032	.058	.041
6	32	.260	.311	.103	.080	.045	.040	.067	.051
8	32	.309	.369	.119	.095	.050	.045	.076	.061
10	24	.359	.428	.136	.110	.055	.055	.086	.070

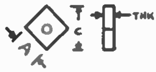
LOCKWASHERS

SCREW SIZE	EXTERNAL TEETH OD	EXTERNAL TEETH THK	INTERNAL TEETH OD	INTERNAL TEETH THK	SPLIT OD	SPLIT THK
2			3/16	.012	.124	.022
4	9/32	.016	17/64	.016	.177	.022
6	5/16	.018	9/32	.018	.205	1/32
8	⅜	.020	21/64	.020	.263	1/32
10	13/32	.022	⅜	.022	.294	3/64

NUTS

HEX

SQUARE



SIZE	THREAD	HEX WIDTH Across corners	HEX WIDTH Nominal	THK	SQUARE WIDTH Across corners	SQUARE WIDTH Nominal
2	56	.205	3/16	1/16	.247	3/16
4	40-48	.275	¼	3/32	.331	¼
6	32-40	.344	5/16	7/64	.415	5/16
6	32		¼	5/64		
8	32-36	.378	11/32	⅛	.456	11/32
8	32		¼	3/32		
10	24-32	.413	⅜	3/32	.497	⅜
10	32		5/16	3/32		

Table 1-8

Decimal Equivalents

1/64	.0156	17/64	.2656	33/64	.5156	49/64	.7656
1/32	.0312	9/32	.2812	17/32	.5312	25/32	.7812
3/64	.0468	19/64	.2968	35/64	.5468	51/64	.7968
1/16	.0625	5/16	.3125	9/16	.5625	13/16	.8125
5/64	.0781	21/64	.3281	37/64	.5781	53/64	.8281
3/32	.0937	11/32	.3437	19/32	.5937	27/32	.8437
7/64	.1093	23/64	.3593	39/64	.6093	55/64	.8593
⅛	.125	⅜	.375	⅝	.625	⅞	.875
9/64	.1406	25/64	.3906	41/64	.6406	57/64	.8906
5/32	.1562	13/32	.4062	21/32	.6562	29/32	.9062
11/64	.1718	27/64	.4218	43/64	.6718	59/64	.9218
3/16	.1975	7/16	.4375	11/16	.6875	15/16	.9375
13/64	.2031	29/64	.4531	45/64	.7031	61/64	.9531
7/32	.2187	15/32	.4687	23/32	.7187	31/32	.9687
15/64	.2343	31/64	.4843	47/64	.7343	63/64	.9843
¼	.25	½	.5	¾	.75	1	1.0

Table 1-9

Temperature Conversion - Centigrade and Fahrenheit

Deg. C	Deg. F	Deg. C	Deg. F	Deg. C	Deg. F	Deg. C	Deg. F
0	32.0	25	77.0	50	122.0	75	167.0
1	33.8	26	78.8	51	123.8	76	168.8
2	35.6	27	80.6	52	125.6	77	170.6
3	37.4	28	82.4	53	127.4	78	172.4
4	39.2	29	84.2	54	129.2	79	174.2
5	41.0	30	86.0	55	131.0	80	176.0
6	42.8	31	87.8	56	132.8	81	177.8
7	44.6	32	89.6	57	134.6	82	179.6
8	46.4	33	91.4	58	136.4	83	181.4
9	48.2	34	93.2	59	138.2	84	183.2
10	50.0	35	95.0	60	140.0	85	185.0
11	51.8	36	95.8	61	141.8	86	186.8
12	53.6	37	98.6	62	143.6	87	188.6
13	55.4	38	100.4	63	145.4	88	190.4
14	57.2	39	102.2	64	147.2	89	192.2
15	59.0	40	104.0	65	149.0	90	194.0
16	60.8	41	105.8	66	150.8	91	195.8
17	62.6	42	107.6	67	152.6	92	197.6
18	64.4	43	109.4	68	154.4	93	199.4
19	66.2	44	111.2	69	156.2	94	201.2
20	68.0	45	113.0	70	158.0	95	203.0
21	69.8	46	114.8	71	159.8	96	204.8
22	71.6	47	116.6	72	161.6	97	206.6
23	73.4	48	118.4	73	163.4	98	208.4
24	75.2	49	120.2	74	165.2	99	210.2
						100	212.0

Table 1-10

CHAPTER ONE

Inductance Capacity (LC) Table

M.C.	L.C.	M.C.	L.C.	M.C.	L.C.	M.C.	L.C.	M.C.	L.C.
16	98.945	45	12.509	74	4.6257	103	2.3878	132	1.4538
17	87.646	46	11.970	75	4.5032	104	2.3421	133	1.4321
18	78.197	47	11.466	76	4.3855	105	2.2977	134	1.4108
19	70.167	48	10.994	77	4.2722	106	2.2545	135	1.3900
20	63.325	49	10.549	78	4.1635	107	2.2126	136	1.3696
21	57.637	50	10.136	79	4.0585	108	2.1718	137	1,3497
22	52.335	51	9.7380	80	3.9577	109	2.1322	138	1.3302
23	47.880	52	9.3675	81	3.8605	110	2.0935	139	1.3111
24	43.975	53	9.0170	82	3.7670	111	2.0560	140	1.2923
25	40.545	54	8.6867	83	3.6767	112	2.0195	141	1.2742
26	37.470	55	8.3735	84	3.6022	113	1.9839	142	1.2563
27	34.747	56	8.0767	85	3.5062	114	1.9492	143	1.2388
28	32.307	57	7.7962	86	3.4242	115	1.9155	144	1.2216
29	30.120	58	7.5296	87	3.3465	116	1.8826	145	1.2049
30	28.145	59	7.2767	88	3.2710	117	1.8554	146	1.1884
31	26.360	60	7.0362	89	3.1970	118	1.8193	147	1.1723
32	24.736	61	6.8072	90	3.1272	119	1.7887	148	1.1565
33	23.260	62	6.5900	91	3.0595	120	1.7590	149	1.1410
34	21.911	63	6.3820	92	2.9925	121	1.7302	150	1.1256
35	20.677	64	6.1840	93	2.9287	122	1.7020		
36	19.565	65	5.9952	94	2.8665	123	1,6744		
37	18.503	66	5.8150	95	2.8067	124	1.6475		
38	17.542	67	5.6425	96	2.7485	125	1.6212		
39	16.654	68	5.4777	97	2.6920	126	1.5957		
40	15.831	69	5.3202	98	2.6372	127	1.5706		
41	15.068	70	5.1492	99	2.5842	128	1.5461		
42	14.409	71	5.0247	100	2.5332	129	1.5223		
43	13.699	72	4.8912	101	2.4833	130	1.4988		
44	13.084	73	4.7532	102	2.4348	131	1.4761		

$$\text{L.C.} = \frac{25332}{f^2\ \text{(megacycles)}}$$

Key:

16-150 MC = L.C.
1.6-15 MC = L.C. x 100
.16-1.5 MC = L.C. x 10000

$$\text{L} = \frac{\text{L.C. (f megacycles)}}{\text{C}} \qquad \text{C} = \frac{\text{L.C. (f megacycles)}}{\text{L}}$$

L in micro-henries

C in micro-micro-farads

INDUCTANCE-CAPACITY (LC) TABLE

Table 1-11

Reactance Chart

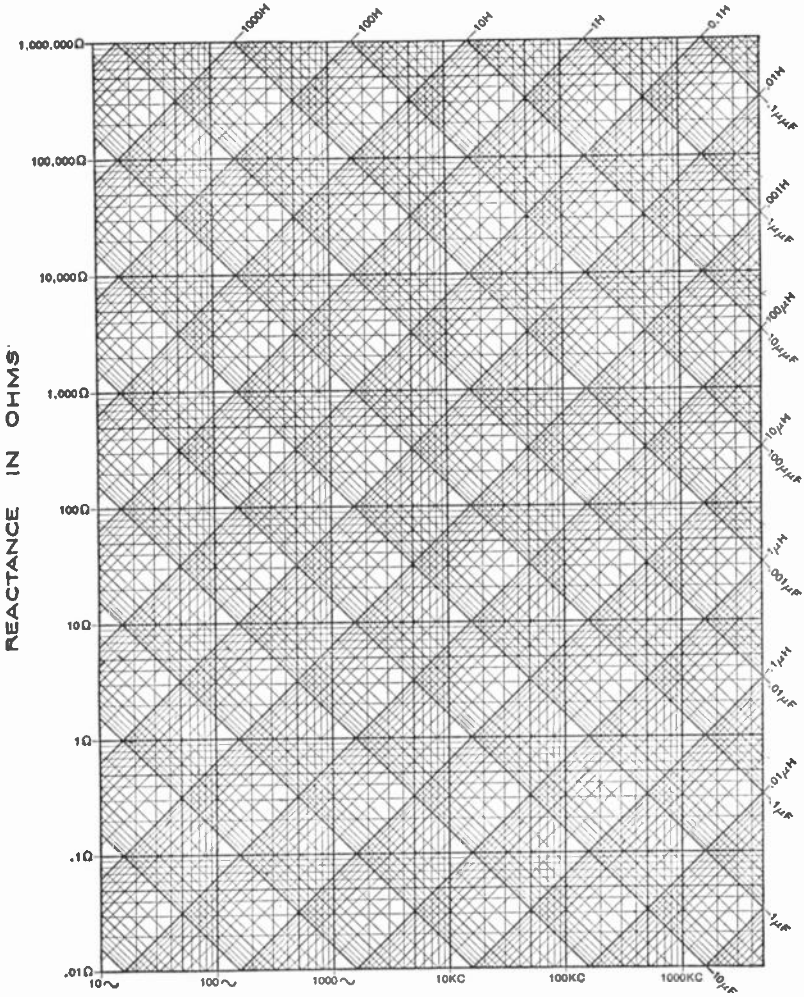
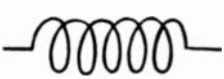


Table 1-12

TRANSFORMERS & INDUCTORS
RADIO FREQUENCY



DESIGN

General Considerations

Three types of windings are commonly used in the design of r. f. inductors; (1) solenoid, (2) universal and (3) bank. Variations of these such as the variable pitch solenoid sometimes employed with permeability tuning, and the progressive bank winding for low r.f. applications are considered as specialized types and in general have essentially the same characteristics as the basic type windings.

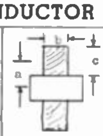
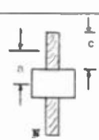
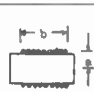
For all practical purposes the inductance can be calculated to an accuracy of approximately one percent. In addition to the inductance there are other parameters such as distributed capacitance, skin effect, Q, shielding and leakage resistance which must be considered. Each of these have an important bearing on the performance for a given application.

Distributed Capacitance

Effectively the inductor behaves as a true inductance with a small capacitor in parallel. The two in combination form a resonant circuit; therefore the inductor possesses a natural resonant frequency of its own.

The capacitor or distributed capacitance may be explained as follows: Since any two turns of an inductor have a difference of potential between them, they behave as the two plates of a capacitor with the result that the combination of all of these minute capacitors com-

INDUCTOR DESIGN CONSIDERATIONS

TYPE	CROSS-SECTION	EQUATION*	NOTES
UNIVERSAL	 a, b and c approximately equal	$L = \frac{0.8a^2N^2}{6a+9b+10c}$	High distributed capacity. Medium Q (can be improved with litz wire and powdered iron core). Recommended frequency range 50KC-2MC. R.F., oscillator and I.F. applications. Maximum inductance for minimum space.
SPIRAL	 c > 0.2a	$L = \frac{a^2N^2}{8a+11c}$	Medium distributed capacity. Medium Q (can be improved with litz wire and powdered iron core). Recommended frequency range 100 KC to 30 MC. Loop antenna applications.
SOLENOID	 b > 0.82a Dimensions "	$L = \frac{a^2N^2}{9a+10b}$ L in µh	Low distributed capacity. High Q. Recommended frequency range 500 KC to 300 MC. R.F., antenna, oscillator and I.F. applications. Accuracy approximately 1%

*Wheeler Proc. I.R.E. March 1929

Fig. 2-1

Design continued

prise what is commonly called the distributed capacitance. A winding which minimizes the potential difference between turns is therefore desirable if a low distributed capacitance is required.

Increased spacing between turns is the obvious answer but unfortunately this decreases the inductance; in an effort to compromise these parameters, several types of winding have been developed. The lowest distributed capacitance is obtained with a space wound solenoid, although as mentioned previously, the inductance for a given physical size is decreased. Next in order of preference is the bank wound type inductor with either a two layer or three layer winding, and last to be preferred for low distributed capacitance is the universal winding. The inductance for a given physical space increases in the order named.

Not only does the distributed capacitance cause a resonant condition to exist but it may appreciably affect the Q or losses of the inductor. The magnitude of the loss depends upon the quality and quantity of the dielectric involved and is especially important where high humidity and high frequencies are involved.

Skin Effect

Skin effect (caused by non-uniform current density distribution throughout the cross-section of the conductor) results in a variation of resistance as a function of frequency. The r.f. current penetrates the conductor to a depth which is inversely proportional to the square root of the frequency. For all practical purposes, if the radius of the conductor is greater than the skin depth, the material inside the current-carrying layer contributes nothing in the way of electrical performance. For copper the skin depth is

$$0.000662 \sqrt{f_{mc}} \text{ centimeters}$$

or approximately 0.001" at seven megacycles. Thus it is possible to copper or silver plate an electrically poor but mechanically stable material, such as Invar, and obtain a conductor having a low r.f. resistance plus an excellent physical temperature coefficient.

Skin effect can also be minimized (for frequencies up to approximately two megacycles) by the use of litzendraht wire. Several sizes are commercially available ranging from 3 to 44 or more strands of number 38 to 44 wire. General practice has led to 3/40 or 7/41 being more or less standard for most applications. Contrary to common belief the effect of one broken strand is relatively unimportant since the broken strand will still assist in the process of conduction.

Q (Figure of Merit)

The Q of an inductor is influenced by such factors as shape, skin effect, distributed capacitance, eddy current losses (in the conductor and nearby metallic objects) and leakage resistance. The magnitude of these losses is determined by the design, in particular the dimensions,

Design continued

wire size and material, winding form and shield; the problem is to effect a compromise between these items that will maximize the Q. Equations have been developed whereby it is practical to investigate the effect of these variables on the Q. Maximum dimensions are ordinarily determined by the availability of space, which often necessitates the use of shielding. If the physical dimensions of the shield are such that its diameter is twice that of the winding and the ends of the inductor are at least the winding diameter distant from top and bottom (assuming a good conductivity shield), the Q will not be decreased more than five percent. It should also be noted when considering Q, that a high Q inductor does not necessarily result in a high Q circuit. This will be discussed in more detail later.

In addition to the factors mentioned, another method of increasing Q is by the use of powdered iron. This increases the inductance without appreciably affecting the resistance. Powdered iron is so finely divided that it does not saturate, so the hysteresis loss is negligible. Eddy current losses, however, vary as the square of the frequency. Because of the distribution of the flux throughout each iron particle (similar to current in a wire—skin effect) the effective permeability decreases with frequency. The failure of the magnetic flux to penetrate the iron entirely is caused by the shielding effect of the eddy currents.

Powdered iron cores are commercially available in quite a wide range of permeability, physical size and shape; typical examples of these are shown in Fig. 2-3.

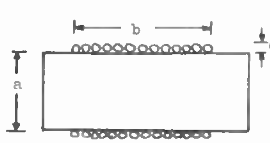
In attempting to realize a high Q through the use of powdered iron, not only the grade and quantity of iron must be considered, but also its physical relationship to the winding. For example in the inductor design as shown in Fig. 2-3B the position of the iron discs either side of the winding is important. Should the discs be located too close

Solenoid Design Considerations

LENGTH / DIAMETER $(\frac{b}{a})$ = 0.3 to 0.5

OPTIMUM WIRE SIZE* ≈ 0.707 b/N

Number of Turns $N = \sqrt{\dfrac{L(\frac{102b}{a}+45)}{a}}$



$$Q = \frac{\sqrt{fLc(\frac{b}{a})^2 a}}{31.62p\left[(\frac{b}{a})^2 a^2 N + 2N^3c^2\right]}$$

Includes skin effect but not losses due to dielectric or eddy currents.

where f is in cycles (frequency)

p is specific resistivity of wire (ohms/cm)

L is in microhenries

dimensions in centimeters

* Wire spaced to occupy 0.7 of winding length

Pollack - Elect. Eng. Sept. 1937

Fig. 2-2

Design continued

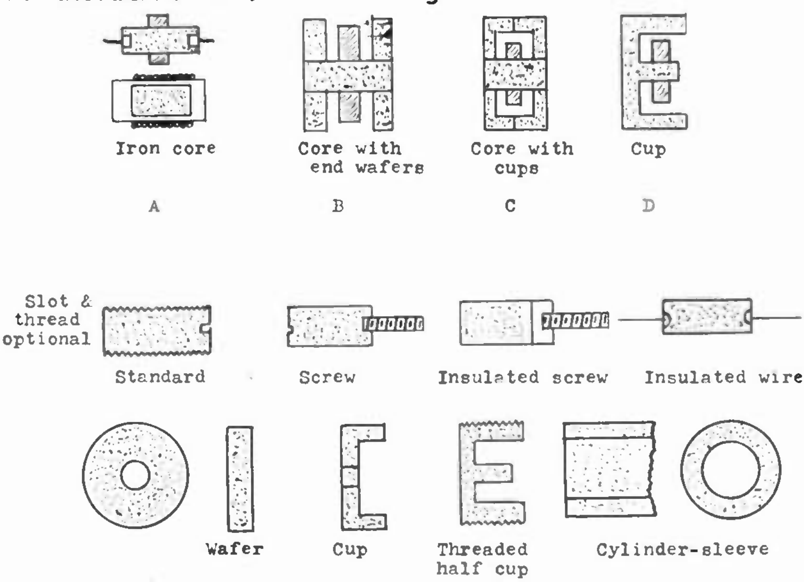
to the winding the distributed capacitance will be increased to such an extent that the Q at high frequencies will decrease, rather than increase as would normally be expected.

Completely enclosing the winding as shown in Fig. 3C effectively confines its field and thus permits locating the unit in close proximity to metallic objects, such as a chassis, with only a negligible effect on the performance. Of course precautions must be taken as with discs to minimize the distributed capacitance.

Coupling

The inductive coupling between two windings of a transformer is determined by measuring the difference in inductance of the two inductors in series, first as connected and then with one winding connec-

Powdered Iron - R. F. Inductor Design



PHYSICAL DIMENSIONS

TYPE	DIAMETER	LENGTH
CORE	0.125-1.5"	0.25-2.0"
WAFER	0.750-1.5"	0.1-0.175"
CUP	0.750-1.5"	0.2-0.375"
SLEEVE	0.437-1.0"	1.0-3.5"

THREADS

IRON	ADJ. SCREW	
10-32	2-56	6-32
1/4-28	3-48	8-32
5/16-20	4-40	10-32
3/8-16	5-40	

ELECTRICAL

Effective permeability 1.2 - 8
Frequency range 30 KC - 150 MC

Fig. 2-3

Design continued

tion reversed, and dividing the difference by four. A more widely used method of specifying coupling is to determine the Coefficient of Coupling. This may be represented by

$$K = \frac{M}{\sqrt{L_1 L_2}}$$

where L_1, L_2 and M are primary, secondary and mutual inductances respectively.

The coupling between transformer primary and secondary is a combination of electro-magnetic and electro-static effects and may be predominantly inductive or capacitive. With both windings in the same direction (normal procedure) and either the starts or finishes connected to grid and plate, the magnetic coupling opposes the capacitive coupling. Capacitive coupling may be made either aiding or bucking by reversing the connections to one of the windings. The former is preferred from a manufacturing standpoint because the position of the windings is not so critical.

Coupling may be increased by the use of powdered iron cores, although as mentioned previously, care should be taken to keep the distributed capacitance at a minimum.

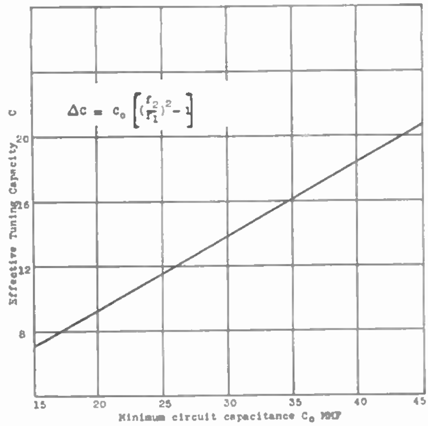
Shielding

The use of shields to minimize the field of the windings and thereby decrease coupling to other parts of the circuit is often necessary. Obviously the larger the shield the less effect it will have on the inductance and Q. Particular care should be taken to locate the winding at least 3/4" from the open end of the shield to prevent any loss of Q due to the proximity of the chassis. Steel parts where used (i.f. trimmers) must also be considered; even terminal lugs should be spaced away from the windings.

The shield material should have a low specific resistivity, such as copper or aluminum, and a thickness of approximately 0.020". Zinc can be employed but usually a heavier gage material will be required for equivalent results.

Winding Form

Ceramic, bakelite or paper winding forms are generally specified according to the individual requirements. Ceramic forms are obviously the most stable from a mechanical and elec-



Effect of minimum circuit capacitance on Tuning Capacitor Range

Fig. 2-4

Design continued

Antenna Circuit Considerations

IN GENERAL, ANTENNA LOADING SHOULD DECREASE SECONDARY Q TO APPROXIMATELY ONE HALF OF UNLOADED VALUE.

FOR LOOP ANTENNA CIRCUITS SEE FIG 6

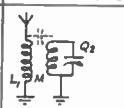
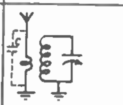
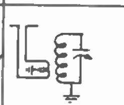
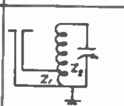
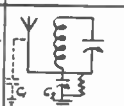
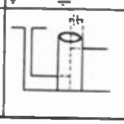
TYPE	SCHEMATIC	RECOMMENDED FREQUENCY	REMARKS
HIGH IMPEDANCE PRIMARY		LOW FREQUENCY 30-500 K.C. BROADCAST 500-2000 KC	PRIMARY RESONATES BELOW TUNING RANGE. CAPACITY COUPLING INCREASES HIGH FREQ. GAIN $GAIN \doteq \frac{MQ_2}{L_1}$
LOW IMPEDANCE PRIMARY		BROADCAST 500-2000 KC HIGH FREQUENCY 2-30 MC	LOW FREQ. GAIN INFERIOR TO HIGH Z PRIMARY. EXCELLENT FOR SHORT WAVE APPLICATIONS. $GAIN \doteq W^2MQ_2C$
BALANCED TRANSMISSION LINE		HIGH FREQUENCY 10-30 MC. VERY HIGH FREQ. 30-300 MC.	GOOD NOISE REDUCING CHARACTERISTICS. EXCELLENT FOR FM AND TELEVISION APPLICATIONS.
GROUNDED TRANSMISSION LINE		HIGH FREQUENCY 10-30 MC. VERY HIGH FREQ. 30-300 MC.	RECOMMENDED FOR AMATUER, FM AND TELEVISION APPLICATIONS. $GAIN = 0.707\sqrt{\frac{Z_2}{Z_1}}$ Z_2 IS EFFECTIVE SECONDARY IMPEDANCE
LOW IMPEDANCE CAPACITY COUPLED		HIGH FREQUENCY 2-30 MC. VERY HIGH FREQ. 30-150 M.C.	RECOMMENDED FOR QUARTER WAVE ANTENNA SYSTEMS. AMATUER AND MOBILE APPLICATIONS. $GAIN \doteq QC_1/C_2$
COAXIAL TUNED ELEMENT		ULTRA HIGH 300-3000 MC.	APPLICATIONS ABOVE 300 M.C. CAPACITY OR INDUCTIVE PROBE MAY BE EMPLOYED IN PLACE OF DIRECT CONNECTION SHOWN.

Fig. 2-5

trical standpoint although the cost is usually prohibitive for most applications. A treated Kraft paper (made with a neutral glue and free from any corrosive elements) will fulfill all normal requirements, especially if it has been thoroughly vacuum impregnated.

Windings and Wire

Litz wire is generally specified for all high grade low frequency antenna and i.f. transformers; 3/40 and 7/41 are the most popular sizes. A universal type winding of two or three sections is recommended for high Q with a minimum of distributed capacitance. In general, narrow windings with a maximum of cross-overs are the most efficient.

Transformers for higher frequencies usually show no advantage with litz wire. Progressive or bank windings using solid wire will be found satisfactory for the higher frequency units; in fact a simple solenoid winding is ideal if space is available. All windings should be

Design continued

vacuum impregnated or otherwise treated to maintain a high leakage resistance between windings under conditions of high humidity and to afford a certain degree of mechanical protection.

APPLICATION

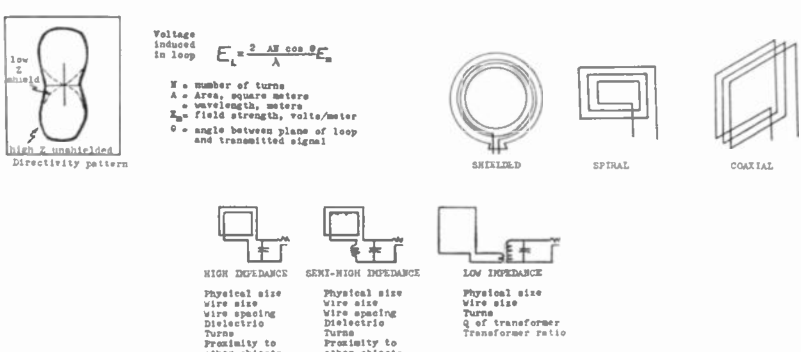
Antenna Stage

Two types of antenna stages are normally employed in present day design: one provides for a long wire external antenna and the other for a loop.

External Antenna

Low and Medium Frequency Operation

The tuned circuit impedance (secondary) and the effect on it by the primary (antenna connected) is the major problem. At low and medium frequencies the tube loading and general circuit losses are at best a second order effect and seldom need be considered. Generally the primary is untuned and coupled to the low potential end of the secondary to minimize capacitive effects. The degree of coupling is so



LOOP ANTENNA DESIGN CONSIDERATIONS

Fig. 2 - 6

established so that serious mis-tracking does not result when different antenna lengths are used (tight coupling) and gain will not be sacrificed (loose coupling). Permeability tuning may be employed if desired.

High Frequency Operation

The design of an antenna stage for high frequency operation, where the input loading of the tube becomes appreciable, requires

Application continued

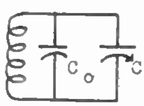
a somewhat different approach since the usual long wire or loop antenna is replaced by a half-wave or doublet with its associated transmission line.

The tuned circuit parameters, especially the inductance begin to assume minute quantities and it is evident that particular attention must be given to all leads and extraneous capacities. This includes tubes; if the tube capacity is large the tuning range for a given tuning capacitor is decreased, which necessitates a decreased L/C ratio and therefore less gain. An example of how the minimum circuit capacity affects the size of the tuning capacitor is shown in Fig. 2-4. It is apparent that every possible bit of minimum capacity should be eliminated from the circuit in order to utilize a small tuning capacitor and therefore obtain a high L/C ratio.

The input resistance of the tube due to transit time, cathode lead inductance and capacity also has an appreciable effect on the effective circuit impedance. The choice of tube types is therefore a major consideration. In general, the smaller the tube elements and the spacing between elements the better the performance at high frequencies. The obvious choice would be one of the "acorn" series; however, because of their relatively high cost, a compromise is suggested. The next logical choice would be a miniature or loktal. These have glass base insulation and in some cases comparatively small element structures with relatively short leads.

The use of ordinary insulating materials in the sockets, coil forms, tuning capacitor and wave switch is no longer feasible. Ceramic, polystyrene, mica or aluminum oxide filled materials should be specified. All unnecessary insulation should be eliminated and heavy short conductors should be employed. Resonant circuits, both parallel and series, have a habit of appearing in the most unexpected places, so particular attention should be given to the wiring layout.

Another potential source of trouble at high frequencies is the tuning capacitor. Whether an insulated rotor with individual wipers or a common rotor should be employed depends on the circuit layout and whether the additional common coupling be-



$$\frac{C_1 + C_o}{C_o} = (f_2/f_1)^2$$

then

$$C_1 = C_o\left[(f_2/f_1)^2 - 1\right]$$

and

$$C_o = \frac{C_1}{(f_2/f_1)^2 - 1}$$

where C_o = circuit capacity
f_1 = low frequency end of band
f_2 = high frequency end of band.

Determination of Allowable Fixed Circuit Capacity for a Specified Frequency Range When Tuning Capacitor Range Is Known.

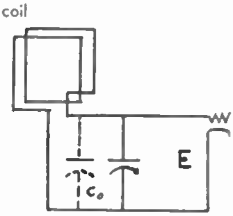
At resonance $-X_c = X_L$
The voltage across capacitor or coil
is then $E = \frac{i}{\omega C}$ or $i\omega L$
Substituting for current (in coil)

$$E = \frac{e}{R}\,\omega L$$

Since

$$Q = \frac{\omega L}{R}$$

the voltage to the grid is
$(E) = eQ$



VOLTAGE ON FIRST GRID WITH TUNED LOOP INPUT.
Fig. 2-7

R. F. Amplifier Considerations

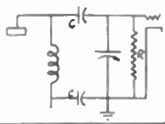
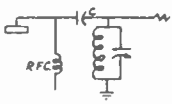
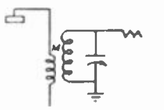
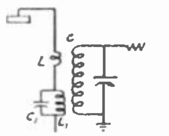
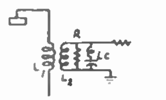
TYPE	SCHEMATIC	GAIN	NOTES
DIRECT COUPLED		GmWLQ	'C' SHOULD BE LARGE COMPARED TO TUNING CAPACITOR. 'R' SHOULD NOT LOAD TUNED CIRCUIT. IN GENERAL DIRECT COUPLED CIRCUITS ARE NOT RECOMMENDED.
CAPACITIVE COUPLED		GmWLQ	COUPLING CAPACITOR 'C' SHOULD BE SMALL (10 MMF) FOR OPTIMUM PERFORMANCE. TUNED CIRCUIT Q OF 200 READILY OBTAINABLE. RECOMMENDED FOR APPLICATIONS TO 300 MC. RFC NOT MUTUALLY COUPLED
INDUCTIVE COUPLED		GmWMQ	RECOMMENDED FOR APPLICATIONS FROM 2-50 MC. PRIMARY SHOULD RESONATE ABOVE TUNING RANGE. GAIN INCREASES WITH FREQUENCY
COMPOUND COUPLED		GmWMQ	RECOMMENDED FOR BROADCAST BAND APPLICATIONS. L RESONATES ABOVE AND L.C. BELOW TUNING RANGE. WITH PROPER PRIMARY CONSTANTS. GAIN WILL BE ESSENTIALLY UNIFORM OVER TUNING RANGE. L_1 - HIGH IMPEDANCE PRIMARY L - LOW IMPEDANCE PRIMARY
UNTUNED		DEPENDS ON BAND WIDTH	L_1 L_2 CLOSELY COUPLED AND TUNED BY TUBE CAPACITY TO GIVE DOUBLE PEAK RESPONSE CURVE. RESISTOR LOADED TO DESIRED CURVE SHAPE. SERIES RESONATE LC FOR SHARP CUTOFF ABOVE OR BELOW BAND.

Fig. 2-8

tween circuits is permissible. One method of eliminating common coupling in the tuned circuits is through the use of permeability or inductive tuning. In general the use of other than capacitor tuning results in the mechanical problems becoming a major consideration.

Gain

The gain is a function of the square root of the primary to secondary impedance times a constant (0.707) due to the untuned primary. See Fig. 2-5.

Since the secondary tuned circuit impedance is effectively shunted by the input impedance of the tube the net secondary impedance is reduced. The effect of the tube on the tuned circuit can be decreased somewhat by tapping the tube down on the tuning inductor. Ordinarily this would be expected to decrease the gain due to transformer action; however, by decreasing the load on the circuit the Q is increased to such an extent that the overall gain is hardly affected. The increased Q results in better selectivity and image rejection.

Loop Antenna Systems

The loop antenna can consist of any number of turns and may be

Application continued

in the shape of a square, rectangle, circle or oval. It can be solenoid or spiral-wound, shielded or unshielded according to the design requirements. Neglecting geometric shape for the moment there are three types of loop antenna systems, namely; high impedance, semi-high impedance and low impedance. Each has its advantages and limitations as will be pointed out. In general the design is dependent upon the physical space available in the cabinet. Every effort should be made to utilize the space to full advantage by choosing the most efficient design.

High Impedance Loop

A high impedance loop has sufficient inductance (without loading or auxiliary inductor) to resonate to the desired frequency band with the tuning capacitor completing the parallel tuned circuit. It should be located as far as possible from metal objects in order to minimize losses due to eddy currents; however, the leads between the loop and the input of the receiver should be kept short to minimize lead capacitance and resistance. Long leads also have inductance which, in combination with lead capacitance, decreases the number of permissible turns in the loop proper thus reducing the signal pickup. A compromise is therefore necessary between loop location and lead length.

Because of the large number of turns required for a high impedance loop the distributed capacitance becomes an important factor in the design. A distributed capacitance of 10 to 15 mmf (broadcast band) is not uncommon and unless extreme care is taken to minimize dieletric losses the Q of the loop may be substantially reduced. High distributed capacitance plus long leads limit the tunable frequency range as shown in Fig. 2-7. As the fixed circuit capacitance increases it is necessary to use a larger tuning capacitor to cover a given frequency range, or assuming the tuning capacitor range to be the highest practical value obtainable, then to satisfy the equation the frequency range would be decreased.

The voltage impressed on the grid of an r-f amplifier or detector tube at resonance can be calculated as shown in Fig. 7. This assumes that the radiation resistance can be neglected, which is true for most cases. The voltage delivered to the grid is equal to the induced voltage multiplied by the Q of the loop. It is desirable then to have as high a loop Q as possible since the signal delivered to the receiver input is directly proportional to the Q.

The most serious disadvantage to a high impedance loop is its susceptibility to humidity. The insulation must be of the highest quality otherwise moisture will increase the distributed capacitance and decrease the leakage resistance across its terminals, reducing the Q and thereby its effectiveness.

Another disadvantage occurs when it is necessary, because of interfering objects, to locate the loop at some point relatively remote from the receiver. The long connecting cable introduces additional circuit capacity which effectively impairs the performance. When the loop

Application continued

is located within the radio cabinet (usual case) the presence of the metal chassis (eddy current loss) and the wood cabinet (moisture absorption) appreciably reduces the Q. Under these conditions it is not uncommon for the Q of the loop to be reduced 50 percent or more.

It is evident then that not only the design of the loop but its position with respect to the chassis and cabinet are of major importance.

Low Impedance Loop

A low-impedance loop (low inductive reactance) commonly consists of from one to six turns of large diameter wire usually No. 10 B & S or equivalent. Copperclad steel instead of solid copper may be employed with excellent results. Since the skin-effect depth is usually much less than the ordinary copper coating thickness, results are entirely satisfactory at most frequencies.

As shown in Fig. 2-6 the loop may be connected to the receiver by means of a cable. The receiver input circuit consists of a powdered iron core coupling or matching transformer with its secondary tuned by a conventional variable air tuning capacitor. The design of the coupling transformer determines to a large degree the performance and will be discussed further.

Design of Transformer

The primary inductance should be approximately equal to the inductance of the loop antenna and the primary Q should be as high as possible. The transformer can be made either with a separate primary and secondary, or as an auto-transformer having a primary tap for the loop. The winding (for the broadcast band) should consist of litz wire having from 7 strands of No. 40 to 45 strands of No. 44; the latter is about the maximum size commercially procurable.

The coupling between primary and secondary should be made as high as possible, or until the secondary Q starts to decrease quite rapidly with increased coupling. The coefficient of coupling of a typical design averages approximately 85 percent. This is attained by the use of high-quality powdered iron with a minimum of spacing between the core and the winding. The winding is usually concentrated by employing a universal wound coil. Some designs make use of powdered iron cup shields to increase the coupling. (At the expense of added capacity and a slight loss of Q). An enclosed, iron shielded coil however can be located in close proximity to metal parts without loss in Q, whereas the unshielded coil should be spaced at least one and one half times its diameter from the metal chassis or other parts. This is frequently a factor in the design of small receivers.

Besides the coefficient of coupling between primary and secondary, the Q of both windings, and the ratio of primary to secondary reactance are important. This would appear to indicate that the greatest voltage gain would be obtained by using a single turn loop with a very high turns ratio in the coupling transformer. This is not strictly true, because a one turn loop would have such a low reactance that the

Application continued

characteristics of the connecting cable could no longer be neglected, so a compromise must be effected between the reactance of the loop and the characteristics of the connecting transmission line.

Briefly the low-impedance loop has the following advantages over the high impedance type. It is less susceptible to humidity effects, is not seriously affected as to Q when placed near a metal chassis (except for directivity pattern), the mechanical construction is more sturdy and the loop does not necessarily have to be installed near the receiver.

Semi-High Impedance Loop

The semi-high impedance loop as its name implies is a compromise between the high and low impedance variety. The inductance may vary from 30 to 70 percent of the total required in the tuned circuit. In applications where space is at a premium most of the inductance would be concentrated in the loading or auxiliary coil. On the other hand where sufficient "free space" is available the larger portion of the inductance would be in the loop. It is obvious that the Q of the loading coil should be high in order to maintain a high overall Q. In general the advantages and disadvantages of each type are in proportion to the relative impedances.

Shielding

The use of an electro-static shield around a loop results in an improved directivity characteristic and an improvement in noise rejection. Directivity is improved because the signal (electric component) produces currents within the loop which are opposite in polarity to those in the shield and these effectively cancel each other with the result that no voltage appears across the loop terminals. The directivity is not adversely affected when one side of the loop is grounded.

The improvement in noise rejection is due to the fact that most noise sources are predominantly electro-static. A reduction of signal pickup of approximately 3 db can be expected.

The loop Q for a small receiver is of the order of 50 to 85 while the Q for a large console may be as high as 120.

R. F. Stage

The main advantages of r.f amplification are decreased noise, improved image response and greater usable sensitivity. Converters in general are inherently noisy unless the signal strength is quite high, therefore the problem resolves itself into amplifying the signal before it reaches the converter so that the inherent noise is effectively swamped. Adjacent channel selectivity can be obtained in the i-f amplifier but the fact that the i-f amplifier can not distinguish between the sum or the difference frequency produced by the oscillator creates a source of interference which can only be eliminated by selectivity ahead of the converter or mixer stage. Of course the i-f can be chosen to separate the undesired response such that a high degree of selec-

Application continued

tivity is realized in the converter input circuit but this results in lower i-f gain due to the high frequency required.

Medium and Low Frequency Operation

The conventional tuned r-f transformer consists of two windings; a primary and a tuned secondary. The primary may be either high or low impedance, inductively or capacitively coupled depending on the particular requirements. See Fig. 8.

In the case of the low impedance primary the winding is made to resonate well above the desired frequency band. This results in decreased selectivity and increased gain with an increase in frequency. The coefficient of coupling is generally quite small and the leakage reactance correspondingly large so that the actual turns ratio between primary and secondary is quite different from the effective ratio of transformation.

For a more uniform response the primary to secondary coupling is decreased and the primary inductance increased until it resonates, with the tube and circuit capacities, just below the low frequency end of the tuning range. Capacitive coupling is sometimes added to increase gain at the extreme high frequency end of the band.

With a high impedance primary resonating slightly below the desired frequency band the plate load in the preceding tube is capacitive. This theoretically prevents oscillation and is therefore extensively employed. The primary turns can be varied over quite a range by the addition of a fixed capacitor to resonate the circuit. Typical performance characteristics for various combinations are shown in Fig. 8. It should be noted that this type of transformer results in more uniform performance over a given frequency band than obtainable with the low impedance primary design.

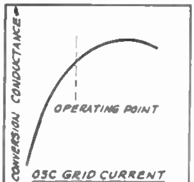
In a circuit application where the input source to a tuned circuit is less than the circuit impedance an improvement in both gain and selectivity will result if the input is tapped down on the tuned circuit. An optimum tapping point exists for gain; however, the lower the tap, the greater the selectivity. Maximum gain occurs where the Q is reduced to one half normal.

A simple method of checking effective circuit Q consists of measuring the gain at resonance (f_0) and the frequency each side of resonance (f_1, f_2) where the gain is decreased to 0.707 of maximum. The effective circuit Q can then be ascertained from

$$Q = \frac{f_0}{f_1 - f_2}$$

When the input source is higher than the circuit impedance tapping down on the tuned circuit decreases the gain; however, in some cases, particularly where the plate circuit gain is high, stability is improved. Tapping may be effected either by employing a separate primary or actually tapping the tuned circuit inductance.

Frequency Converter Considerations



EFFECT OF OSCILLATOR STRENGTH ON CONVERTER GAIN

$$\text{CONVERTER GAIN} = \frac{S_c r_p Z_L}{r_p + Z_L}$$

CONVERSION CONDUCTANCE

	TRIODE	PENTODE
FUDAMENTAL	$0.28\,g_o$	$0.23\,g_o$
2ND HARMONIC	$0.13\,g_o$	$0.11\,g_o$
3RD HARMONIC	$0.09\,g_o$	$0.07\,g_o$

S_c = CONVERSION CONDUCTANCE
g_o = MAX ZERO BIAS TRANSCONDUCTANCE
r_p = PLATE RESISTANCE
Z_L = LOAD IMPEDANCE

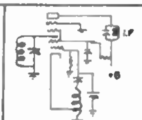
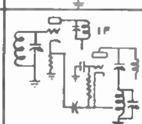
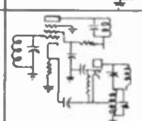
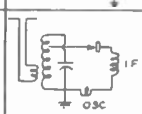
TYPE	SCHEMATIC	FREQUENCY	REMARKS
PENTAGRID		100 KC - 15 MC	OSCILLATOR FREQUENCY STABILITY WITH VARIATION IN SIGNAL STRENGTH FAIR CAN BE IMPROVED BY NEUTRALING CAPACITY BETWEEN G_1 AND G_3. OSCILLATING CONDUCTANCE LOW WHICH LIMITS FREQUENCY RANGE. VERY POOR SIGNAL TO NOISE RATIO. BROADCAST-SW APPLICATIONS ONLY
TRIODE		100 KC 300 MC	CATHODE INJECTION RECOMMENDED. LOW NOISE. FEED BACK THROUGH GRID-PLATE CAPACITY REQUIRES LOW CAPACITIVE REACTANCE IN PLATE CIRCUIT TO MINIMIZE INPUT LOADING HIGH CONVERSION CONDUCTANCE. RECOMMENDED FOR HIGH QUALITY APPLICATIONS
PENTODE		100 KC 50 MC	SIGNAL TO NOISE RATIO FAIR CATHODE OR SIGNAL GRID INJECTION RECOMMENDED SCREEN OR SUPPRESSOR INJECTION REQUIRE HIGH OSCILLATOR VOLTAGE AND ARE NOT RECOMMENDED INPUT LOADING NEGLIGIBLE.
CRYSTAL OR DIODE		300-3000 MC	LOW CONVERSION GAIN LOW IMPEDANCE REQUIRES TAP ON TUNED CIRCUIT TO REDUCE LOADING. SIGNAL TO NOISE RATIO POOR HIGH RESONANT FREQUENCY RECOMMENDED FOR MICROWAVE APPLCTNS

Fig. 2-9

In some applications it is desirable to employ an r-f choke (primary) that is not inductively coupled to the tuned secondary circuit. Coupling is obtained by a small fixed capacitor, the value of which is not too critical but should be as low as possible consistent with desired performance. The inductance of the r-f choke should be at least ten times that of the tuned secondary inductance and its natural period must be outside the desired tuning range. Usually the natural period is below the desired tuning range, and the result is a desirable capacitive reactance in the plate circuit.

High Frequency Operation

The design of an r-f stage for high frequency operation is similar in many respects to that employed in the antenna stage. Because of the small circuit parameters, feedback, minimum circuit capacity and dielectric losses are still a major problem. In the ideal case, where the only feedback is that due to grid-plate capacitance, the theoretical gain of a single stage is expressed by

Application continued

$$\text{Gain}_{max} = \sqrt{\frac{g_m}{\pi C f}}$$

Unfortunately this gain is not practically attainable because the effective grid-plate capacity is increased over that of the tube by the socket, associated wiring and other components. It is also assumed that all other sources of feedback are negligible which is rarely the case in a practical design. For this reason the actual stable gain is more nearly one half the calculated value.

Tube loading and minimum circuit capacity in the r-f as in the antenna stage are major factors in limiting the gain. In general the same limitations in design exist in the r-f stage as in an antenna stage.

Pre-Selection

Additional selectivity and image rejection can be obtained by the use of a pre-selector where sensitivity is not a major consideration. The Q of a pre-selector stage depends mainly on the form factor, winding form and wire size of the inductor. It is assumed of course that the tuning capacitor and other dielectric materials in the circuit are of low-loss construction. No great difficulty should be experienced in obtaining a Q of 150 to 200 since the circuit is not loaded by a tube. Where the pre-selector is also the input circuit and therefore loaded by the antenna, the Q will be reduced one half; this assumes maximum gain is desired and the antenna coupling is optimum. Where high selectivity is desired the antenna may be loosely coupled. This will result in lower gain (approximately 20%).

The greatest difficulty with a pre-selector is to obtain good circuit tracking, although with stable components and a rigid mechanical design the problem resolves itself into one of maintaining accurate control of tolerances. Coupling between the antenna and pre-selector or pre-selector and first grid circuit should of course be primarily due to mutual inductance. In some designs this is difficult to realize because of ground currents in the chassis and tuning capacitor rotor unless the latter is of the insulated type.

Untuned R. F. Stage

The usual untuned r-f transformer is very tightly coupled which results in two peaks appearing at the extremities of the required band. Such designs are usually limited to a frequency ratio range of approximately three to one. Circuit capacities should be kept to a minimum to realize maximum gain at high frequencies.

Difficulties are often encountered when using an untuned r-f stage due to increased spurious responses. These can be attenuated by means of trap circuits. Resistance and impedance coupling are sometimes used but are not recommended since the stage gain is low and the signal-to-noise ratio is poor.

Application continued

Frequency Conversion

The choice of a frequency converter depends upon several factors such as frequency range, stability requirements, available signal strength and cost.

Basically, frequency conversion is a simple problem; however, if optimum performance is to be obtained, certain precautions must be taken. A resume of desirable characteristics would include:

1. High conversion gain, with reasonable uniformity on all bands.
2. High oscillator strength of fairly uniform amplitude and stability.
3. Freedom of interaction between oscillator and signal frequency circuits.
4. Low microphonism.
5. Low tube noise.

Each of these items require considerable attention to achieve optimum performance. Furthermore some items, such as maximum gain and minimum noise, are not mutually consistent and therefore it is up to the designer to evaluate the relative importance of each and compromise accordingly.

Conversion Transconductance

The conversion conductance of a tube instead of the more familiar mutual or control-grid to plate conductance is the important parameter to be considered in the design of the first detector stage. This is the ratio of an increment of current in the i-f transformer primary to the increment of signal voltage required to produce it. Knowing the conversion conductance the gain can be calculated.

The sum or difference (signal plus oscillator or signal minus oscillator) frequency may be used since the amplitudes of each are equal in the converter plate circuit. The oscillator may be above or below the signal frequency; usually it is above for low and medium frequency tuning ranges (higher possible i-f gain) and below at ultra high frequencies (greater stability).

For wide frequency coverage a separate oscillator tube is recommended because of the difficulty in obtaining the desired characteristic in a combination tube. This also permits the choice of a wide variety of injection circuits since mixing can be accomplished in series with or inductively or capacitively coupled to the signal or other grids. In the case of converter tubes with built-in oscillator sections, the oscillator voltage is often present on more than one element and, unless the phase relationship of the two injection voltages is correct, partial cancellation or demodulation results. In general, it can be said that mixer tubes with separate oscillators are usable at higher frequencies.

Of the two basic circuit arrangements; (1) signal and oscillator injection on the same element, (2) signal and oscillator injection on separate elements, the second is probably the most popular although the first is not without merit. In the case of oscillator and signal injection on the same element we find crystals, diodes, triodes and pentodes

Application continued

being used as mixers. Where the signal and oscillator are applied to different elements obviously only multi-element tubes are used.

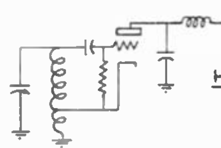
Pentagrid Converters and Mixers

The ordinary pentagrid converter has several disadvantages which are inherent in its design. Tubes of this construction have relatively low oscillator transconductance and therefore the oscillator performance is rather poor at high frequencies. Variation in the space charge which is inherent and essential to the operation of the tube results in a voltage (space charge coupling) at the signal grid which is out of phase with the oscillator voltage when the oscillator is higher than the signal frequency and in phase when the oscillator is below the signal frequency. The former results in decreased gain at high frequencies while the latter, if increased bias is employed to nullify the effect at higher frequencies, results in decreased gain at the lower frequencies. Since the signal voltage controls the electrons taken from the virtual cathode it affects the capacity of the oscillator section and results in variations in oscillator frequency.

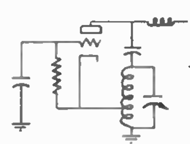
An improved pentagrid converter (See Fig. 2-9) minimizes the oscillator frequency shift by having collector plates on the side rods of the screen grid. These plates intercept some of the electrons returning from the virtual cathode to the main cathode with the result that signal voltages have less effect to the oscillator frequency. With this type tube, oscillator voltage may still appear on the signal grid, particularly if the percentage difference between signal and oscillator frequencies is small and the impedance of the signal circuit at the oscillator frequency is appreciable.

The voltage may be effectively neutralized by the addition of a small capacity between G_1 and G_3. If the neutralizing capacity used is below optimum in value the result will be a reduction in conversion transconductance. Should the capacity be too great, grid current will flow which will load the incut circuit, or if the neutralizing capacity is increased still further serious interaction between oscillator and signal circuits will result. Neutralizing should be adjusted at the highest frequency of operation

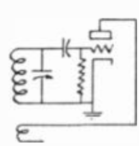
BASIC OSCILLATOR CIRCUITS



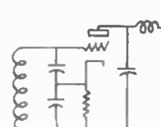
HARTLEY



TUNED PLATE



TUNED GRID



COLPITTS

Fig. 2-10

Application continued

and the amplitude of the oscillator voltage should be fairly uniform throughout the frequency band to be covered.

In this type of tube the cathode returns through the oscillator coil, which incidentally is the secret of its stability since the total cathode current is available for feedback. Variations in signal grid voltage have a negligible effect on the total cathode current and this accounts for the improved oscillator stability. Voltage variations on the screen grid shift the oscillator in an opposite direction so the combined results nearly cancel one another.

Operation is usually satisfactory except for poor signal-to-noise ratio at frequencies as high as 30 to 50 megacycles.

Another type of converter, the triode-hexode, is essentially two tubes in one. The oscillator conductance can be made relatively high and the presence of the shield at the cathode effectively eliminates interaction between oscillator and signal circuits, making the tube more desirable for high frequency operation.

The pentagrid mixer requires a separate oscillator source and consequently there is little interaction between signal and oscillator frequency circuits. In general pentagrid mixers have a relatively poor signal-to-noise ratio as compared to triodes or pentodes with a separate oscillator source.

Pentode Mixers

Some pentodes make excellent mixers, and although they are slightly inferior to triodes from a noise standpoint they are far superior in this respect to tubes of the pentagrid class.

Oscillator Stability Characteristics

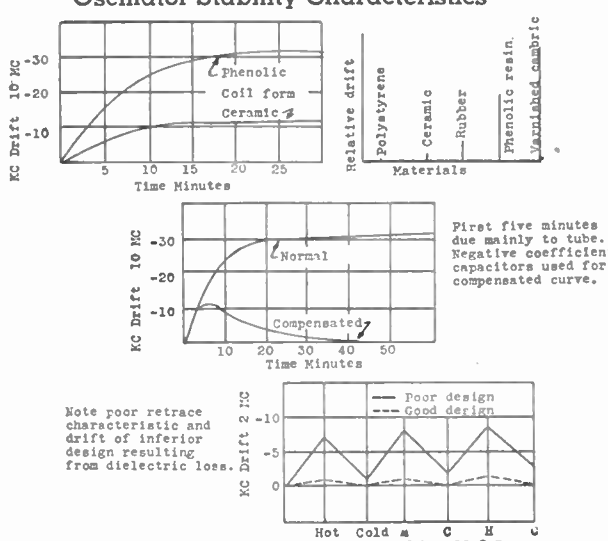


Fig. 2-11

Application continued

Cathode injection is usually employed since it is comparatively easy to completely modulate the plate current by this method. Both the screen and the suppressor require quite high oscillator voltage and are rarely employed for injection. Inductive, capacitive or combination coupling to the signal circuit can be employed but are quite difficult to control in production, especially for high frequency operation. A small amount of signal circuit coupling is sometimes employed with cathode injection to compensate for undesired coupling due to grid-cathode tube capacity. This coupling, assuming the oscillator frequency is above the signal, is out of phase with the oscillator voltage. Other factors (images, frequency range) besides coupling effects must be considered in deciding whether the oscillator should be above or below the signal frequency.

Because of the low grid-plate capacity in the pentode, loading of the signal circuit due to feedback through this capacity is ordinarily not serious.

In frequency converter service the advantages of pentodes may be summarized as follows: high conversion transconductance, good signal-to-noise ratio, high plate resistance and low grid-plate capacity. Disadvantages are interaction between signal and oscillator circuits when the signal and oscillator are injected on the same grid, transit time and cathode lead inductance at high frequencies. The effect of the latter may be minimized by the use of tubes designed especially for high frequency operation.

Triode Mixers

High transconductance triodes make excellent mixers if certain precautions are taken to nullify the effect of relatively high grid-plate capacitance.

Oscillator voltage injection in the cathode circuit is probably the most popular since complete modulation of the plate current is easily attained. Signal-oscillator circuit coupling is due primarily to grid-cathode tube capacitance although variations of space charge at oscillator frequency are evident. In general oscillator voltage in the signal grid circuit (with proper precautions) will not be a serious factor unless the resonant frequencies of the two circuits are nearly identical.

When using triodes input circuit loading becomes a factor at high frequencies due to grid-plate capacitance feedback. This is particularly important with an appreciable capacitive reactance (at signal frequency) in the plate circuit. Since high frequency operation usually dictates the use of a high i-f it is evident that a compromise between gain in the i-f transformer and input loading of the signal circuit must be made. Input loading effects can also be reduced by using a relatively high oscillator injection voltage if grid leak bias is employed. This will bias the tube near cut-off so the cathode current only flows during a small part of the cycle, consequently the loading is minimized during part of each oscillator cycle. Oscillator voltage in the plate circuit of the mixer can effectively be nullified by the use of a resistance loaded

Application continued

tuned circuit (inductor and tube capacity) resonant at the approximate center of the oscillator frequency range. The use of an inductor also reflects a negative resistance into the signal circuit which decreases the circuit losses.

Transit time and lead inductance effects may be minimized by special high frequency tube design.

Triodes as mixers are characterized by high conversion conductance, excellent signal-to-noise ratio and low cost.

Very High Frequency Operation

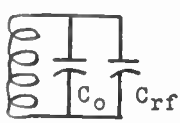
As the operating frequency of a receiver is increased it becomes more and more difficult to obtain satisfactory frequency conversion. Ordinary tubes must be replaced by special tubes designed specifically for these frequencies. Such factors as transit time, lead inductance and input resistance become of importance and the necessity of eliminating their effects is imperative. This has been at least partially accomplished by the use of special diodes and crystal converters.

Diodes

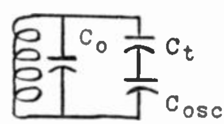
Diodes give low conversion gain (less than unity) when used as frequency converters, the signal-to-noise ratio is rather poor, they have

Oscillator Tracking Considerations

R. F.



OSCILLATOR



$$C_{rf} = \left[C_o\left[\left(\frac{f_2}{f_1}\right)^2 - 1\right]\right]$$

$$C_o = \frac{C_{rf}}{\left(\frac{f_2}{f_1}\right)^2 - 1}$$

where:

- f_1 = low frequency range (ant.)
- f_2 = high frequency range (ant.)
- C_o = fixed circuit capacity
- C_1 = maximum tuning capacity
- f_o = I-f
- $f_3 = f_1 + f_o$ (osc)
- $f_4 = f_2 + f_o$ (osc)
- f_5 = mid frequency (ant)
- f_6 = mid frequency (osc)

$$C_t = K.C_{osc}{}^{*}$$

$$K = \frac{Z(X-Y)}{Y-(XZ)}$$

where

$$X = \left[\left(\frac{f_4}{f_3}\right)^2 - 1\right]$$

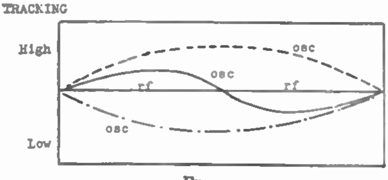
$$Y = \left[\left(\frac{f_4}{f_6}\right)^2 - 1\right]$$

$$Z = \frac{\left(\frac{f_2}{f_1} - 1\right)}{\left[\left(\frac{f_2}{f_1}\right)^2 - 1\right]}$$

For graphical solution see Fig. 2-13.

*Assume C_{rf} and C_{osc} of equal capacity range.

TRACKING



——— Normal three point tracking

— — — Requires +osc L; $-C_o$; $-C_t$

— . — . — Requires —osc L; $+C_o$; $+C_t$

Fig. 2-12

Application continued

high oscillator harmonic response and they produce an appreciable damping effect on the signal circuit. Ordinarily such characteristics would discourage most designers, but if each is investigated it will be found that the diode is not such a poor device after all.

Conversion gains of less than unity are not too unreasonable if one considers how much gain can be obtained with tubes in the microwave region. In other words, some signal is better than no signal at all. The fact that the oscillator harmonic response is high is very fortunate indeed since this permits harmonic operation of the local oscillator with an improvement in stability.

The effects of damping on the signal input circuit, which incidentally is due to diode current, can be decreased by tapping the diode down on the input coil. This does not necessarily result in less gain (unless carried too far) since, when the loading across the tuned circuit is reduced, the Q increases and nearly offsets the loss due to the step-down transformer action.

Unfortunately a diode converter will work in both directions; that is, the signal will be converted by the oscillator to an intermediate frequency and likewise the i-f is reconverted by the same oscillator back to a signal frequency. The degree to which this occurs is dependent upon the circuit impedance so the effect can be minimized by proper design, although it is always a factor in obtaining maximum converter efficiency.

Diodes should be operated with fairly high bias voltages (properly bypassed) and correspondingly high oscillator voltage injection. Under these conditions the conversion gain is relatively independent of small variations in oscillator amplitude and the output is essentially proportional to the input voltage.

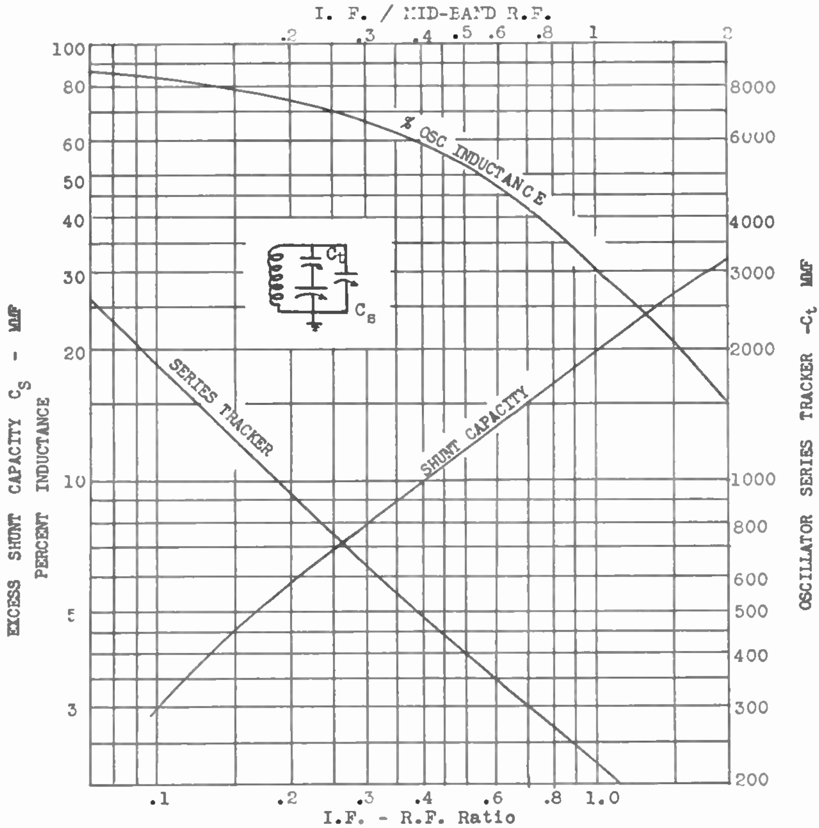
The diode elements must be small physically and the spacing between anode and cathode should be close to minimize transit time effects. Small elements obviously result in increased conduction resistance which will impair the conversion efficiency, but a compromise is only a few db as compared to a loss of approximately 10 to 12 db when a crystal is employed.

Crystal Mixers

The modern crystal resembles a small cartridge, completely enclosed, with the adjustment more or less permanently fixed. Not only does the small size increase the resonant frequency so that operation in the microwave region of a few centimeters is possible, but it makes the crystal particularly suitable for use in wave guides, resonant cavities and transmission lines.

Crystals are subject to erratic operation when their resonant frequency is approached by either the fundamental signal or its harmonics. It is important that the unit be designed in such a manner that the series resonance is well above the operating frequency. Resonance is caused by the series inductance of the contact lead and the capacity across the crystal element.

Oscillator Circuit-Parameter Chart



Locate ratio of $\frac{\text{intermediate frequency}}{\text{mid-band r-f frequency}}$ on abscissa and read required values at intersections of curves to obtain oscillator series and shunt capacities and oscillator inductance in percent of r-f inductance.

Fig. 2-13

Another limitation in the use of crystals is their efficiency. This decreases gradually with an increase in frequency, due mainly to the capacity across the actual crystal element. In spite of the disadvantages, and the fact that crystals are not as uniform in characteristics as diodes, they make better detectors or mixers for centimeter applications than any type of tube now available.

Noise in Converters

Noise produced in the converter tube as the result of random fluctuation in the space current and its division between plate and the

Application continued

other positive electrodes is quite similar to that encountered in amplifier service with one exception: the space current, and therefore the noise, varies over the oscillator cycle. In the pentagrid type converter a further complication exists because of the virtual cathode.

In the order of desirability from a noise standpoint the triode is the most desirable, the pentode is next, and the pentagrid tube is the least desirable.

Oscillators

The design of the oscillator circuit in the frequency converter stage is of major importance since its characteristics determine to a large extent the performance of the receiver. For satisfactory operation the following requirements must be fulfilled.

1. Substantially uniform output over the frequency range without dead spots, parasitic oscillation flutter or squegging.
2. Low harmonic content.
3. Reasonable stability with variations of supply voltage, temperature humidity and vibration.

Uniformity of Output

The need for uniform output over the frequency range is two fold. If the amplitude of the oscillator exceeds a given maximum, harmonic interference whistles are likely to be encountered; on the other hand if the oscillator amplitude falls below a given minimum the conversion gain will be reduced.

There is usually little trouble in obtaining sufficient oscillator output although the fact that the amplitude of some oscillators have a tendency to increase with frequency requires consideration. A simple solution to the problem is to insert a fixed resistance in the feedback circuit which, together with the circuit capacity, effectively limits the amplitude. The value of the resistor depends on the design and the frequency. In the plate tuned oscillator a resistance-capacity shunt feed is also effective since it damps the tuned circuit. This solution while inexpensive is likely to increase the harmonic content and should be used with caution. A resistance-capacity shunt effectively removes the high voltage from the tuning capacitor and is desirable from the Underwriter's standpoint.

Parasitics, Flutter and Squegging

Parasitic oscillations usually occur at very high frequencies and are often due to lead inductance and stray capacitances. Leads should be as short as practicable; however, if the grid and plate circuit leads are nearly identical a tuned-grid tuned-plate oscillator will result with the grid-plate capacity of the tube providing the feedback path to sustain oscillation. By making the plate leads longer than the grid leads the conditions for oscillation are not satisfied and the parasitic will be eliminated. The simplest expedient is to insert a small resistor (10 to 20 ohms) close to the grid or plate connection of the tube. Since the

Application continued

resistor is in the parasitic tuned circuit but not in the regular tuned circuit it has a negligible effect on normal operation.

Another cause for parasitics is where the feedback coil is nearly self-resonant at the operating frequency. Obviously the remedy for such a condition is to decrease the inductance of the coil and if necessary increase the coupling to the L/C circuit to sustain oscillation. Often when the feedback coil approaches resonance the oscillator frequency will tend to jump as the tuning is varied over the band.

Squegging is an interruption of the normal oscillation due to excessive amplitude and is caused by large positive pulses of grid voltage producing current to charge the grid capacitor to a negative voltage beyond plate current cutoff. As the capacitor discharges through the grid leak the plate current again begins to flow and oscillation is resumed, whereupon the cycle is repeated with the interruption frequency depending upon the time constant of the grid leak and capacitor.

Audio flutter is often encountered due to frequency modulation of the oscillator. This can be the result of voltage variations caused by a combination of strong audio signals and a high impedance "B" supply. Additional filtering may be employed or the low frequency audio response can be reduced to alleviate the situation.

Some of the many possible oscillator circuits are shown in Fig. 2-10, each of which by careful design fulfill most of the requirements, although certain types are to be preferred. Only the three most commonly used circuits will be discussed: (1) tuned-grid, (2) tuned-plate and (3) Colpitts.

Tuned-grid

The tuned-grid circuit is quite popular since it is comparatively easy to adjust and functions quite well over a wide range of frequencies. As can be seen from the schematic the plate circuit is highly reactive, which prevents operation on the straight-line portion of the E -I curve. Since the load line is essentially an ellipse, severe and often objectionable harmonics are generated. This is generally undesirable in frequency converter service.

When the grid circuit takes power (normal operation), the tube acts as a diode and the grid leak, together with the reflected resistance, effectively loads the circuit. Such an extremely low load impedance gives poor efficiency and output. In other words, large currents are required to realize an appreciable output voltage. With the current limited in the tube this means that the low plate load impedance will result in a small plate voltage swing and in turn low grid excitation or oscillator voltage output. The operation is equivalent to coupling a high impedance generator into a variable low-impedance inductive load.

Tuned-plate

The tuned-plate oscillator is characterized by good efficiency, low harmonic content and high load impedance. The high impedance plate load permits greater voltage change (compared to the tuned-grid cir-

Application continued

cuit) and since the phase relationship is correct this voltage is effectively used for feedback or greater excitation.

With the tuned circuit in the plate, the load is essentially resistive and has a high impedance at resonance which permits use of a low impedance grid circuit. The result is a negligible reflected reactance into the plate load which does not vary appreciably with frequency. Because of the small variations in reflected load (equal to the coupling reactance squared divided by the secondary reactance), the frequency stability of the plate-tuned oscillator is much greater than the previously discussed tuned-grid circuit.

Colpitts

The Colpitts circuit admirably lends itself to push-button tuning because of the fact that no taps are required on the tuning inductance. It also permits the grounding of one side of the coil, which further simplifies the push-button switch. Excitation is adjusted by the choice of a suitable value of C_2 and tuning is accomplished by varying the inductance of L by means of an iron core.

Ease of adjustment, stability and reliable operation are features of this circuit. Obviously it is not suitable for variable capacitor tuned circuits.

Oscillator Inductor

Design Notes

With the type of oscillator circuit decided upon, the next step should be the design of the oscillator inductor or transformer. In general the following are desired:

1. Low resistance windings.
2. High mutual inductance between grid and plate windings.
3. Low capacity, both between windings or individual coils.
4. Low self-inductance feedback winding.

Since these characteristics are to some extent contradictory, compromises are necessary. For instance,

I. F. AMPLIFIER CHARACTERISTICS

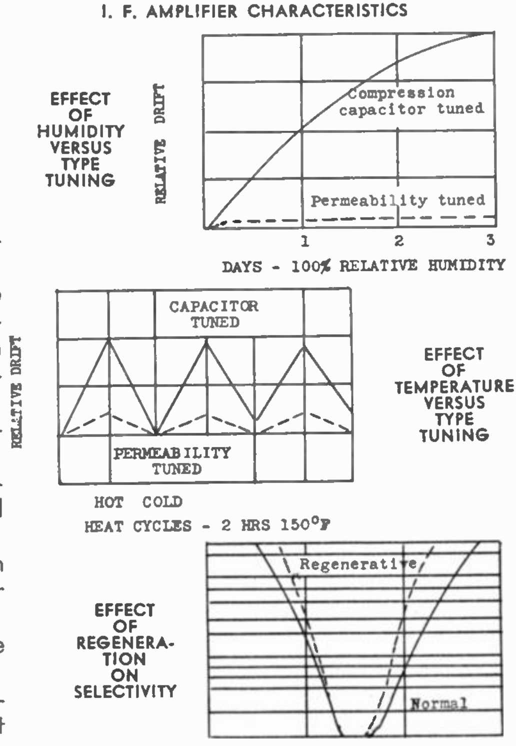


Fig. 2-14

Application continued

it is general practice to specify a rather small L/D ratio to insure a good coupling factor, although in doing this the distributed capacity is increased, which may result in poor stability. This of course depends upon the quality of the dielectric involved. Obviously a compromise must be made which will result in a satisfactory design for the requirements at hand.

Frequency Stability

Satisfactory stability may be achieved by straightforward design without resorting to unusual circuits. Frequency stability is determined by several factors and not temperature alone. Under these circumstances the problem must be approached systematically and the causes of the drift segregated and studied separately. Only when each contributing factor has been isolated and corrected as far as possible can the drift be minimized to a point where compensating capacitors may be employed to full advantage. The principal factors contributing to oscillator frequency drift can be divided into four parts. These are (1) temperature, (2) humidity, (3) operating parameters and (4) shock and vibration.

Temperature

The effect of temperature variation is probably of greatest importance since it is present under nearly all operating conditions. An example of the frequency drift of an uncompensated oscillator showing the effect of aging after repeated accelerated heat cycling is given in Fig. 2-11. It should be noted that the oscillator frequency decreases with an increase in temperature as the result of capacitive or inductive changes. Noteworthy also is the fact that the zero or starting point for each successive cycle tends to increase in frequency and the drift per heat cycle tends to decrease, due probably to volatilization of some of the insulating materials. Subjecting the oscillator to repeated heat cycles accelerates this effect and is useful for purposes of study. Under normal operating conditions the shift in the zero setting would be substantially less than indicated, although over a long period of time the end result would undoubtedly be the same.

Frequency instability due to variations in ambient temperature can be compensated (over a small frequency range) by the use of suitable megative coefficient capacitors, however, the results are far from satisfactory if no other precautions are taken to stabilize the circuit.

First, consideration should be given to component layout. Leads should be short and direct. Ventilation should be provided to prevent the heat radiated by the tubes from raising the temperature of nearby components excessively.

The temperature of the tube usually requires at least five minutes to stabilize, while the other components may require an hour or more depending upon their mass. This is indicated in Fig. 2-11 by the steepness of the curve during the first few minutes of operation. It can be

Application continued

verified by operating an oscillator until the frequency has stabilized and then quickly replacing the hot tube with a cold tube and noting the rapid change of frequency as soon as operation begins. Of course the cold tube-base will have a slight cooling effect on the tube socket, but if the mass of the socket is large the results will be quite accurate.

Having determined the magnitude of the tube drift, a separate compensator with provisions for quick heating may be employed to offset the effect. With the tube drift accounted for and corrected, the effect of other components can be studied.

Inductors

The component usually responsible for the greatest amount of drift is the inductor or oscillator transformer. Variations in the distributed capacitance, coil form and wire dimensions and the figure of merit or Q should be investigated. Fig. 11 shows the relative drift of inductors wound on form of different materials. The absolute drift depends upon the proportion of the inductor drift to the remainder of the circuit, however, the curves are comparable and indicate the relative characteristics of the different materials. For example, an inductor on a phenolic form has more drift than a similar coil on a ceramic form because of the greater change in distributed capacitance and the greater coefficient of expansion of the phenolic materials over ceramics.

Because of the higher C/Q ratio of the phenolic material, the distributed capacity for a given design is greater. In general it can be stated that the frequency instability varies in direct proportion to the C/Q ratio of the dielectric.

Instability due to dimensional changes in the coil form is much more difficult to analyze since the thermal coefficients of expansion of the diameter and length are not always equal. The expansion of the wire must also be taken into consideration. Theoretically it is possible to design a coil wherein the expansions of wire and coil form balance both radially and axially to give a zero change of inductance with changes in temperature.

Recommended Tubes for R. F.-I. F. Amplifier Applications

TYPE	TUBE	Gm	Cgp	GRID CUT-OFF
Miniature	6AG5	5000	0.025 mmf	Sharp
	6AK5	5100	0.020 "	Sharp
	6AU6	5200	0.0035 "	Sharp
	6BA6	4400	0.0035 "	Remote
Lock-in	7A7	2000	0.005 "	Remote
	7AG7	4200	0.005 "	Sharp
	7H7	4200	0.007 "	Semi-remote
	7V7	5800	0.005 "	Sharp
	7W7	5800	0.0025 "	Sharp
Octal	6AB7	5000	0.015 "	Remote
	6AC7	9000	0.015 "	Sharp
	6SJ7	1650	0.005 "	Sharp
	6SG7	4000	0.004 "	Semi-remote
	6SK7	4900	0.004 "	Sharp
	6SH7	2000	0.005 "	Remote

Fig. 2-15

Application continued

The most practical design approach is to choose a low loss factor material having relatively stable physical characteristics and design the windings to minimize the distributed capacitance. The anticipated maximum operating temperature and the coefficient of expansion, together with the C/Q ratio of the material should influence this choice. So much for the winding form—next the wire must be considered.

Consulting a table of the properties of metals it is noted that copper has a coefficient of expansion of 16 parts per million per degree centigrade and a comparatively low specific resistance. Investigating further, it is found that Nilvar (36% nickle-steel) has a temperature coefficient of less than one part per million although its specific resistivity compared to copper is quite high. The latter property is important because of the "skin effect" phenomena of high frequency currents. Taking advantage of this effect it is practical to deposit a plating having a low specific resistivity (such as copper or silver) on wire that is thermally stable. The plating thickness should be approximately 50% greater than the calculated skin depth for the lowest operating frequency. An inductor wound on a good ceramic form with this composite wire will contribute less than one part per million per degree centigrade change to the frequency drift of an oscillator.

Some rather unusual designs have been known to result in stable operation, as for instance the use of a bimetal element to change the position of a shorted turn or copper vane to vary the inductance and incidentally the Q of the coil. Another design employs a powdered iron core having a long brass rod which elongates with increases in temperature to compensate for the normal inductance change.

An oscillator transformer having a tickler winding may be improved by spacing the winding from the secondary with polystyrene or equivalent low loss tape.

It is strongly recommended that straightforward design rather than novel compensating arrangements be employed in the oscillator transformer and that particular attention be given to the choice of materials to obtain an inherently stable component.

Capacitors

The frequency instability contributed by tuning capacitors is ordinarily negligible provided a good mechanical and electrical design has been followed. Points worthy of mention are: heavy end supports to prevent any twisting action of the frame when the plates are rotated; wide plate spacing; adequate rotor and stator supports; ceramic insulation; expansion of dissimilar metals which might affect the capacitance; ball-type bearings and the location of insulation out of strong electro-static fields as far as possible.

Compensating capacitors may be used successfully to compensate for changes in circuit constants due to temperature variations. Their compensating abilities however are limited to a range of approximately 40 degrees centigrade if a linear characteristic is desired. A more detailed discussion of their characteristics will be found in the chapter on fixed capacitors.

Application continued

Insulation and Insulating Supports

Wiring panels, standoff insulators and wire insulation have a very definite effect on the frequency stability of a tuned circuit. In general it is a function of the capacitance due to the material employed. Any design that minimizes the circuit capacitance should be favored. All high potential (r-f) leads should be short and as direct as practicable. In cases where the lead must pass through a metal partition or chassis, the hole through which it passes should be of sufficient size to preclude the possibility of a short. Where space limitations do not permit large openings, ceramic feed-through bushings should be employed.

Phenolic insulation should be avoided since this material "ages" over long periods of time when subjected to high temperatures. The results of tests on sample insulating materials showing the relative drift for a given value of capacitance are given graphically in Fig. 2-11.

Humidity

The effects of humidity are invariably greater than those due to temperature variations if good insulation is not employed. Components should be non-porous and possess a surface that does not easily wet. Even the slightest film of moisture has good conductivity and obviously depreciates the value of the dielectric.

Unfortunately some precautions taken to overcome humidity effects can seriously impair the operation from a temperature standpoint. Wax impregnation is not always the answer to humidity problems. A thin coat of wax is of little value except to prevent formation of a film of moisture because all commonly used waxes absorb water to a certain extent under conditions of high humidity. Once the moisture has penetrated the wax layer it remains trapped for long periods of time even under conditions of low relative humidity. In order to protect a component properly by wax impregnation it is therefore necessary to apply a heavy coating (without pin holes) after the part has been thoroughly vacuum impregnated. Another objection to wax is that it adds more dielectric loss to the circuit. If the loss was constant with temperature and time it probably would not be too objectionable. However the dielectric constant of wax is not constant with temperature and volatilization of some of its constituents usually occurs over long periods of time.

Good humidity protection with a minimum of temperature instability can be obtained by treating the part with a polystyrene or equivalent impregnant. This involves much more care and time but has the advantage of adding less dielectric loss, absorbing practically no moisture and increasing the useful life of the unit.

Drift due to humidity can also be decreased by the use of desiccants such as silica gel. Special units are available on the market for this purpose.

Operating Parameters

The stability of an oscillator, neglecting changes in the constants

Application continued

of the frequency-determining circuit, is mainly dependent upon changes in the effective input and output impedances of the oscillator tube, the harmonic content of the generated wave and the oscillator load.

The tube reactance, which is in parallel with the tuned circuit, varies with applied voltage to change the frequency of oscillation. This can be nullified by introducing a suitable neutralizing reactance in series with the grid or plate but unfortunately to be effective it should vary with the oscillator frequency. Since this is impractical a more realistic method of overcoming the difficulty is to partially isolate the tube from the tuned circuit by tapping down on the coil. This expedient is also of advantage in reducing the effect of variations in the inter-electrode capacities.

Another method by which the frequency can be substantially independent of operating parameters is to make the tank circuit capacitance large compared to the inter-electrode capacitance so that any change due to the tube is effectively swamped out. Increasing the tank capacity to swamp out changes in tube capacity is usually only satisfactory at low or medium high frequencies because the additional capacity will tend to reduce the strength of oscillation; for this reason when the oscillator is required for high frequency work it is better to employ harmonic operation, that is, operate the oscillator at one half the required fundamental frequency. This will reduce the frequency instability by a factor of approximately two and will result in very little loss in conversion efficiency.

In general the values of the component parts comprising the oscillator circuit, such as the grid resistor and capacitor, tap of the oscillator coil, etc., affect the drift by being more or less influenced by the operating parameters and therefore the choice of each part should be made with care. The effect on frequency stability of different taps on the oscillator coil with variations in plate voltage is particularly important.

Harmonics generated by the oscillator cross-modulate with each other and with the fundamental to produce fundamental currents which are not in phase with the fundamental current due to normal operation. Obviously then, the resultant current affects the frequency of operation and therefore the harmonics should be suppressed. Here again a high effective tank Q with a low L/C ratio is desired, since the impedance to harmonics will then be minimized.

Since power-line voltages are not constant, and since a variation in the input voltage to the oscillator power supply will result in variations of the plate and heater potentials impressed on the tube, it is obvious that steps could be taken to overcome the difficulty. As a last resort, because of the cost involved, the power for the oscillator may be supplied either by a voltage-regulating transformer or a gaseous regulator tube to maintain constant plate voltage. A change in heater potential about the design center is not likely to cause serious trouble unless the grid-cathode capacitance is critical or the tube is emission limited.

Application continued

Shock and Vibration

Shock and vibration can seriously affect the frequency stability of an oscillator if the individual components or the complete unit are of poor mechanical design. This usually shows up as frequency modulation of the oscillator output signal. Components for the frequency-determining circuits should be mounted sturdily and as close together as practicable to provide short leads.

The effects of vibration can be minimized by the use of rubber cushions in the form of shock mounts. For greatest isolation the mounts should be placed in the plane of the center of gravity. Should this not be practical, a compromise in the choice of the mount may be made to obtain the desired stability.

The load rating of a shock mount determines the load which it will carry for a predetermined deflection. Knowing the weight of the unit the proper size mounts are usually chosen to give a normal deflection under load of approximately 1/16 inch.

Often the problem is not only to protect against simple vibration but also to protect against sudden shock. In such cases a compromise must be effected in choosing the proper mounting. Several types of mounts are available on the market so that no difficulty should be experienced in obtaining the proper type for a particular application.

Compensation

After all possible precautions have been taken to increase the frequency stability of an oscillator, then, and only then, should the designer resort to methods of compensation. Fortunately most components parts have a positive temperature coefficient and can be corrected by the use of a negative coefficient capacitor. It is good practice to provide two compensators, one to nullify the rapid drift due to tube warmup and the other to compensate for the slow change due to other components.

Tracking

The ganging together on a common rotor shaft of the capacitors tuning the signal and oscillator circuits presents a problem in circuit alignment. In a tuned r-f type receiver where each circuit covers the same frequency range "tracking" as it is commonly called is rather simple.

Consider the basic resonant circuit of Fig. 2-12; with a given frequency coverage specified the first step is to determine the value of the tuning capacitor and the minimum circuit capacity to fulfill the requirements. It should be noted that the minimum circuit capacitance is the total of all of the capacitive elements in the circuit such as the tuning capacitor minimum, padding capacitor, tube capacity (input plus grid to plate), tube socket, wiring, distributed capacity of antenna coil or loop etc. In the ordinary receiver these total to approximately 40 to 50 mmf.

Application continued

The effective tuning capacitor range will depend upon the minimum circuit capacity; the smaller the fixed circuit capacity the smaller the range of the tuning capacitor to cover a given frequency band. It is evident then that for any given frequency coverage some tuning capacitor range will satisfy the requirements for any given value of minimum circuit capacity. Practically, however, the maximum of the tuning capacitor is limited to approximately 520 mmf which in turn limits the maximum permissible minimum circuit capacity to 65 mmf for the broadcast band.

With values of maximum and minimum capacity established, the inductance required to resonant at the low frequency end of the desired range is calculated. The above discussion assumes ideal conditions which unfortunately do not always exist. In the case of an r-f transformer where a primary is employed it may be found necessary to increase the value of the secondary inductance in order to track it with a similar circuit. In some instances the reflected reactance of the primary may make it impossible to track perfectly with another circuit, in which case a compromise must be made between the desired primary and the tracking.

So much for the tuned r-f circuit. The superheterodyne, however, presents a more difficult problem because of the fact that the oscillator frequency must be maintained at a constant numerical margin (equal to the i-f) above or below the signal frequency. From a tracking standpoint it is desirable to place the oscillator above the signal frequency since the tuning range is smaller and therefore more readily attained. It is evident that the frequency range of the oscillator and signal circuits are not identical. Two methods of correcting this condition are (1) a special shaped plate tuning capacitor can be employed for the oscillator section, (2) a series "tracking" capacitor can be employed.

In a single band receiver method (1) is recommended because of its low cost, however, the plate shape must be designed for a specific frequency range and a given value of minimum circuit capacitance. As a matter of information the special oscillator section plate must be physically shaped to maintain a constant frequency difference at any point of rotation over a given frequency range.

Method (2) is to be preferred for multi-band receivers because of the simplicity of changing (switching) the tracking capacitor for each desired frequency range.

When identical values of tuning capacitance are used in both the oscillator and signal circuits the oscillator frequency coverage is too large. To reduce the tuning range a fixed capacitor is connected in series with the regular tuning capacitor. This provides three variables for adjusting the rate of change versus angular rotation of the tuning control and permits tracking at three points in the tuning range.

Briefly the series capacity controls the tracking at the low frequency end of the band, while the parallel capacity determines the tracking at the high frequency end of the band. Fig. 12 shows typical tracking curves for various conditions. For example, Curve A (series

Application continued

tracking capacitor too large) indicates that the oscillator frequency is increasing at too great a rate and the inductance has been made too small in order to track at the low end of the band. To correct a curve of this shape it is necessary to increase the oscillator inductance and decrease the capacitance of the series tracking capacitor. In order to compensate for the increased inductance the parallel circuit capacity must also be readjusted to obtain the correct high frequency range.

Conversely if the oscillator curve is low in the center with respect to the ideal antenna curve the oscillator tuned circuit inductance should be decreased and the series tracking or "lag" capacitor (as it is sometimes called) and the high frequency padding capacitor are increased to readjust the end points of tho band.

It is assumed that the antenna circuit has previously been adjusted to give the required frequency coverage before an attempt is made to track the circuits. The chart (Fig. 2-13) is quite useful in ascertaining preliminary values of oscillator inductance, series and parallel capacity for a given i-f and tuning range although final values must be determined experimentally.

I. F. Amplifier

Because the major portion of the sensitivity and selectivity of a receiver is dependent upon the i-f amplifier the choice of components for this application is important.

In general, permeability tuned transformers are to be preferred and the choice of the i-f should lean toward the lower frequencies so far as is consistent with other factors. The stability of the usual tuned circuit is nearly inversely proportional to the resonant frequency; as the frequency is increased the frequency stability decreases due principally to losses in the insulating materials. Obviously then all insulating materials should be of the highest quality; coil forms and impregnants are particularly important.

It is good practice to specify a plated mica or temperature compensating type capacitor to complete the resonant circuit. When capacitor tuned transformers are specified the major portion of the capacity should be either plated mica or of the compensating type with only sufficient variable capacity in pre-aged or heat treated trimmers to permit proper tuning.

Typical stability characteristics are shown in Fig. 2-14.

Choice of Tubes

The parameters to consider in the choice of a suitable tube are high transconductance (high gain) and low grid-plate capacitance (low feedback). Since these are the controlling factors it is common practice to consider their ratio as a figure of merit. It should be pointed out that the figure of merit does not take into consideration input and output capacities nor sources of feedback other than that due to grid-plate capacitance. Typical tubes recommended for i-f applications are shown in Fig. 2-15.

Application continued

Gain

The gain of an i-f amplifier using a pentode type tube can be expressed as:

$$\text{Gain} = Gm\omega L\frac{Q}{2}$$

This assumes the primary and secondary inductances and Q to be equal with critical coupling between circuits.

Since high inductance and high Q are synonymous it is evident that the capacity of the tuned circuit should be decreased to a minimum. This can only be carried to the point where variations in tube and circuit capacities with changes in temperature become appreciable.

The maximum gain with high transconductance tubes combined with high impedance tuned circuits is limited by the magnitude of the feedback present and is dependent on four factors:

1. Grid-plate tube capacitance.
2. Common coupling in the voltage supply circuits.
3. Extraneous coupling between stages.
4. Ground currents.

Of the above sources of regeneration the grid-plate tube capacitance is the least important.

Common coupling is the most prolific source of feedback; it may occur in the plate, screen, grid or a.v.c. supply circuits. The intelligent use of bypass capacitors and decoupling resistors however will largely eliminate the trouble. Care should be taken to use short leads on the capacitors in order to avoid undesirable series resonant effects. The indiscriminate use of filters however adds unnecessarily to the cost and should be avoided.

Extraneous coupling between stages can be minimized by shielding. Aluminum or zinc transformer shields of 0.20" thickness will be found satisfactory for most designs, although it is advisable to separate the transformers by a tube or an equivalent space to minimize interstage coupling.

With chassis space at a premium the usual 1⅜" i-f shield may be replaced by a smaller ¾ or 1" can with little or no loss in performance. The small transformers differ somewhat in construction from the larger units in that the windings are partially or completely enclosed in powdered iron shields. This confines the field of the winding so that the smaller shield has little effect on the Q.

In addition to shielding it is necessary that the physical layout of components be such as to minimize critical leads, either through "dressing" or separate shielding. The placing of bypass capacitors (with outside foil connected to ground) to effectively shield a "hot" lead is recommended. Shielded wire however is not recommended because of its cost, its low Q and high capacitance; also it is difficult to handle in production.

Ground currents in the chassis and wiring are often a source of feedback and in general are difficult to isolate. Unfortunately it is not

Application continued

practical from a production standpoint to return all bypass capacitors and grounds to a common point; numerous wiring panels and ground lugs must be employed which may often introduce a common impedance path. The actual location of a bypass capacitor is important and steps should be taken to bypass at the correct point and not make it necessary for the current to flow through devious paths in order to complete the circuit. Correct grounding is one of the finer points and should be treated as such. No fixed rules can be formulated to alleviate the situation since every design has its own particular fix. Even with precautions a factor of safety should be allowed in establishing the maximum usable gain because of possible production variations.

Selectivity

Selectivity is independent of frequency if the effective circuit Q of the stage is increased in proportion to the increase in frequency, assuming regeneration is negligible. Regeneration may result in an asymmetrical response curve since the circuits are regenerative on one side of resonance only. This is shown in Fig. 2-14. A small amount of regeneration is sometimes desirable because of the additional selectivity, although it must be properly controlled or instability is likely to result.

No great difficulties will be encountered in obtaining sufficient circuit Q up to frequencies of 20 or 30 megacycles; at higher frequencies insulation loss, tube input impedance and stray coupling become a factor to such an extent that the choice of a higher frequency i-f is not recommended.

Spurious Responses

Spurious responses or undesired signals result principally from poor image attenuation or direct i-f pick-up; interference due to signals separated by the i-f in frequency and harmonics of the signal or oscillator are sometimes encountered but usually the front-end selectivity is sufficient to minimize this type of interference.

Image Response

An image signal is received when the receiver is tuned to a frequency of twice the i-f either above or below (depends on whether the oscillator is above or below the signal frequency) the normal tuning point. Without an r-f stage the image response varies approximately as the Q of the coil and inversely as the ratio of the i-f to signal frequency.

Two methods may be employed to minimize such interference; (1) the operating frequency of the i-f amplifier may be chosen such that the receiver will not tune to the undesired frequency. (2) adequate selectivity may be provided ahead of the converter to attenuate the undesired response.

Application continued

Direct I. F. Pickup

Interfering signals (in the i-f pass-band) are particularly troublesome in low cost broadcast receivers where no r-f stage is employed. It occurs when the selectivity is not sufficient to attenuate the interfering signal. Unfortunately, if the interfering signal strength is high, pickup will not be confined to the antenna circuit but will be present in the i-f amplifier, in which case front-end selectivity will be ineffective. The elimination of direct i-f pickup requires the use of adequate shielding as well as good selectivity.

Choice of Operating Frequency

Summarizing—the choice of a suitable operating frequency depends on the required degree of gain, selectivity, signal frequency range, image response and stability.

Standard practice is to specify 262.5 or 455 kilocycles for low and medium frequency applications, with 455 kc generally preferred. High frequency applications such as the 100 megacycle FM band require a higher operating frequency, such as 10.7 megacycles. Higher frequencies can of course be employed although the difficulties involved in obtaining high impedance circuits with a high Q at a reasonable cost are not usually justified.

Wide Band I. F. Amplifiers

Two methods are commonly used for wide-band i-f amplifier applications; (1) stagger-tuned single circuits and (2) overcoupled double tuned transformers. The first type is widely used in television receivers where the pass-band may be several megacycles wide. Such amplifiers are rather difficult to align; however their simplicity and low cost are attractive.

The second type is generally employed in wide-band FM applications. A flat top characteristic is obtained by the use of damping resistors, a single peak intermediate transformer or a combination of both. An increase in gain can be realized if the alternate (single peak critical coupled) transformer is designed to "fill-in" that portion of the curve between the two peaks of the over-coupled units. So long as the overall characteristic is reasonably flat, no distortion will be evident.

Typical wide-band FM applications require an attenuation of 35 db at a frequency of 200 kc off resonance. Assuming three transformers will be employed (usual requirements) an attenuation of approximately 10 db per stage will be required when allowances are made for possible production variations.

A simple method of checking the possibilities for such a design is through the use of the Universal Selectivity Curve shown in Fig. 2-17.

Given a desired attenuation at a specified frequency the value of $Q\Delta f_0/f_0$ is obtained by reference to the curve for either isolated or critically coupled as the case may be. This point is referred to Scale B and a line projected to the desired value on the Δf_0 scale. A second

Application continued

line is then erected from the I. F. center frequency (f_0) through the intersection of the first line at Scale A. The terminus of the second line indicates the required Q for the conditions given.

Composite I. F. Amplifier

The combining of wide-band and narrow-band characteristics in an i-f amplifier for AM and FM reception is good engineering practice since it simplifies the overall design. A typical example is shown in Fig. 16 where the high frequency wide-band section is above ground potential by the impedance of the narrow-band (low frequency) circuit.

The impedance of the narrow-band tuned circuit must be relatively low at the operating frequency of the wide-band section to effectively ground the low side of the high frequency section. This requires the use of larger than normal capacitors for tuning the low frequency circuit and consequently reduces the gain. In actual practice wide-band applications require the use of high transconductance tubes to realize an appreciable gain, so it is entirely within good design procedure to sacrifice low frequency gain by the use of a high C circuit in order to obtain a better high frequency wide-band performance. The fact that the low frequency i-f can be designed to serve as a bypass to ground for the low potential end of the high frequency section usually eliminates the need for switching from one type of operation to the other.

DETECTION

Diode

The simplest and most popular detector is the diode. The choice of values for the diode load resistor and associated components and the proportioning of the a-c to d-c ratio to obtain low distortion with high percentage modulated signals are the main design consideration.

A family of average characteristics for a typical diode detector is shown in Fig. 2-18. Each curve is obtained by varying the d-c load resistance and measuring the diode current with a constant signal input voltage. Several values of input are used to complete the family. For purposes of illustrating how these curves are used in the design of a detector we will assume a desired load resistance of one megohm. A load line (AB) having a slope of one megohm is drawn on the family of curves.

Starting at zero voltage and current as one point, the line extends to the left to –30 volts and 30 microamperes as the other point. (One megohm at 30 volts passes a current of 30 microamperes). Assume an unmodulated carrier voltage with an amplitude of 10 volts RMS impressed on the diode. This establishes the operating point at the intersection of the load line and the 10 volt curve. (The d-c voltage resulting from the carrier is used for AVC purposes). When modulation is applied to the carrier the operation is more complex, particularly when the modulating frequency varies.

Application continued

I. F. Amplifier Considerations

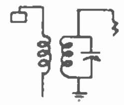
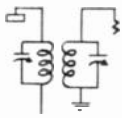
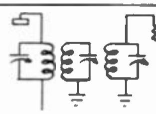
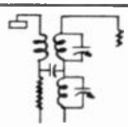
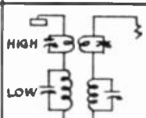
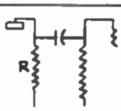
TYPE	SCHEMATIC	REMARKS
SINGLE TUNED		SINGLE TUNED I.F. AMPLIFIER RECOMMENDED WHERE HIGH GAIN AND LOW SELECTIVITY ARE DESIRED. IDEAL FOR FEEDING DIODE DIRECTORS. $GAIN = G_m WLQ$
DOUBLE TUNED		RECOMMENDED FOR ALL GENERAL APPLICATIONS GOOD GAIN AND SELECTIVITY. WHERE TUNED CIRCUITS AND IDENTICAL IN Q AND L $GAIN = G_m \frac{\omega LQ}{2}$
TRIPLE TUNED		RECOMMENDED FOR HIGH FIDELITY APPLICATIONS WHERE BROAD NOSE SELECTIVITY CURVE IS REQUIRED. CIRCUITS MAY BE PERMEABILITY TUNED FOR ANY TYPE INDUCTIVE COUPLING TO IMPROVE FREQUENCY STABILITY.
SINGLE TUNED COMPOSITE		SINGLE TUNED TWO FREQUENCY OPERATION RECOMMENDED FOR LOW COST RECEIVERS ONLY. LOWER TUNED CIRCUIT BYPASSES HIGH FREQUENCY CIRCUIT.
DOUBLE TUNED COMPOSITE		RECOMMENDED FOR AM-FM APPLICATIONS. NO SWITCHING REQUIRED SINCE CAPACITY OF LOW FREQUENCY CIRCUIT PROVIDES EFFECTIVE GROUND FOR HIGH FREQUENCY TANK.
RESISTANCE COUPLED		LOW GAIN, POOR SELECTIVITY, RECOMMENDED ONLY WHERE SMALL GAIN AT LOW COST IS REQUIRED. $GAIN = G_m Z$ G_m IS LOW BECAUSE OF VOLTAGE DROP IN R AND HIGH TUBE CAPACITY.

Fig. 2-16

From the schematic diagram it can be seen that so far as audio frequencies are concerned the one megohm load resistor is shunted by the AVC, the diode capacitor and the input circuit of the following audio stage. Since the circuit components are not all resistive the effective load impedance varies with frequency. A few simple calculations will show that the effective load impedance will vary from 610,000 to 210,000 ohms as the frequency is increased from 50 to 5000 cycles. These new values of load impedance are drawn in dotted lines and indicate the range over which the impedance will vary under the specified conditions. From these we can secure enough points to draw a curve showing the diode output as a function of carrier voltage input. Note that with the 210,000 ohm load (operation at 5000 cycles) the current is cut off with low signal inputs causing distortion with a high percentage modulated carrier.

The following summarizes standard practice in diode circuit design.

Application continued

1. The value of the diode-load shunt capacitor should greatly exceed the diode plate-cathode capacitance but should still present a high impedance to the modulating frequency.
2. The diode-load resistor should at least equal the reactance of the diode capacitor at the maximum modulation frequency.
3. The value of the AVC resistor and volume control should be as high as consistent with good component design. Volume controls of over two megohms are not recommended.

Other Detectors

Grid leak-capacitor, plate and infinite impedance detectors are seldom employed and since the first two mentioned are so well known only the latter will be discussed.

The infinite impedance detector is a variation of the more common plate detector except that in the latter the audio signal is obtained from the plate load impedance, while in the infinite impedance detector the audio load resistor is inserted in the cathode circuit and the plate is bypassed to ground for audio frequencies. The cathode load resistor actually serves two purposes; it acts as the load for the rectified audio signal and provides automatic grid bias according to the strength of the carrier. Unlike the diode it does not load the input transformer and therefore gain and selectivity are not sacrificed. Unlike the plate detector it is not subject to serious overloading with large signal inputs.

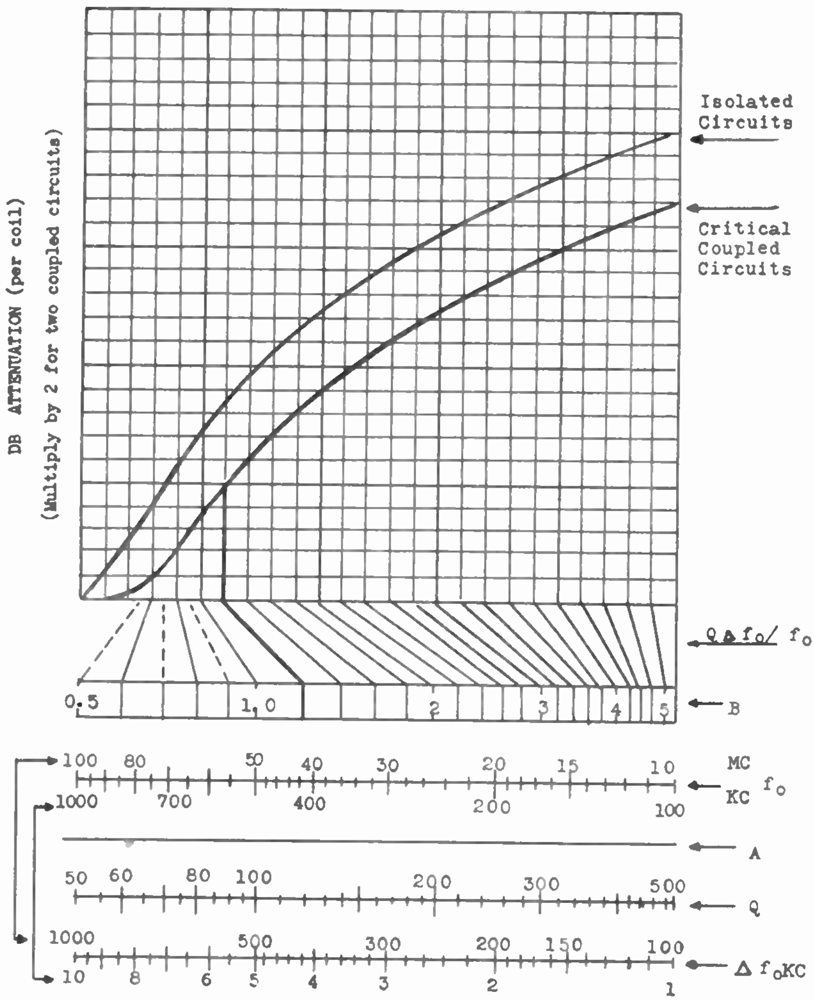
A note of caution as to a possible source of spurious response should be included in any discussion of detectors. Because of the i-f harmonics present in the second detector stage, any spurious coupling between the second detector and the r-f is likely to result in whistle interference when the incoming signal is of the same frequency as one of the i-f harmonics. This can be particularly troublesome in receivers employing a loop antenna unless the antenna can be located out of the field of interference. Filtering shielding and good design layout usually eliminate this type of interference.

Limiters

The fact that a frequency modulated wave has constant amplitude makes it possible to eliminate amplitude modulated signals by leveling the signal to a predetermined value. This is accomplished by a limiter stage as illustrated in Fig. 2-20.

A prerequisite to good limiting is a strong signal input; in other words, a minimum input voltage is required for normal operation and unless this is provided amplitude modulated interference will likely be present. Theoretically after the signal passes through the limiter it has a constant amplitude; the degree to which this is maintained depends upon the operating point of the tube and the circuit constants. Essentially it is a sharp cut-off tube operating at low plate and screen voltages (10 to 40) with bias supplied by a grid leak and capacitor.

Universal Selectivity Graph



Use f_0 and f_0 scales as indicated by connecting lines

Fig. 2-17

Application continued

Going into more detail, the action is as follows. Assume the signal input to be several times the threshold value in amplitude; the positive peaks will charge the grid capacitor and produce a negative bias nearly equal to the peak of the signal voltage. The capacitor charging time is a function of the tube grid resistance, which is normally low, therefore the charging time is short. The discharging time is dependent upon the value of the resistor, being relatively long with a high value of resistance and vice versa. In other words, the smaller the resistance the shorter the discharge time and the higher the peak signal input required to provide the necessary limiting bias. Since the negative signal peaks drive the tube to cut-off, the plate current will consist of pulses produced by a portion of the positive signal peaks.

When the amplitude of the peak signal input is increased, either due to amplitude modulation or noise, the grid will be driven more positive but since a smaller percentage of the positive half cycle will be effective in producing the plate current, it is evident the plate current pulses must be narrower. This results in a reduction of the average plate current (limiter output) and is undesirable. The grid leak and capacitor must therefore be chosen to provide a constant average plate current over a wide range of signal inputs. In selecting the proper values the time constant of the combination must also be considered, otherwise limiting will be ineffective on short pulses of noise. Unfortunately optimum constants to satisfy the requirements of amplitude limiting of both signal and impulse noise peaks are not the same, so a compromise design is necessary with a one tube limiter stage.

In addition to the grid-leak capacitor action, limiting takes place due to operation of the tube at low plate and screen voltages. Harmonics produced by limiting are effectively attenuated by the tuned plate circuit.

A two tube cascade limiter must be used if full advantage is to be realized in the reduction of noise along with good reduction of amplitude modulated signals. The first section is designed with a short RC time constant to reduce peak impulse noise and the second section is designed for optimum signal amplitude limiting. A typical schematic is shown in Fig. 2-20.

The limiter output voltage, while constant in amplitude, may be adjusted in level to provide a predetermined signal to the discriminator. The point (threshold) above which the limiter operates is determined by the gain in the limiter stage, also to a certain extent by the amount of audio amplification following the discriminator. A single tube unit using a compromise design may have a gain of nearly three, while a cascade limiter is capable of gains of approximately six. In general limiting should take place with an input of less than four volts from the i-f amplifier.

Discriminators

Frequency modulated signals do not vary in amplitude with the percent audio modulation; instead, the carrier frequency deviated in

Application continued

equal amounts about its center position. In order to restore the original variation in loudness of the program being transmitted it is necessary to employ a detector that responds to changes in frequency. Such a detector is known as a discriminator and has a frequency characteristic as shown in Fig. 2-21.

Briefly the operation is as follows; the primary L_1 is connected to the mid-point of the secondary L_2 through a small coupling capacitor. This capacitor (50 mmf is a good value) should have a low reactance at the carrier frequency. The two diode load resistors R_1 and R_2 are by-passed for i-f with approximately 50 mmf and their mid-point is connected (for d-c) to the center of the discriminator secondary. An r-f choke is used for this purpose otherwise the secondary mid-point and the primary would be effectively grounded at its operating frequency.

With L_1 and L_2 tuned to resonance the phase relations are such that the voltages across R_1 and R_2 are equal in magnitude but opposite in polarity and no output is obtained from the discriminator. As the signal deviates from its center frequency (due to modulation) the rectified voltages across R_1 and R_2 are no longer equal because the phase relations between primary and secondary voltages have been changed. Now, since the signal is swinging across resonance at an audio rate determined by the modulating frequency the resultant rectified voltage will be the desired audio signal; the amplitude or loudness being determined by how far it swings over the discriminator curve.

Referring again to the discriminator characteristic, it is noted

Diode Detector Considerations

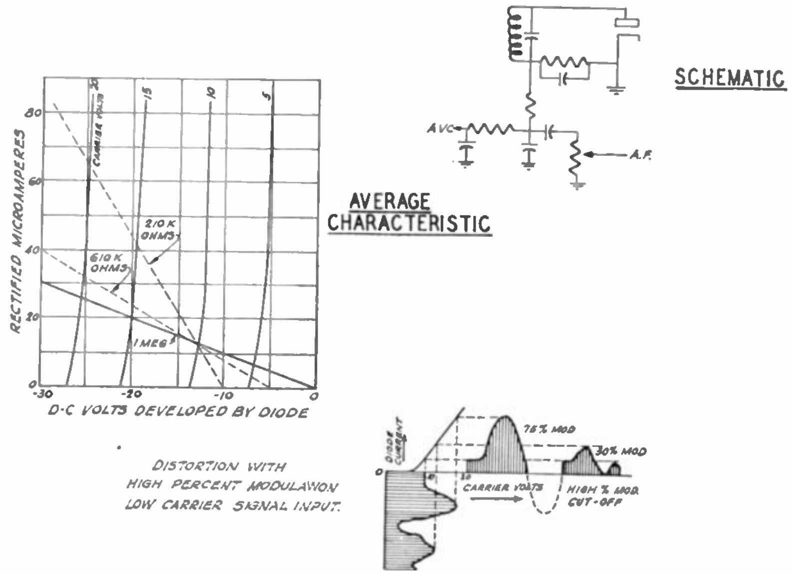


Fig. 2-18

Application continued

there is an essentially linear portion where a change in frequency on either side of the center point will produce equal changes above and below the zero output line. If the frequency is varied past the linear portion the output voltage is reduced and distortion will result. Obviously then, to prevent distortion the straight part of the curve must be such that at no time the frequency deviates into the non-linear region.

The length of the straight portion may be controlled by the separation of the peaks A and B, although due to regeneration or degeneration this is not always an indication of the usable range. Careful checking of the linear section of the characteristic is necessary and it is good practice to allow a tolerance of 20 percent over the required deviation range for good tuning and to ensure distortion-free opera-

Audio Detector Considerations

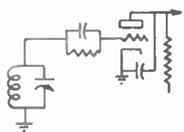
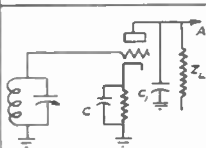
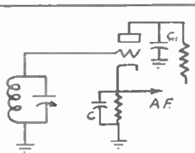
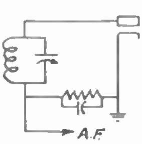
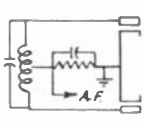
TYPE	SCHEMATIC	NOTES
GRID-LEAK CAPACITOR		SQUARE LAW DETECTOR. HIGH DISTORTION (FUNCTION OF PERCENT MODULATION) 2^{ND} HARMONIC = $100\frac{m}{4}$ m = MODULATION FACTOR FEW CURRENT APPLICATIONS
PLATE		HIGH INPUT IMPEDANCE. FAIR DISTORTION CHARACTERISTIC. MEDIUM OUTPUT. C = A.F. BYPASS C_1 = R.F. BYPASS OUTPUT = $m E_o S_c Z_L$ m = MODULATION FACTOR E_o = CARRIER VOLTS S_c = CONVERSION CONDUCTANCE
INFINITE IMPEDANCE		HIGH INPUT IMPEDANCE - HIGH OUTPUT CAPABILITY. SUBJECT TO NEGATIVE PEAK CLIPPING WHEN PERCENT MODULATION EXCEEDS AC/DC IMPEDANCE RATIO OF LOAD. COMMUNICATION RECEIVER APPLICATIONS. C = R.F. BYPASS C_1 = A.F. BYPASS
HALF WAVE DIODE		LOW INPUT IMPEDANCE. LOW EFFICIENCY. LOW DISTORTION. GENERAL APPLICATIONS. AVC VOLTAGE AVAILABLE.
FULL WAVE DIODE		ONE HALF OUTPUT OF HALF WAVE. LESS R.F. FILTERING REQUIRED. SELDOM EMPLOYED IN PRESENT DAY APPLICATIONS. A.V.C. VOLTAGE AVAILABLE.

Fig. 2-19

Application continued

tion in case of oscillator drift. The separation between peaks (when the primary and secondary are less than critically coupled) is determined by the effective secondary Q and the carrier frequency. The peak separation in kilocycles equals the carrier frequency in kilocycles divided by the circuit Q.

In general the primary tuning affects the symmetry of the peaks, while the secondary tuning centers the cross-over point on the correct frequency.

SPECIFICATIONS

The specification of r-f inductors or transformers should include only those items specifically required to obtain the desired performance. Specifications that are too exacting unnecessarily increase the cost, but on the other hand insufficient specification of tolerances often result in assembly problems (increased labor) and sometimes inferior products. The Specification Check List and sample drawing Fig. 2-22 should be used as a guide.

Amplitude Limiters for FM Applications

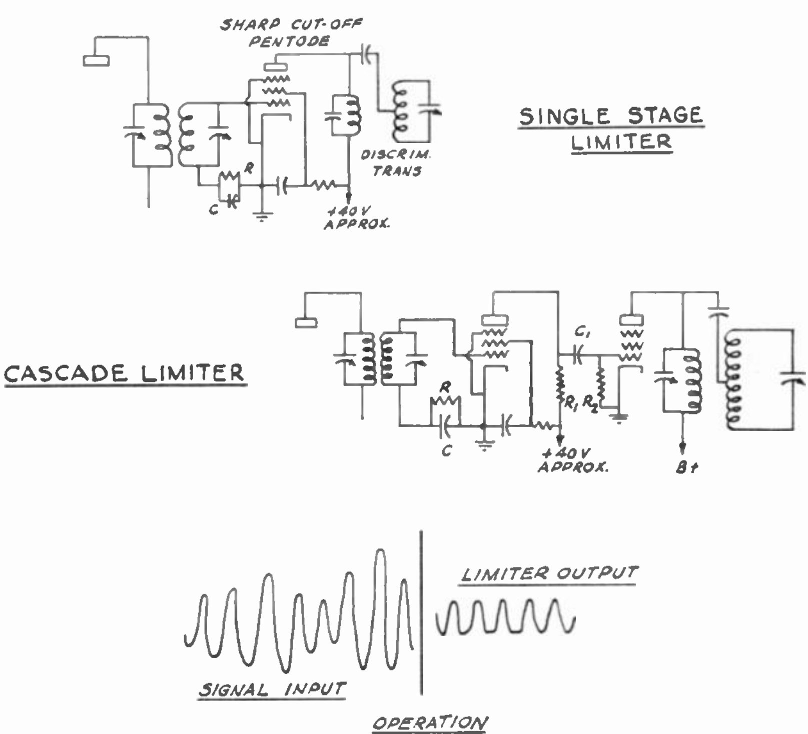


Fig. 2-20

F M Detector (Discriminator)

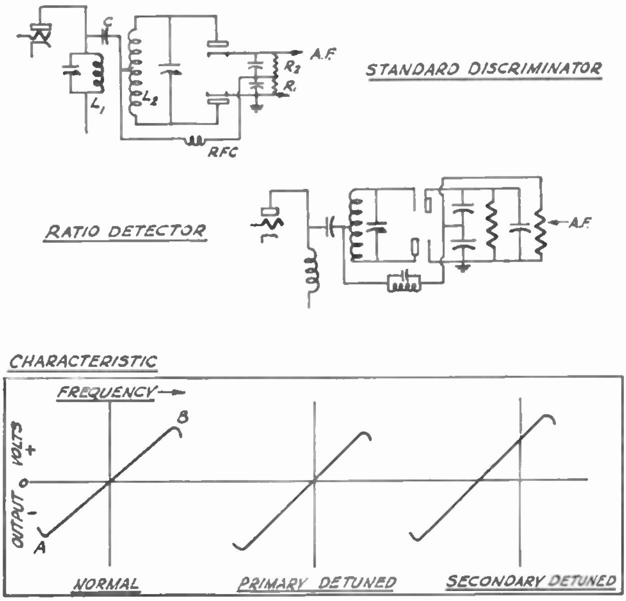


Fig. 2-21

SPECIFICATIONS
Inductors and Transformers
radio frequency

PHYSICAL
- **Dimensions**
  - Overall
  - Mounting
- **Type**
  - Shielded
    - Material
  - Unshielded
- **Terminals**
  - Location
  - Leads
    - Length
  - Lugs
    - Type
- **Winding**
  - Wire size
  - Insulation
  - Turns
  - Type
    - Solenoid
    - Universal
    - Bank
    - Progressive
- **Winding Form**
  - Dimensions
  - Material
  - Iron Core
- **Impregnation**

ELECTRICAL
- **Inductance**
  - 1000 cycle
  - r. f.
    - overall
    - tap to start
- **Coupling factor**
- **Q at Operating Frequency**
- **Distributed Capacity**
- **Underwriters requirements**
- **Humidity requirements**
- **Gain with circuit.**
- **Selectivity with circuit**
- **Leakage**
  - Between windings
  - Winding to shield

GENERAL
- **Approval of Sample**
- **Identification**

Table 2-1

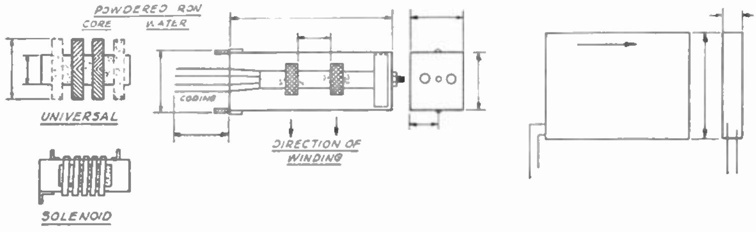
Dimensions. It is good practice to specify maximum overall dimensions without a tolerance. This gives the supplier a certain amount of latitude that often results in a cost saving. Of course the electrical requirements must be satisfied but if these are adequately defined the importance of physical size, excepting maximum overall, is usually of little importance.

Electrical Characteristics. The end use of the component part is the major consideration and should be definitely indicated. Specification of all details such as wire size, turns, physical spacing between coils or shield, winding form material and dimensions together with the inductance, Q, mutual, coupling factor, gain and selectivity in a typical circuit only confuse and restrict the supplier. Few manufacturers have the same facilities for the fabrication of parts; one may have equipment which is not suitable for the size and type of wire specified yet his design may be capable of meeting the required performance. If the designer has too completely specified the component, new equipment or technique may be required, obviously at an increase in cost.

Such situations can be avoided by specifying only overall characteristics and dimensions without reference to raw materials. Design data may be included for reference purposes and as such serves as a guide not only to the part manufacturer but to other engineers who might be considering the use of the same component in another design.

In general specify the widest possible tolerance in as simple a manner as possible, indicating the method of testing only where required.

Typical Specifications - R. F. Inductors



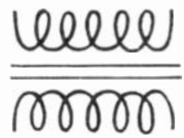
R.F. I.F. LOOP

PART Nº	WINDING TYPE	WINDING FORM MATERIAL DIMENS	LUGS TYPE LOCATION	LEADS TYPE DIMENS	INDUCTANCE 1000~ TOTAL TAP MUTUAL	L TOLERANCE	Q-KC	IRON GRADE DIMENS

WIRE SIZE	T.P.I.	DISTRIBUTED CAPACITY SELF RESONANT FREQ	SHIELD MATERIAL THICKNESS	GAIN IN TEST CIRCUIT	A.C.A.	CAP COUPLING AID - BUCK	TREATMENT

Fig. 2-22

TRANSFORMERS & REACTORS
POWER & AUDIO FREQUENCIES



DESIGN

Transformers and reactors for operation in the frequency range of 20 to 10,000 cycles require the consideration of several factors not ordinarily specified for high frequency operation. Their design involves such items as flux density, magnetizing force, electrolysis, core and copper losses, in addition to the more common parameters of inductance and leakage resistance which are so familiar to radio engineers.

Electrical Steel in Magnetic Circuits

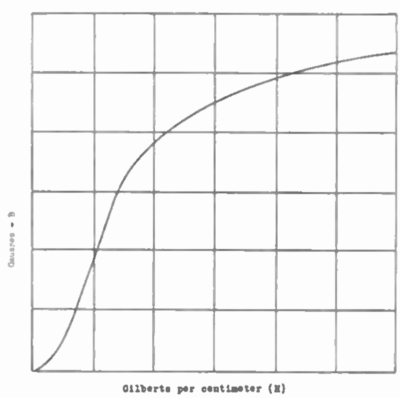
The magnetic material comprising the core of a transformer or reactor has certain characteristics which are well known, however, as a reminder or refresher, a brief summary will be included before considering some of the design factors.

Magnetization

When a core is magnetized the relationship between the flux density (B) and magnetizing force (H) follows the shape of the curve shown in Fig. 3-1. This is known as the magnetization curve. If the magnetizing force is reversed and points are plotted as the force is decreased in magnitude the resultant curve will be a loop. This is known as a hysteresis loop and is a record of B/H performance when the magnetizing force is an alternating current. The ratio B/H is known as permeability and is an important parameter in the consideration of magnetic core materials. When both a-c and d-c magnetizing forces are concerned the resultant permeability is known as incremental permeability and for a typical core material may be represented as shown in Fig. 3-2. It should be noted that the incremental permeability increases, up to the knee of the curve (saturation point of the core material), as the a-c flux density is increased and decreases as the d-c magnetization (H) increases.

Core Loss

The selection of core material is generally made on a permeability basis for audio transformers and filter reactors and on standard watt-loss specification as supplied by the lamination manufacturer for power transformers. Such a curve is shown in Fig. 3-3 for a typical material. The core loss is divided between that due to hysteresis and that caused by eddy currents.



Typical Magnetization B/H Curve

Fig. 3-1

Eddy Current Loss

The core material, being a good conductor of electricity,

Design continued

acts as a short-circuited turn and because of the variable magnetic flux a voltage is developed and consequently current flows in the core. This current (eddy current) sets up a flux which tends to decrease the original flux and thus the inductance of the windings is effectively decreased. Because of the decreased inductance high current flows which results in excessive power or eddy current loss. In the design of efficient magnetic circuits this is remedied by breaking the core into thin sheets or laminations (insulated from one another) thus confining the eddy currents to each separate sheet. The insulation between laminations (a tightly adhering oxide) is automatically obtained during the annealing process used to soften the material for magnetic purposes. This results in less current flow and therefore lower losses. The addition of a small percentage of silicon to the steel also has a similar effect since it increases the resistance of the path. The combination of the two (thin sheets of silicon-steel) results in low eddy current loss.

Hysteresis

When iron or steel is subjected to a reversing magnetic flux more energy is consumed in magnetization than is returned on demagnetization. The difference in energy is dissipated in heat and is known as hysteresis loss. It is proportional to frequency and may be reduced to a minimum by the use of sufficient silicon steel core material. As the silicon content of the material increases the core loss decreases for a given sheet thickness; the saturation flux density decreases and the permeability increases for flux densities below maximum.

A reduction in core size and weight (30 to 50%) can be obtained by employing a newly developed high permeability silicon steel (Hipersil —Westinghouse Electric & Manufacturing Co.). Its excellent magnetic properties (existing only in the rolling direction of the steel) also make it possible to save up to 10 per cent in copper. Because the superior magnetic properties exist only in the direction in which the steel is rolled, the core design is rather unorthodox. The material (in a thin strip) is wound in layer form on a mandrel to the desired size, annealed, impregnated to make a solid unit and then cut into two segments. This method of construction eliminates the handling of many separate thin gage laminations since only the two sections of the core are stacked. The saturation point of Hipersil is also higher than that of ordinary silicon steel which results in greater straight-line response

Typical Incremental Permeability Curve Showing Effect of d-c Magnetization H).

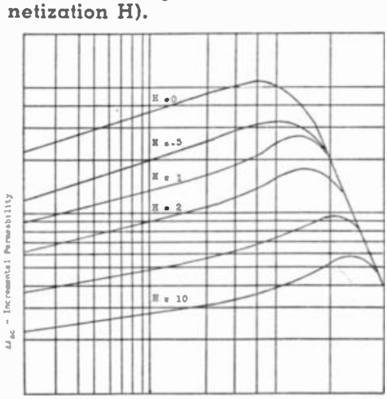


Fig. 3-2

Design continued

and therefore less possibility for harmonic generation. In general such cores are not adaptable to conventional mountings; they are most applicable to large transformers or in small units where size and weight are more important than cost.

Copper Losses

Since the windings of a transformer have resistance, it is evident there will be an I^2R loss whose magnitude is dependent upon the size or cross-section of the wire employed. The larger the wire, the lower the resistance and likewise the I^2R loss. Copper loss can also be reduced by increasing the volts per turn ratio (less wire), which is another way of decreasing the resistance. Such an expedient can only be carried to the point where the flux density becomes so high that the core saturates.

Experience has shown that the losses at relatively high flux densities are not excessive and, being dependent upon the reactive current in the primary, can be decreased by the use of higher permeability core material. However, experience also indicates that high silicon content laminations are not the answer to the problem, since at high flux densities the average a-c permeability of a relatively low silicon content steel is usually the greatest. It is evident that the design for best overall characteristics must be based on a compromise of wire size and core material.

Apparent Inductance

Designs wherein the transformer or reactor must carry direct current are subject to variations of inductance and likewise apparent permeability according to the amount of polarizing current in the winding and the length of the air gap in the magnetic circuit. In general, where the steady magnetomotive force is high the best air gap will be large, and where it is low, the optimum air gap will be small. In fact, sometimes the normal air spaces in the lamination stacking provide sufficient air gap. Fig. 3-4 shows the general classifications for such designs.

Silicon Steel Core Loss Curve

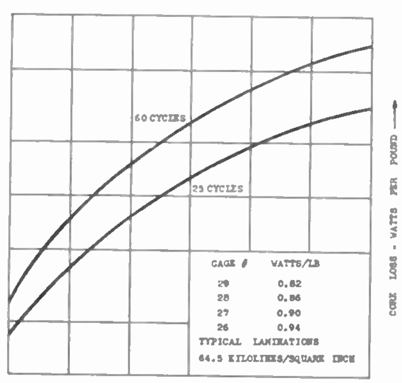


Fig. 3-3

Electrolysis

Failure of windings through copper corrosion in the presence of moisture is a common source of trouble to the radio engineer. Corrosion of the usual type involves the formation of a greenish material

Design continued

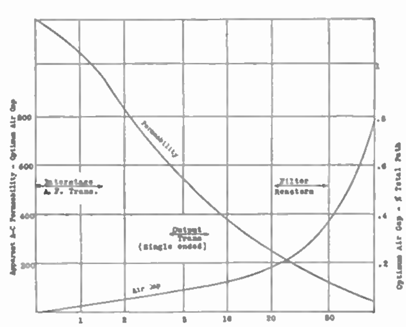
(copper salts) on the surface of the wire which gradually decreases its cross-section uutil a break occurs. Extremely small amounts of chemical impurities in the insulating materials, particularly if the unit is operated at a positive potential above ground, (example—a filter reactor or a-f transformer) are sufficient to cause serious corrosion under conditions of high humidity and temperature.

Obviously, the finer the wire employed, the faster the corrosion takes place once it has started, consequently the specification of wire sizes smaller than #29 (practical limit) should be accompanied by adequate provisions for minimizing corrosive producing elements (free acids).

It might be pointed out at this time that corrosive action may take place in either a-c or d-c windings if the unit is not operating. Under operating conditions there is usually sufficient heat generated to keep the component free of moisture. Intermittent operation, where the winding absorbs moisture during the off period, and leakage occurs before normal heating drives off the moisture, is particularly favorable for these effects. The relative humidity has an appreciable influence on the life of the component. Windings subjected to 90 percent humidity will usually last several times longer than those subjected to 95 percent humidity.

Components connected to a positive d-c potential are especially subject to electrolysis because any leakage to ground if accompanied by an electrolytic action from free ions in the material, results in a decomposition of the wire. This effect can be greatly reduced by the use of acid free materials in the construction.

Commercial acid free tapes and papers are satisfactory under average conditions, and varnished paper or cambric is satisfactory except under extreme conditions of humidity and temperature. Cellulose acetate, rubber and a number of the synthetic styrene and vinyl resin insulating materials have been found to be ideally suited where electrolysis is a problem. A simple test as to whether a material is corrosive consists of threading two pieces of fine wire through the material, connecting a potential between the wires, and subjecting the test specimen to high humidity. Within a day or so at the most, evidence of corrosion will begin to appear if the material has any corrosive tendencies.



Classification of Components by Optimum Air Gap and A-C Permeability.

Note: 3.20 $\frac{H}{\text{gilberts/cm}}$ = ampere turns/inch

Fig. 3-4

Filter Reactors

The laminated iron core filter reactor is gradually being replaced by the speaker

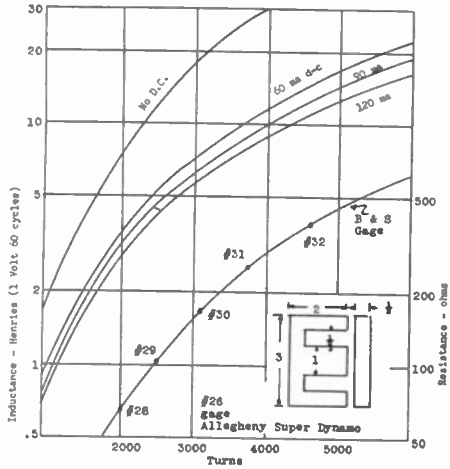
Design continued

field for filtering power supplies. However the filter reactor is far from being obsolete as a radio component.

Inductance

The apparent inductance and likewise the apparent permeability of the magnetic core varies with the amount of d-c in the winding. With a particular core size the highest inductance is obtained by employing the largest possible number of turns for the available space. This is limited by the maximum allowable d-c resistance and the minimum gage of wire which will safely carry the required current. For a specific design and a given d-c polarizing current in the winding, the optimum inductance is obtained by varying the air gap until the inductance is at a maximum. The saturating effect of the d-c always decreases the inductance.

Filter Reactor Design Curves



Inductance with and without d-c for optimum air gap using EI laminations as shown with square center stack.

Fig. 3-5

The inductance is also influenced by the amplitude of the (a-c) ripple voltage, consequently the inductance is designed with a definite a-c magnetizing current and a given a-c voltage impressed.

Fig. 3-5 summarizes the information required for most design applications. Knowing the maximum allowable resistance and the desired inductance, the wire size and number of turns can easily be determined. Note that the curves show the inductance in terms of best air gap for a specified d-c magnetizing force; also the information is based on a specific grade and size of lamination.

For additional design notes refer to general considerations following power transformer design.

Audio Transformers

The important elements of an audio transformer are the turns ratio of the windings, the primary inductance, the primary resistance (which is in effect an addition to the plate resistance of the tube), the leakage resistance and the effective secondary capacitance. The amplification in general is dependent upon the turns ratio although the primary inductance determines the low frequency response and is dependent upon the a-c flux density with the proper d-c in the winding. Eddy current resistance can usually be ignored. The schematic and equivalent circuits of a transformer are shown in Fig. 3-6.

Amplification at high audio frequencies is determined by the secondary inductance and capacitance and the leakage inductances of

Design continued

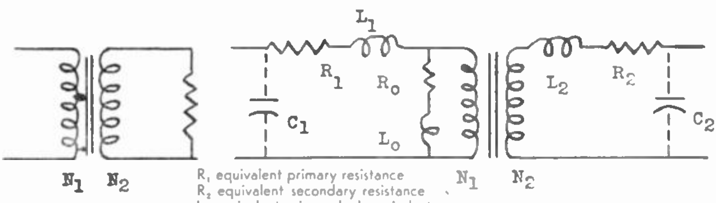
both windings. The leakage inductance and distributed capacitance (due to charging currents between layers of the winding) should both be minimized, otherwise these two parameters will resonate in the desired frequency band and result in a peak in the response curve.

The primary winding is generally placed next to the core with its start connected to the plate of the tube. The finish of the secondary is then connected to the following grid in order to minimize the effect of capacitance bteween windings.

Output Transformers

This type of transformer operates under quite different conditions than an interstage audio transformer. The secondary is shunted by a relatively low impedance load and a step-down turns ratio is employed to reflect the proper impedance into the primary circuit. The power handling capacity is not of importance as are the primary inductance (determines the low frequency response) and the ratio of transformation (determines matching of the load to the tube plate circuit).

Because of the higher a-c primary voltages involved precautions must be taken to prevent core saturation, which will produce a highly



R_1 equivalent primary resistance
R_2 equivalent secondary resistance
L_1 equivalent primary leakage inductance
L_2 equivalent secondary leakage inductance
R_0L_0 equivalent core loss
C_1C_2 primary and secondary equivalent lumped capacity.

Schematic & Equivalent Circuit of a Laminated Iron Core Transformer

Fig 3-6

distorted wave of magnetizing current. Harmonics introduced by the non-linearity of the magnetization curve of the core are always present to some extent. They can be minimized by designing the transformer in such a way that the a-c flux density in the core is small under operating conditions and by making the inductive reactance of the primary high.

The apparent inductance and likewise the apparent permeability of the magnetic core vary with the amount of d-c in the winding and the length of the air gap in the magnetic circuit. Both quantities depend on the a-c permeability of the core material. In a closed magnetic circuit of uniform cross-section (d-c in the winding) the apparent permeability of the core is equal to the a-c permeability. When an air gap is inserted in the magnetic circuit the d-c flux density obviously decreases while the a-c permeability is increased. In other words, for a given value of a-c flux density the a-c permeability decreases with an

Design continued

increase in d-c flux density, and vice versa. If the a-c flux density is decreased to very small values (d-c constant), the a-c permeability approaches a definite minimum. In the design of audio frequency transformers this minimum, known as the initial a-c permeability is of importance since small a-c flux changes are involved.

The core material should be selected on a permeability basis, that is, the apparent a-c permeability as established by the actual inductance of some definite design and not the theoretical permeability as given in so called saturation (B/H) curves. Such curves are not directly usable when the core material is polarized by a relatively heavy d-c magnetizing force, as for example as output transformer for a single-ended amplifier.

Eddy current and hysteresis losses can be ignored or considered part of the load resistance. The primary and secondary copper resistances are effectively a part of the plate and load resistances respectively. Eddy current loss in general is relatively low at the flux densities encountered in most audio applications. It is mistakenly thought that high eddy current loss is present at the higher audio frequencies, since it is known that the loss is proportional to the square of the frequency. Actually the flux density required to induce a given voltage is inversely proportional to frequency, so the eddy current loss for a given induced voltage is independent of the frequency.

Resonance due to leakage inductance and distributed capacitance is not especially important in an output transformer because of the low load resistances involved.

The windings should be thoroughly dried and vacuum impregnated in an acid free wax or other insulating compound to protect them against moisture. This, with proper clamping, also tends to eliminate mechanical lamination hum. The impregnating compound should obviously not soften at the maximum operating temperature nor crack at the lowest.

Power Transformers

Power transformers for radio receivers usually have an overall efficiency of about 85 percent (see Table 3-2). The losses should be approximately one half core loss and the other half copper loss. Since the regulation is relatively poor, it is usual to neglect the effects of leakage reactance and capacitance.

A transformer designed for a definite frequency may operate at frequencies which are considerably higher or lower than that for which it was designed.

Transformer Core Area vs. Watts

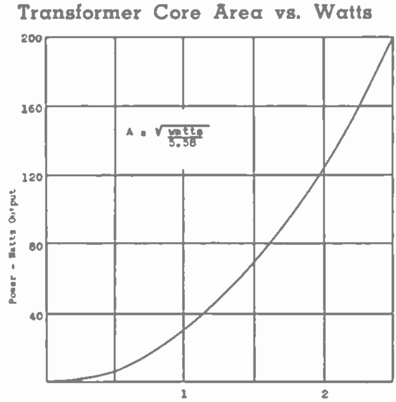


Fig. 3-7

Design continued

If at the design frequency the copper and iron losses are equal and the efficiency a maximum, then at lower frequencies the iron loss will be larger than the copper loss and at higher frequencies the copper loss will predominate. In other words, for the same rating and efficiency, the lower the frequency the larger the amount of iron and the heavier the transformer.

The primary winding should be located next to the core to keep its resistance low and provide good heat conductivity through the iron.

Due to the form factor of the rectified current the primary volt-amperes will be slightly higher than the d-c power in watts. When a transformer supplies the heater current as well as the high voltage to the rectifier, a portion of the load will be pure resistive and the primary volt-amperes will approach more closely to the total secondary power output.

Eddy current loss at high flux densities require consideration, although laminations of #29 gage (annealed after stamping) are a good practical compromise. Interleaving 100 percent is also recommended to maintain high core permanence, although standard practice is to stack laminations in groups of at least two.

In general the design of a power transformer for radio receivers consists of a balancing of cost between large primary wire and higher volts per turn of winding, with its decreased wire and winding time, against low silicon content steel.

Stray Fields

Stray fields created by power transformers are dependent on the size of the unit, flux density of the core, geometry and shielding. Most efficient designs to minimize stray fields have equal copper and iron losses, equal mean length of magnetic and copper circuits and equal cross-sectional area of core and window opening.

General Considerations

All windings should be insulated and impregnated with acid free materials to withstand a 60 cycle test voltage having a peak value of twice the rated working voltage plus 1000 volts. The insulation resistance between all possible combinations of windings and case should exceed 100 megohms for the desired operating conditions. In the design of high voltage transformers sharp corners on all live parts should be avoided to prevent possible corona or breakdown.

Designs should be based on a maximum temperature rise in the windings of not more than 50°C under normal rated operating conditions. The unit should also be capable of withstanding a 25 percent overload at an ambient temperature of 50°C without serious deterioration. Hermetically sealed units should provide for normal expansion of the filling compound without damage to the seal. Potted units should not show signs of leakage under any of the above conditions.

Terminals or leads should be suitably marked or color coded.

Design continued

Rectifier - Filter	K
Capacitor input, full wave rectifier	0.717
Rtactor input, full wave rectifier	0.5
Capacitor input, half wave rectifier	1.4
Reactor input, half wave rectifier	1.06

Plate watts $= E_s \times I_{d.c.} \times K$

Transformer Plate Watts Rating versus Rectifier-Filter

Table 3-1

Watts Output	Approximate % Efficiency
20	70
30	75
40	80
60	83
80	85
100	86
150	88
200	90

Transformer Efficiency versus Watts Power

Table 3-2

Rectifier - Filter	K
Capacitor input, full wave rectifier	1.06
Reactor input, full wave rectifier	0.707
Capacitor input, half wave rectifier	2.2
Reactor input, half wave rectifier	1.4

RMS amperes $= I_{d.c.} \times K$

RMS Amperes versus Rectifier-Filter for Plate Wire Size

Table 3-3

LI² and VA Ratings of Different Core Sizes

					60 Cycles		400 Cycles	
LI²	Core	E	Stack Height	Cm/A	Bm	VA	Bm	VA
.009	F-12	3/8	7/16	300	96.75	1.7	35.47	5.0
.0195	EI-21	1/2	1/2	400	90.3	3.9	32.2	9.5
.0288	EI-625	5/8	5/8	475	90.3	5.8	31.6	15.0
.067	EI-75	3/4	3/4	500	90.3	13.0	30.3	30.0
.088	EI-75	3/4	1	500	90.3	17.0	29.7	38.0
.111	EI-11	7/8	7/8	550	87.1	24.0	29.0	50.0
.200	EI-12	1	1	600	83.8	37.0	27.1	80.0
.300	EI-12	1	1 1/2	630	83.8	54.0	25.8	110.0
.480	EI-125	1 1/4	1 1/4	710	80.6	82.0	25.2	180.0
.675	EI-125	1 1/4	1 3/4	725	77.4	110.0	25.2	230.0
.850	EI-13	1 1/2	1 1/2	800	77.4	145.0	23.8	325.0
1.37	EI-13	1 1/2	2	850	70.9	195.0	22.5	420.0
3.70	EI-19	1 3/4	1 3/4	1050	67.7	525.0	20.6	1100.0

Bm = kilolines per square inch

Cm/A = circular mils per ampere

VA = volt-amperes

The above table gives the maximum values of LI² and VA ratings at 60 and 400 cycles for various size cores. Ratings are based on a 50°C rise above ambient. These values can be reduced to obtain a smaller temperature rise. VA ratings are based on a two winding transformer with normal operating voltage. When three or more windings are required the VA ratings should be decreased slightly.

Table 3-4

Design continued

Power Transformer Design

The limiting consideration in the design of a power transformer for radio equipment is usually temperature rise. When the temperature rise requirement is satisfied, the regulation, exciting current and losses generally are satisfactory. An example of recommended design procedure is given to show the various steps involved.

Procedure:

1. Determine the output watts rating:
   a. Filament watts = E x I (RMS).
   b. Plate watts = Es x Idc x K (See Table 3-1 for K)
   c. Determine the approximate watts input by dividing the output watts by an estimate of the transformer efficiency from Table 3-2.
2. Divide the input watts by the line voltage and by 0.9 power factor to obtain the approximate primary current for determining primary wire size.
3. Determine the core area from Fig. 3-7.
4. Determine maximum current density from Fig. 3-8.
5. Each conductor area in circular mils will be determined by multiplying the current by the current density. For plate winding wire size calculation see Table 3-3. Use the RMS amperes to determine current density. Note: Because of excellent heat dissipation, due to location, filament windings may have a current density as high as 400 circular mils per ampere.

Power Transformer Design - Current Density vs. Watts Output

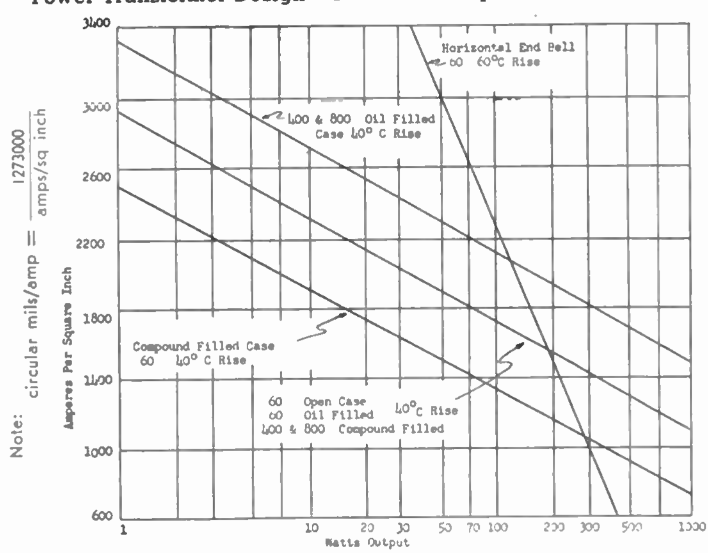
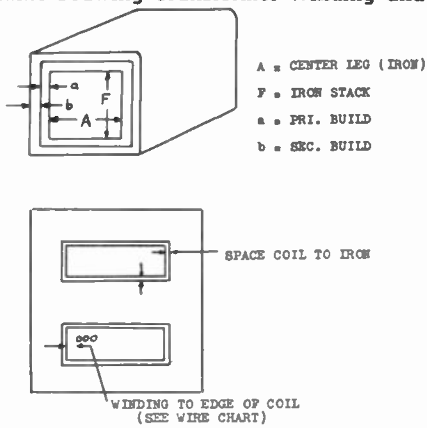


Fig. 3-8

Outline Drawing Transformer Winding and Core



Coil	Tube Size	Space Coil to Iron
Small	A 1/64 x F 1/64	1/64
Medium	A 1/32 x F 1/32	1/32
Large	A 1/32 x F 1/16	1/16

Fig. 3-9

Typical Summary Design Sheet

DATA SHEET No.

Date:

TYPE: RATING: TEMP RISE °C

CONSTRUCTION:

CORE	GRADE	INDUCTANCE	AT	VOLTS	AMP DC
WGT	THICKNESS	LEAKAGE IND.	AT	VOLTS	CYCLES
STACK	AIR GAP	NET CS			
STACKED	RATIO	CORE LOSS	WINDOW	SP. FAC.	
B =					

WINDING RATED VOLTS OPEN CIRCUIT VOLTS CALC-LOAD VOLTS RATED AMPERES TOTAL TURNS TAPS TURNS PER LAYER NUMBER OF LAYERS WIRE TRAVERSE						
WIRE SIZE SIZE OF COND (INSUL) CROSS SECTION CM PER AMP.						
MEAN LENGTH OF TURN TOTAL LENGTH RESISTANCE I. R. DROP LB COPPER						
WINDING FORM DIMEN. INSUL. UNDER COIL CONDUCTOR INSUL. BETWEEN LAYERS INSUL. OVER COIL BUILD TOTAL BUILD						

Fig. 3-10

Design continued

6. Calculate the core cross-sectional area (stack x center leg of iron) and multiply by a stacking factor of 0.94 for alternate stack or 0.88 for butt joint.
7. Calculate the number of turns to give a flux density of 70 to 80 kilolines per square inch at 60 cycles.

$$N = \frac{22.5 \times E\ 10^8}{A\ B\ f}$$

where E = primary voltage

A = cross-sectional area x stacking factor in sq. in.

B = kilolines per square inch

f = frequency

N = number of primary turns.

8. Calculate the mean length of turn of primary using the outline drawing of Fig. 3-9 as a guide.
9. Multiply mean turn length by total of primary turns and divide by 12 to obtain total length in feet. Knowing total length, find resistance and IR drop in primary. Then find percentage of voltage drop in primary which is reflected in all other windings.
10. Tabulate results. (See Fig. 3-10).

APPLICATION

Power Supply Circuits

The application of power transformers in radio receiver design requires a knowledge of the basic circuits involved. Rectification may be obtained by the use of either electron tubes or selenium rectifiers. Basic circuits are shown schematically in Fig. 3-11. For the sake of completeness several non-transformer (a-c/d-c) versions have been included. It should be noted that the rectifier filament windings are not shown center tapped. This results in an a-c (supply frequency) voltage equal to half the filament potential being introduced in the d-c rectified output, however, for most applications it has no serious effect on the overall performance.

Basic Power Supply Circuits

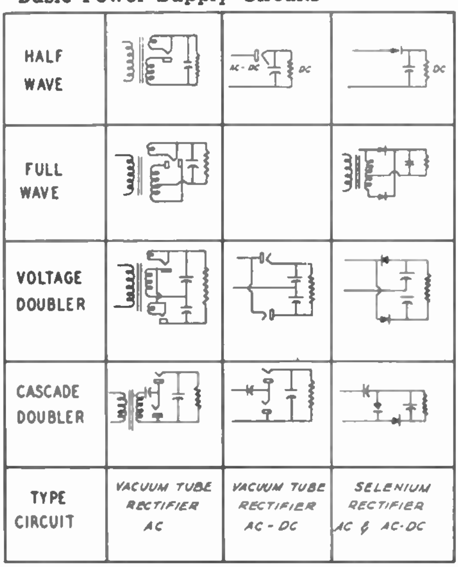


Fig. 3-11

Selenium Rectifier - Typical Characteristics

Line volts = 117.

Circuit	Protective Resistor	Load MA	DC across C_1 C_3	Ripple thru C_1 MA	Peak AC Ripple C_1
Half wave	No	50	150	160	12
Half wave	No	100	140	280	22
Half wave	Yes	50	135	125	11
Half wave	Yes	100	120	220	19
Full wave doubler	No	50	285	165	12
Full wave doubler	No	100	252	270	20
Full wave doubler	Yes	50	252	125	10
Full wave doubler	Yes	100	202	210	18
Series line-feed doubler	No	50	260	210	13
Series line-feed doubler	No	100	220	360	22
Series line-feed doubler	Yes	50	240	175	13
Series line-feed doubler	Yes	100	172	320	22

Table 3-5

Half Wave Rectifiers

Half wave rectifiers are not generally employed for a-c (transformer) operation. Two reasons account for this; (1) the ripple frequency is equal to the supply frequency and being quite low is difficult to filter unless the load requirements are small, (2) the transformer core is subject to saturation because of d-c in the high voltage secondary winding. The latter may be nullified to a large extent by very liberal design or permitting excessive power losses.

Most applications of half wave rectifiers are of the transformerless or a-c/d-c variety. Although one objection (core saturation) has been eliminated, hum or ripple is still a problem. In addition, new problems have been created from a safety standpoint because the rectified d-c output is now directly connected to the primary power supply source. If the design is to be free of shock hazard ,steps must be taken to isolate all primary voltage points from possible contact by the user. Reference should be made to "Requirements for Power Operated Radio Receiving Appliances" published by the Underwriters' Laboratories, Inc., N.Y. for detailed information on this subject.

Average operating characteristics for typical half wave rectifiers are shown in Fig. 3-12. Circuit applications requiring larger than a 40 mfd capacitor for the filter input should include a protective resistor of sufficient size to limit the maximum peak current.

Selenium type rectifiers have been widely used in half wave circuits, particularly a-c/d-c applications. The low internal voltage drop may require a higher working voltage for the filter capacitor as compared to that normally specified for a vacuum tube rectifier. A small protective resistor (27 to 56 ohms) is recommended in series with the input capacitor to protect against high initial charging current and the inverse current characteristics of the unit. Ripple current with and without a protective resistor is tabulated in Table 3-5.

Application continued

Full Wave Rectifiers

Because of the balancing effect of the current when a center tapped winding is employed, full wave rectifiers do not subject the power transformer core to d-c saturation. This is the same effect as encountered in a push-pull output transformer where the d-c magnetizing forces cancel one another, depending of course on the accuracy of the center tap.

The ripple frequency is twice the fundamental supply frequency and thus allows a more economical filter design. The use of parallel operation for high current output applications is possible. It is good engineering practice in such cases to connect both plates of each full wave tube together as shown in Fig. 3-11.

Average operating characteristics for typical full wave rectifiers are shown in Fig. 3-13. These curves make it possible to determine the rectified d-c output voltage for a given a-c volts per plate at any desired current drain within the normal rating of the tube.

Selenium rectifiers may be employed in full wave circuits by observing the precautions cited under half wave operation. General practice however, restricts their use to half wave and voltage doubler a-c/d-c applications where the saving in heat dissipation (no filament required) can really be appreciated.

Voltage Doubler Circuits

The application of voltage doubler circuits has largely been confined to a-c/d-c operation, although the possibilities of transformer operation, particularly for television, should not be overlooked. Typical schematics are shown in Fig. 3-11. In the conventional or more widely employed circuit the capacitors should be in separate containers to prevent any possibility of leakage between sections. The cascade doubler, in spite of ripple current appreciably higher than that of the conventional circuit, has certain advantages in that the capacitors may be combined in a single container; or if a-c operation only permits a common terminal between the supply and the output voltage.

Typical operating characteristics for selenium rectifiers are tabulated in Table 3-5. It should be noted that these values represent operation at normal line voltages and this must be taken into consideration when specifying filter components.

Typical Operating Characteristics—AC-DC Wave and Voltago Doubler Circuit - Type 50x6 Tube

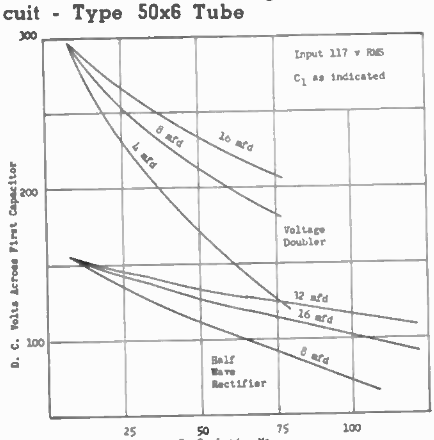


Fig. 3-12

Filter Circuits

The application of lami-

Application continued

nated iron core reactors in power supply filter circuits can be simplified by the use of curves to determine the percent ripple for a given type of filter. Designs can be broken down by sections and by applying the ripple from the initial section to curves for subsequent sections the overall result can be ascertained. Three basic types—reactor, capacitor and resistor input—with commonly employed variations are shown schematically in Fig. 3-14.

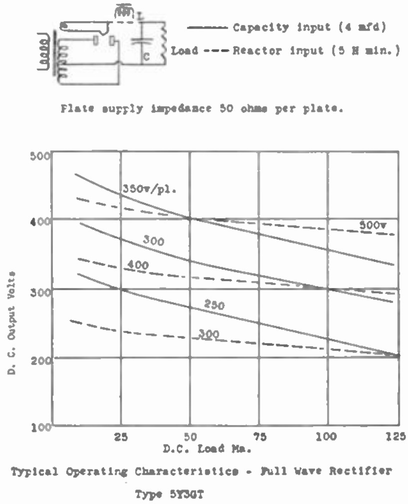


Fig. 3-13

It should be noted that the reactor or resistor is usually placed in the positive lead although it can be used in the negative lead to take advantage of the d-c drop across the unit for bias purposes. Obviously in such a circuit adequate additional filtering must be employed as shown. Such a circuit permits the use of a lower voltage power transformer for a given power output, but may result in increased ripple voltage since the possibility now exists for high ripple frequencies to bypass the reactor through the transformer or wiring capacity to ground.

Reactor input—Good regulation. Not generally used because of lower output voltage.

Capacitor input—High output voltage with relatively poor regulation. Generally employed in most applications where cost is a factor. Widely accepted for a-c/d-c applications with a resistance

Power Supply Filter Circuits

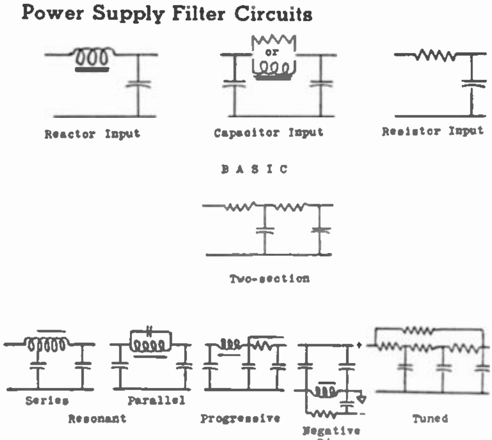
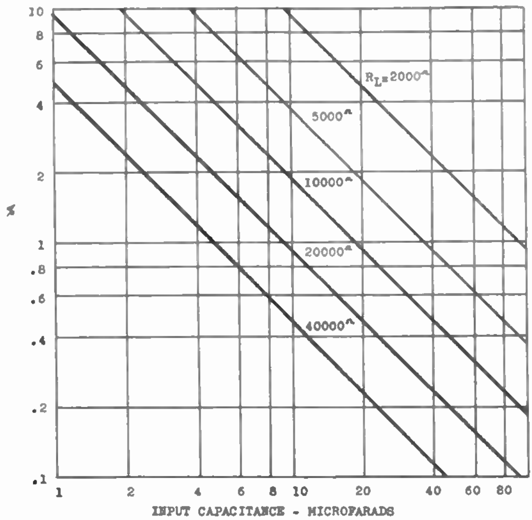


Fig. 3-14

Application continued

element substituted for the iron core reactor or speaker field.
Resistor input—Employed for low current applications; as for example high voltage television supplies.



Percent Ripple—Capacitor Input Filter, Full Wave Rectifier (Ripple Frequency 120 Cycles); For Half Wave Rectifier (60 Cycle Ripple) Multiply Capacitance by Two.

Fig. 3-15

Capacitor Input

The family of curves given in Fig. 3-15 is based on a full wave rectifier operating with an input supply frequency of 60 cycles. The data may be applied to other combinations of supply frequency and rectification by multiplying the values as indicated.

The degree of filtering depends upon the value of the input capacitor and load. Precautions should be taken not to exceed the maximum peak current capacity of the rectifier by the use of too large a capacitor. When an electrodynamic speaker is used the field is often employed for the filter reactor. In the case of permanent magnet type speakers, particularly for a-c/d-c applications, a resistor is often substituted for the reactor.

Reactor Input

The family of curves given in Fig. 3-16 is based on a full wave rectifier with an input supply frequency of 60 cycles. The data may be applied to other combinations of frequency by multiplying the value of LC by a factor as shown.

Single section reactor input filters are seldom employed since it is generally more economical to specify a two section unit for a given ripple attenuation. An alternate design consists of parallel tuning the reactor to the fundamental ripple frequency. While such a circuit provides excellent filtering for the ripple frequency, it has little effect on the harmonics of the ripple and therefore a second filter section is required. It should also be noted that any change in inductance due to large variations in the load current may appreciably affect the resonant frequency and thus the filtering efficiency.

Percent Ripple - Reactor Input Filter
Ripple frequency 120 cycles.

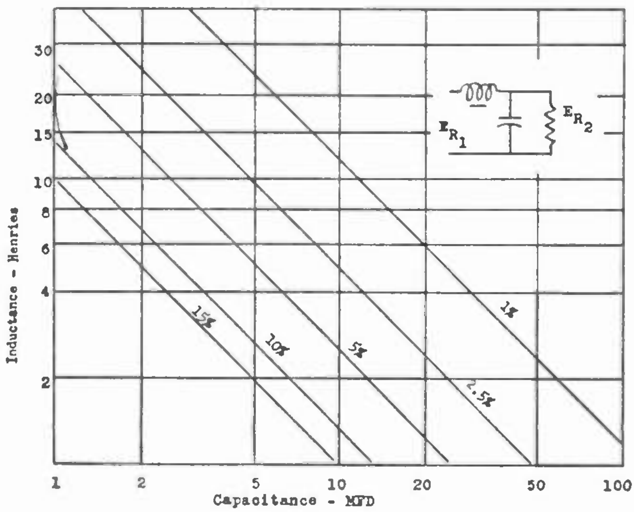


Fig. 3-16

Percent Ripple Voltage for R - C Filter

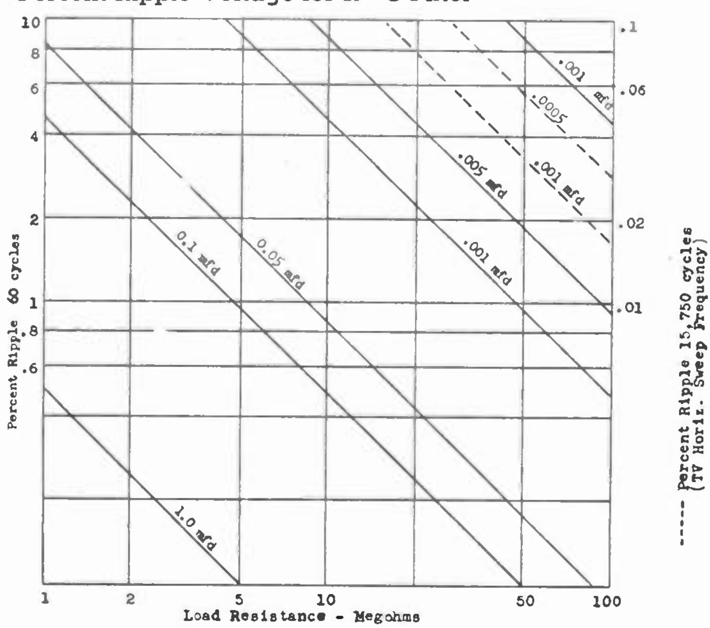


Fig. 3-17

Application continued

Resistor Input

The filtering action of a resistor-capacitor combination is shown for a 60 cycle full wave rectifier in Fig. 3-17. In most applications this type of filter is limited to low values of current (high load resistance) such as encountered in high voltage television supplies, screen, bias, and in the case of resistance coupled amplifiers, plate circuit filtering.

Component Ratings

The specification of ratings and tolerances for components employed in filter circuits is only mentioned as a reminder to the design engineer. Obviously circuit operating conditions must be anticipated and provisions made to insure reliable operation through the specification of adequate ratings and tolerances, keeping in mind the cost factor of course.

Audio Amplifier Circuits

Basic audio circuits for transformers and reactors are shown in Fig. 3-18. For the sake of completeness resistance-capacity amplifiers are also included.

Transformer Coupled

Laminated iron core audio transformers and reactors, because of their costly construction, are seldom employed for interstage applications. Some designers prefer transformer coupling from a single ended amplifier to a push-pull stage; however the trend even here appears to be in favor of resistance-coupled phase inverters. Nevertheless, transformers are required for certain types of phonograph pickups and for matching the speaker voice coil to the output stage.

Input (pickup matching) transformers usually have a fairly high step-up ratio since the source impedance (pickup unit) is generally quite low which permits the use of a relatively low primary inductance and consequently a great number of secondary turns. Core materials having a high permeability are ideal for such applications since there is no polarizing current involved. This results in a physically small unit whose field can be effectively confined within a reasonably inexpensive magnetic shield.

Input transformers should be placed as far as convenient from any source of hum. This sometimes is not a practical expedient, in which case it is good engineering practice to mount the transformer where it will minimize or buck-out the source of interference. The correct position can be determined experimentally on an actual design.

Output transformers match the plate of the output tube or tubes to the speaker voice coil and are therefore step-down transformers. Transformers for single ended amplifiers are definitely more costly than those for push-pull applications because in the latter the effect of the d-c plate current is nullified by cancellation. Push-pull is therefore recommended for applications where a high d-c plate current is involved.

The limitation in size of the output transformer is determined

Basic Audio Frequency Application

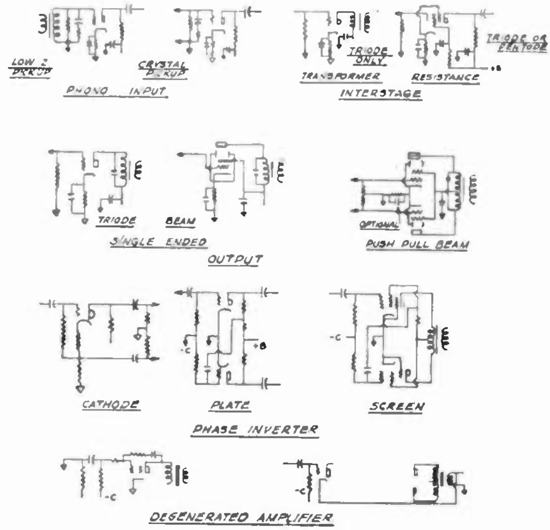
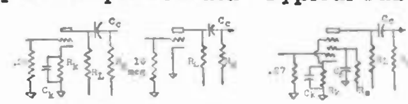


Fig. 3-18

Resistance Coupled Amplifier Data - Typical Tube Types



Self bias Zero bias
TRIODE PENTODE

$$C_c = \frac{1.6 \times 10^6}{f_1 R_g} \text{ mfd} \qquad C_k = \frac{1.6 \times 10^6}{f_1 R_k} \text{ mfd} \qquad C_s = \frac{1.6 \times 10^6}{f_1 R_s} \text{ mfd}$$

$$f_1 = \text{low frequency limit}$$

TUBE TYPE	6C5GT (triode)				7R7 (diode pentode)			
E_b	100v		250v		100v		250v	
R_L (megohm)	1 meg	.27	1 meg	.27	1 meg	.47	1 meg	.47
R_g (megohm)	.47	.47	.47	.47	.47	1.0	.47	1.0
R_k (ohm)	3900	8200	3900	[illegible]	1200	[illegible]	[illegible]	[illegible]
R_s (megohm)					.39	1.0	[illegible]	[illegible]
I_b (ma)	[illegible]	.277	[illegible]	.57	.61	.163	[illegible]	.44
E_o (volts)	[illegible]	38.7	122	[illegible]	32.5	20.5	[illegible]	[illegible]
E_{in}	.5	.5	1.0	1.0	1	1	1	1
E_{out}	[illegible]	6.7	14.25	14.1	8.9	12.5	[illegible]	[illegible]
Gain	[illegible]	13.4	14.25	14.1	89	125	[illegible]	[illegible]
% Dist.	[illegible]	1.9	1.3	1.6	4.3	3.9	2.1	3.1

TUBE TYPE	7C6 (diode triode) Zero bias				Self bias			
E_b	100v		250v		100v		250v	
R_L (megohm)	1	.47	1	.47	1	.47	1	.47
R_g (megohm)	.47	1.0	.47	1.0	.47	[illegible]	.47	1.0
R_k (ohm)					4700	[illegible]	[illegible]	[illegible]
E_o (volts)	[illegible]	63.4	[illegible]	100	84.4	65.7	[illegible]	[illegible]
E_{in}	1	1	1	1	1	1	1	1
E_{out}	[illegible]	5.37	4.12	6.75	2.9	[illegible]	[illegible]	6.52
Gain	[illegible]	[illegible]	43.2	[illegible]	[illegible]	[illegible]	[illegible]	66.2
% Dist.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7

Table 3-6

mainly by the amount of current it can dissipate due to the I^2R loss (heating) of the windings and the voltage that can be applied without saturation of the core.

Resistance-Capacity Coupling

Resistance-capacity coupling data is shown in Table 3-6 for representative type tubes; this, together with a determination of the

Application continued

operating point, provides essentially all the information required for most applications.

Operating Point

With a resistance load in the plate circuit, the plate voltage will vary with changes in plate current due to the signal. To obtain the actual operating point it is necessary to construct graphically a load line on the plate family characteristic curves. This is shown in Fig. 3-19 where the maximum plate supply voltage is (B). The load line (AB) is constructed with the slope corresponding to the required plate load resistor (100,000 in example) between the point of zero plate current-maximum voltage and the appropriate current 2.5ma. (I = E/R). Under Class A amplifier operation there is no grid current so (CD) is drawn from the intersection of the load line and the zero bias curve. This establishes the lowest instantaneous plate voltage from which the mean of the operating point can be ascertained. With the operating point established the correct bias (E) is noted and, knowing the bias voltage and corresponding plate current, it is possible to calculate the bias resistor.

SPECIFICATIONS

Before releasing specifications the engineer should methodically check the following items. At the same time it should be kept in mind that the minimum permissible specifications should be employed; unnecessary specifications only increase the manufacturing problems and the cost.

Overall dimensions—Will satisfactory clearance be obtained with transformers having maximum allowable tolerances? Have provisions been made for larger transformers (25 cycles)? Where practical specify absolute maximum rather than nominal with tolerance.

Mounting dimensions—Is the minimum allowable chassis cut-out large enough for maximum tolerance transformer? Are mounting holes of sufficient size to mount the transformer freely? Holes that are too large are as objectionable as those too small, since they may require the use of washers for satisfactory use. If threaded studs are employed, are the threads of adequate size to carry the necessary weight and the stresses encountered

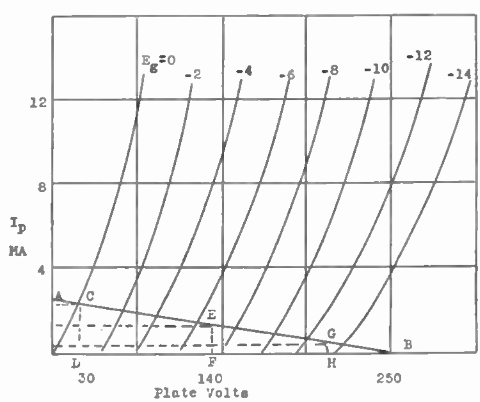


Fig. 3-19

Specification continued

in shipment? Is the length sufficient to mount properly with nut and lockwasher on the specified chassis material? Have provisions been made to accept studs that are not absolutely aligned?

Finish—Will finish meet requirements under all conditions?

Terminals—Are terminal dimensions (location and size) satisfactory from a clearance standpoint? Is spacing between terminals, and terminals to case sufficient to withstand test voltages under all conditions of operation? Will the terminal design permit easy soldering without danger of arc-over due to decreased spacing? Will the seal (hermetic) be damaged in soldering? Will the seal withstand all conditions of operation? If leads are specified, is the size, insulation and length satisfactory? Normal tolerance on average lead lengths are —0 +1/2, long leads —0 +1". Is the length of bare wire (stripping of insulation) sufficient? Normal strip and tin 7/16" + 1/16". Closer tolerances require special set-up.

Voltage & Current—Are voltages and currents satisfactory under all conditions of operation? Will breakdown or corona occur with maximum primary voltages at specified frequency? Are frequency tolerances specified? Are voltages and currents satisfactory for operation with the specified rectifier tube at maximum ambient temperature with lowest specified frequency?

Insulation Resistance—Is the minimum insulation resistance sufficient (between windings, and windings to case) to prevent damage to the unit or other components under specified conditions of humidity?

Temperature Rise—Will the transformer withstand the maximum allowable temperature rise at the highest required ambient temperature and operating voltage without excessive softening or leakage of the impregnant?

Special Requirements—Have all other requirements such as, electrostatic shield, grounded core, capacity, inductance, core loss, excitation current and leakage reactance been specified? Have all service conditions such as altitude, humidity, temperature, shock and vibra-

Specifications — TRANSFORMERS & REACTORS — power and audio frequencies

PHYSICAL	Windings	ELECTRICAL	GENERAL
Dimensions	Wire size	**Voltage & Current**	
Overall	Insulation	Tolerance	**Underwriters'**
Mounting	Turns	**Efficiency & Response** (min)	
Type	Location	**Frequency**	**Ambient Temperature**
Open		**Inductance** (min)	
Encased	**Iron**	**Capacitance** (max)	**Temperature Rise**
Material	Grade	Distributed	
Hermetic sealed	Stacking	Between windings	**Humidity-Altitude**
Mounting	Quantity	**Voltage Breakdown**	
Vertical	Dimensions	Between windings	**Mechanical Hum**
Horizontal		To core or case	
Pierced flange	**Impregnation**	**Leakage Resistance** (min)	**Electrostatic Shield**
Inserts	Vacuum	Between windings	
Clamps	Dip	Windings to case	**Grounded Core**
Studs	Pot	**Core Loss** (max)	
Terminals	Oil	**Excitation Current** (max)	
Location	Wax	**Leakage Reactance** (max)	
Leads	Bituminous		
Length	**Finish**		
Size & insulation			
Skin & tin			
Lugs			
Dimensions			

Table 3-8

Size B & S Gauge	Diameter Min.	Diameter NOm.	Diameter Max.	Area Cir. Mils.	Layer Insul.	Turns per in.	Square	Margin 200% Rect.	Size B & S Gauge
PLAIN ENAMEL WIRE CHART*									
10	.1024	.1039	.1054	10400.	.010 K	9.	.2500	.2500	10
11	.0913	.0927	.0941	8230.	.010 K	10.	.2500	.2500	11
12	.0814	.0827	.0840	6530.	.010 K	11.	.2500	.2500	12
13	.0726	.0739	.0750	5180.	.010 K	12.	.2500	.2500	13
14	.0648	.0660	.0670	4110.	.010 K	14.	.2500	.2500	14
15	.0578	.0589	.0598	3260.	.010 K	15.	.2500	.2500	15
16	.0515	.0525	.0534	2580.	.007 K	17.	.1875	.2187	16
17	.0460	.0469	.0477	2050.	.007 K	19.	.1875	.2187	17
18	.0410	.0418	.0426	1620.	.007 K	22.	.1875	.1875	18
19	.0366	.0374	.0381	1290.	.005 K	24.	.1562	.1875	19
20	.0326	.0334	.0341	1020.	.005 K	27.	.1562	.1875	20
21	.0292	.0299	.0305	810.	.005 K	30.	.1562	.1875	21
22	.0261	.0266	.0273	642.	.003 K	34.	.1250	.1562	22
23	.0232	.0239	.0244	510.	.003 K	38.	.1250	.1562	23
24	.0208	.0213	.0218	404.	.002 G	42.	.1250	.1562	24
25	.0186	.0190	.0195	320.	.002 G	47.	.1250	.1562	25
26	.0166	.0170	.0174	254.	.002 G	53.	.1250	.1562	26
27	.0148	.0152	.0156	202.	.0015 G	59.	.1250	.1562	27
28	.0132	.0136	.0140	160.	.0015 G	65.	.1250	.1562	28
29	.0118	.0122	.0126	127.	.0015 G	73.	.1250	.1562	29
30	.0105	.0109	.0112	101.	.001 G	82.	.1250	.1562	30
31	.0094	.0097	.0100	79.7	.001 G	91.	.1250	.1250	31
32	.0085	.0088	.0091	63.2	.001 G	101.	.0937	.1250	32
33	.0075	.0078	.0081	50.1	.001 G	114.	.0937	.1250	33
34	.0067	.0069	.0072	39.8	.001 G	128.	.0937	.1250	34
35	.0059	.0062	.0064	31.5	.001 G	142.	.0937	.1250	35
36	.0053	.0055	.0058	25.0	.001 G	158.	.0937	.1250	36
37	.0047	.0050	.0052	19.8	.001 G	174.	.0937	.1250	37
38	.0042	.0044	.0047	15.7	.001 G	198.	.0625	.1250	38
39	.0036	.0039	.0041	12.5	.0007 G	220.	.0625	.0937	39
40	.0032	.0034	.0037	9.89	.0007 G	246.	.0625	.0937	40
41	.0029	.0031	.0033	7.84	.0007 G	274.	.0625	.0937	41
42	.0026	.0028	.0030	6.22	.0005 G	304.	.0625	.0937	42

* Courtesy Foster Transformer Company

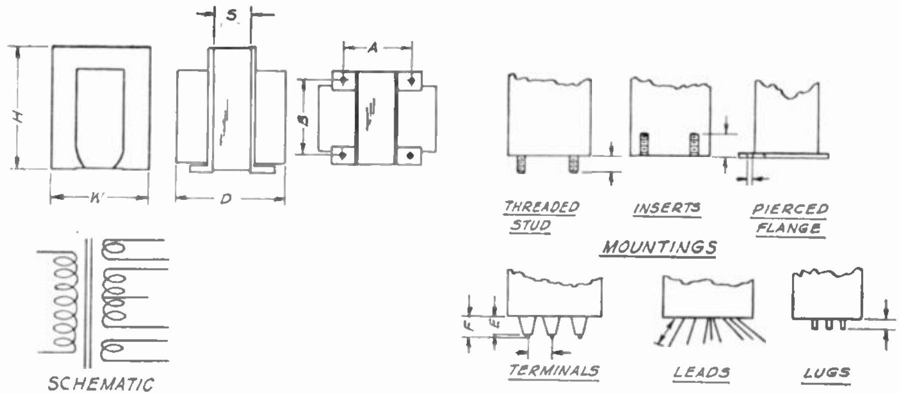
PLAIN ENAMEL WIRE CHART

Size B & S Gauge	lbs. per. 1,000 feet	feet per lb.	(1) ohms per 1,000 feet	(1) feet per ohm	(1) ohms per lb.	(1-2) ohms per cubic in.	(2) turns per square in.	Size B & S Gauge
10	31.4	31.8	.999	1000.	.0318	.00584	70.	10
11	24.9	40.1	1.26	794.	.0505	.00904	86.	11
12	19.8	50.6	1.59	630.	.0804	.0139	105.	12
13	15.7	63.8	2.00	499.	.128	.0210	126.	13
14	12.4	80.4	2.53	396.	.203	.0341	162.	14
15	9.86	101.	3.18	314.	.323	.05075	191.	15
16	7.82	128.	4.02	249.	514	.0797	238.	16
17	6.20	161.	5.06	198.	.817	1305	310.	17
18	4.92	203.	6.39	157.	1.30	.21	398.	18
19	3.90	257.	8.05	124.	2.07	.318	473.	19
20	3.09	323.	10.2	98.5	3.28	.526	621.	20
21	2.45	408.	12.8	78.1	5.22	.800	750.	21
22	1.94	512.	16.1	62.0	8.30	1.275	952.	22
23	1.54	648.	20.4	49.1	13.20	1.935	1140.	23
24	1.22	818.	25.7	39.0	21.0	3.41	1598.	24
25	.970	1030.	32.4	30.9	33.4	5.325	1974.	25
26	.769	1300.	40.8	24.5	53.1	8.140	2392.	26
27	.610	1640.	51.5	19.4	84.4	12.79	3009.	27
28	.484	2070.	64.9	15.4	134.	21.05	3894.	28
29	.384	2610.	81.8	12.2	213.	32.81	4745.	29
30	.304	3290.	103.	9.69	339.	50.90	5904.	30
31	.241	4150.	130.	7.69	539.	77.85	7189.	31
32	.191	5230.	164.	6.10	858.	121.4	8888.	32
33	.152	6890.	207.	4.83	1360.	192.5	11172.	33
34	.120	8310.	261.	3.83	2170.	312.3	14336.	34
35	.0954	10500.	329.	3.04	3460.	475.	17324.	35
36	.0757	13200.	415.	2.41	5480.	729.	21330.	36
37	.0600	16700.	523.	1.91	8720.	1110.	25404.	37
38	.0476	21000.	660.	1.52	13900.	1750.	31878.	38
39	.0377	26500.	832.	1.20	22000.	2920.	42020.	39
40	.0299	33400.	1050.	.953	35000.	4480	51168.	40
41	.0237	42000.	1350.	.763	54000.	6860.	62746.	41
42	.0188	52800.	1680.	.605	87400.	10390.	75392.	42

(1) Resistance at 20° C
(2) Layer insulated coils using proper thickness paper

Table 3-7

Typical Transformer Specification



PART Nº.	DIMENSIONS					MOUNTING		TERMINAL LEADS						CORE				VOLTAGE BREAKDOWN		LEAKAGE RESISTANCE	
	H	W	D	A	B	C	THREAD	E	F	1	2	3	ETC	S	GRADE	GAGE	STACTING	WIND TO WIND	WIND TO CORE	WIND TO WIND	WIND TO CORE

WINDING	LOCATION	INDUCTANCE	TURNS	WIRE	CORE LOSS	EXCITATION CURRENT	TEMP RISE	OPER FREQ	EFF %	ALTITUDE	TEMP RANGE	IMPREGNATION	MECH HUM	FINISH	VOLTAGE TOLERANCE
PRIMARY															
SECONDARY															

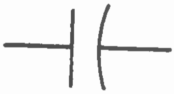
Fig. 3-20

Specification continued

tion, mechanical hum and Underwriters' requirements been considered? Has an actual sample been operated satisfactorily in the proposed design?

Drawing—Does the outline drawing show necessary information as to type, impregnation, winding and core data?

CAPACITORS
FIXED



DESIGN

Three types of fixed capacitors are generally employed in present day designs; (1) molded mica, (2) ceramic and (3) paper. Cross-sectional views of typical prototypes are shown in Fig. 4-1.

Molded Mica Design

The molded mica dielectric capacitor is available in two types; those having foil conducting plates and those which employ a metal coated dielectric film. Both are relatively small physically, have high leakage resistance, and medium to good Q. In addition the coated film (so called plated mica) type has excellent stability characteristics with variations in temperature and humidity and due to the method of fabrication is adaptable to close tolerance applications. Since both types are so nearly alike in construction their design will be discussed concurrently as far as possible.

Schematically the capacitor may be represented by the equivalent circuit shown in Fig. 4-2 where L represents the residual inductance, R the effective series resistance (loss in the metallic structure), G the effective parallel conductance (dielectric loss) and C the true capacitance. The capacitance remains practically constant over a wide frequency range, deviating only as the insulating material approaches its transition point. The dielectric loss is seldom serious below 10 megacycles but increases with frequency depending on the quality of the material employed. The metallic loss (eddy current in the conducting material and skin effect) is also negligible at low frequencies but becomes comparable to that introduced by the dielectric as the frequency is increased.

Cross Sectional View - Fixed Capacitors

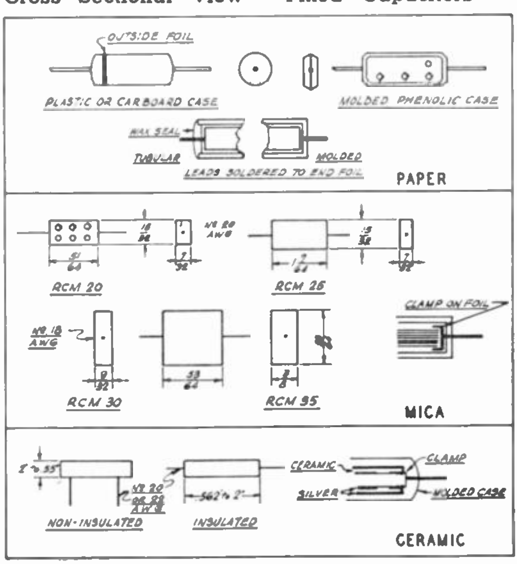


Fig. 4-1

Mica, while a most efficient dielectric under dry conditions, is not impervious to moisture. During the process of manufacture precautions must be taken to keep both the dielectric and electrodes dry. Even a thin film of moisture will seriously affect the quality of the unit.

The foil type of construction is subject to another variation due to unavoidable air pockets between the plates and the dielectric. Unless the mold-

Design continued

ing pressure is quite high when the units are cased these air pockets expand to such an extent that the capacitance decreases. The ordinary "brown" bakelite case requires a high molding pressure with the result that the temperature coefficient is positive, due to the normal expansion of the materials alone; on the other hand most of the low-loss insulators require a lower molding pressure, which accounts for the generally negative temperature coefficient of this type capacitor.

Fixed Capacitor - Equivalent Circuit

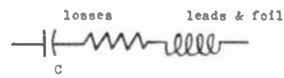


Fig. 4-2

Recognizing these inherent limitations in design the so called "plated mica" capacitor was developed wherein the conducting electrodes are plated or sprayed on the dielectric film. With such an intimate contact existing between the electrode and the dielectric the possibility of air pockets or moisture between them is eliminated. Since the physical expansion of the mica is nearly balanced by its change in dielectric constant an extremely stable capacitor results. The remaining problem is one of minimizing surface leakage on the case and can be effectively solved by an external application of wax or equivalent treatment. This not only serves to minimize surface leakage but by sealing the leads, moisture is prevented from entering the unit.

Typical characteristics are grouped in Fig. 4-3.

APPLICATION

Fixed mica dielectric capacitors of the foil type are available with tolerances of ±2, 5, 10 and 20 percent while the metallic coated film type are available with tolerances of ±1, 2, 5, 10, and 20 percent. The stability and Q can also be specified when these characteristics are important. The greater the allowable tolerance, the lower the cost, and obviously each application should be considered from this viewpoint. Applications requiring tolerances other than those considered as standard by the manufacturer becomes a special problem to all concerned and their cost is increased accordingly.

A factor often overlooked in the application of mica or other type fixed capacitors is the series resonant effect. The type construction, physical size and capacitance together with the lead inductance

Standard Voltage Ratings

100
200
400
600
1000
1500

Tolerances

From but not including	Tolerance %	
0 to 0.002 mf	—25, +60	STANDARD
0.002 to 0.01	—15, +40	
0.01 to 0.1	—20, +20	
0.1 and up	—10, +20	
Any	—10, +10	OTHER
	—15, +15	
	—20, +20	
	— 0, +25	
	—15, +40	
	—25, +60	

Table 4-1

Characteristics - Mica Dielectric Capacitor

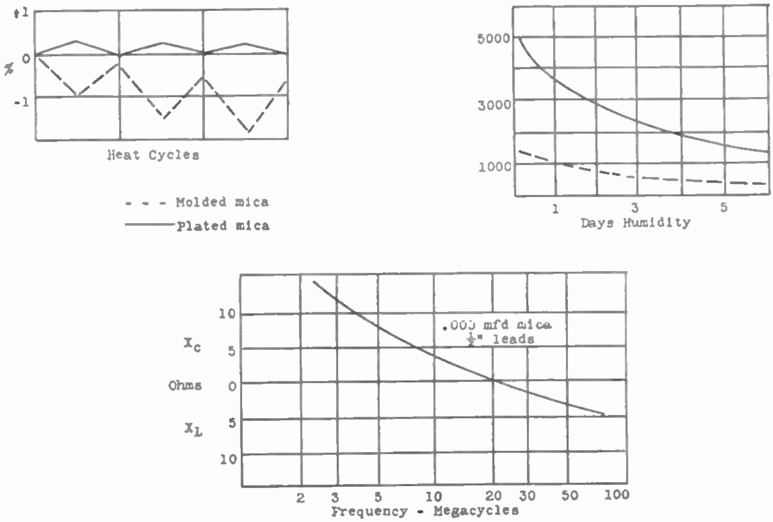


Fig. 4-3

(inside and outside the case) determine the series resonant point. A curve of resonant frequency versus lead length for a representative molded capacitor is shown in Fig. 4-4. These factors should be taken into consideration, particularly in applications where it is desirable to maintain a common r-f potential at several physically separated points. Considering the necessary lead lengths involved, the highest capacitance unit which resonates at the desired frequency should be employed.

Capacitor Resonance

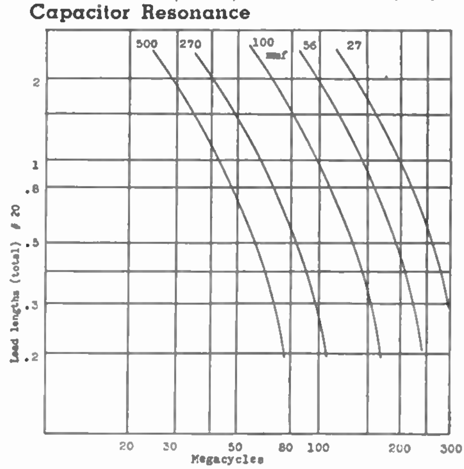


Fig. 4-4

Coupling capacitors isolating d-c potentials, such as the plate and the grid of succeeding tubes, require a high value of leakage resistance. If under conditions of high humidity even a minute amount of current flows across the capacitor the grid potential of the latter tube may be changed to such an extent that abnormal operation results. This is especially true in cases where a high d-c resistance, such as an AVC decoupling resistor, completes the path to

Typical Capacitor Impregnants

Impregnant	Maximum required Insulation Resistance	Minimum Meg x mf	Cap. change at °C 25°C normal		Maximum °C
Oil					
Mineral	6000	2000	—15%	—55°	+85
Synthetic	4500	1500	—30%	—55°	—
Vegetable	1500	500	—30%	—55°	+85
Wax	6000	2000	—10%	—20°	+60

Table 4-2

Typical Paper Dielectric Capacitor Applications

BY-PASS	
1.0 mfd (non-inductive) 1" leads	500 KC
0.1 mfd (non-inductive) 1" leads	15 MC
0.01 mfd (non-inductive) 1" leads	10 MC
0.1 to 10 mfd (inductive)	1000 cycles
TONE CONTROL	
0.001 to 0.03 mfd	
AUDIO COUPLING	
0.001 to 0.1 mfd.	

Table 4-3

Standard Physical Dimensions - Paper Tubular Capacitors

Capacity	Voltage Rating —30°C to +70°C					
MFD	100	200	400	600	1000	1600
0.001				⅜x1	⅜x1¼	7/16x1¼
0.002				⅜x1¼	⅜x1¼	7/16x1¼
0.003				⅜x1¼	⅜x1¼	7/16x1⅝
0.005				⅜x1¼	7/16x1¼	½x1⅝
0.01	⅜x1¼	⅜x1¼	⅜x1¼	7/16x1¼	7/16x1⅝	9/16x1⅝
0.02	⅜x1¼	⅜x1¼	7/16x1¼	7/16x1⅝	½x1⅝	¾x2⅛
0.03	⅜x1¼	⅜x1¼	7/16x1⅝	½x1⅝	⅝x1⅝	⅞x2⅛
0.05	7/16x1¼	7/16x1¼	7/16x1⅝	½x1⅝	⅝x1⅝	⅞x2⅛
0.10	7/16x1½	½x1⅝	9/16x1⅝	⅝x2	¾x2	
0.15	½x1⅝	9/16x1¾	⅝x1¾	¾x2	13/16x2½	1⅛x2½
0.25	9/16x1¾	⅝x1¾	11/16x2 13/16	13/16x2½		
0.50	⅝x2	¾x2	⅞x2	1x2⅝		
1.0	⅞x2	13/16x2½	1x2½			

Table 4-4

Application continued

ground. Such applications require the use of wax or other impregnations to break up the moisture film path.

Occasionally it is necessary to employ a small fixed capacitor as part of a tuned circuit. The main considerations then become stability and Q, depending of course on the operating frequency and the ratio of the fixed capacitor capacitance to the remainder of the circuit.

Fixed Ceramic Capacitors

DESIGN

Fixed ceramic dielectric capacitors consist usually of titanium dioxide dielectric separating two fired silver plates. Titanium dioxide has a dielectric constant of approximately 85 and is characterized by its negative temperature coefficient. By combining the titanium dioxide with other ceramics any desired temperature coefficient may be obtained between approximately 1.2×10^{-4} to -33×10^{-4} per degree centigrade temperature change.

With the silver plates in intimate contact with the surface of the ceramic there is little possibility of air pockets between them. This gives an inherently stable design. Axial or radial leads are available and are soldered to the silver conducting plates. Units may be sealed against effects of humidity by enclosing the capacitor in plastic or ceramic cases and treating with a wax or other suitable impregnant. Maximum capacitance values are obtained with a high dielectric constant which corresponds to a high negative temperature coefficient. As the temperature coefficient is made more positive the maximum capacitance for a given physical size is decreased.

Assuming the conducting plates are properly fired and the ceramic mix is correct the main design consideration is the outer case. Most designers prefer the enclosed axial lead type as there is less possibility for shorts to other components in case the outer insulator is damaged.

APPLICATION

Fixed ceramic dielectric capacitors are useful as direct substitutes for mica capacitors in most applications. They are particularly applicable in tuned circuits where it is desirable to compensate for the positive tem-

Characteristics—Typical Ceramic

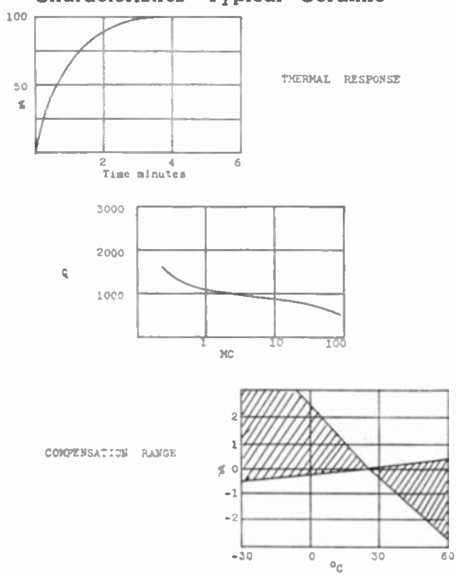


Fig. 4-5

Application continued

perature coefficient of other parts with changes in operating or ambient temperature. The correction time is dependent on the location and should be such as to duplicate the thermal change of the main part being compensated.

Typical operating characteristics are shown in Fig. 4-5 and are self explanatory. Color coding is generally applied to indicate the characteristic and capacitance as shown in Fig. 4-6.

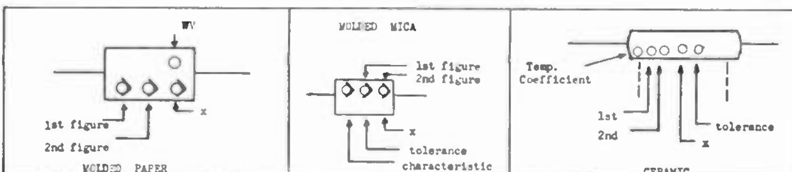
Ceramic capacitors up to 0.01 mfd are available for applications where temperature compensation is not a factor. These are quite similar in construction in that they have permanently bonded electrodes and are physically small. The dielectric constant is of the order of 1200. Units are available with tolerances of ±10 and 20 percent and because of their small size are particularly useful for high frequency bypass applications. Phenolic or wax impregnation is optional according to humidity requirements.

Paper Dielectric

The paper dielectric capacitor usually consists of two thin metallic foils separated by two or more plies of special capacitor tissue to prevent possible weak spots or metallic particles from coinciding and shorting or weakening the capacitor. The conductor and dielectric are rolled into a compact cylindrical form, impregnated and enclosed in a suitable case. Case constructions vary with the application requirements. Cardboard tubular cases are adequate for most general applications. Where extremely low leakage is required, sealed metal or molded bakelite or plastic cases are recommended.

Paper is used as the insulator although it contributes an appreci-

Capacitor Color Coding



COLOR	SIGNIF. FIGURE	X	W.V.	X	TOLERANCE	CHAR.	TEMP. COEFF. PTS/MIL/°C	X	TOLERANCE 10 or less	TOLERANCE Over 10
BLACK	0	1		1	20	A	0	1		±20
BROWN	1	10	120	10	1	B	-30	10	±.1 mmf	±1
RED	2	100	200	100	2	C	-80	100		±2
ORANGE	3	1000	300	1000	3	D	-150	1000		±2.5
YELLOW	4	10000	400	10000		E	-222	10000		
GREEN	5		500		5		-330		±.5	±5
BLUE	6		600				-470			
VIOLET	7						-750			
GRAY	8		800			I	-30	0.01	±.25	
WHITE	9					J	-120 -750	0.1	±1	±10
GOLD		0.1	1000	0.1						
SILVER				0.01	10					

Fig. 4-6

Design continued

able loss, due to dielectric hysteresis, when subjected to alternating currents. The loss appears in the form of heat which results in an increase in power factor, which in turn further increases the loss so that the effect is cumulative.

Temperature

The dielectric strength of paper capacitors decreases with an increase in temperature, for this reason capacitors for continuous service require a higher rating than those employed intermittently. Operating temperatures depend to a large extent on the impregnation; mineral oil, castor or synthetic oil and wax are preferred in the order named. Rated voltage is generally based on a maximum ambient temperature of 40°C; operating temperatures exceeding this value require that a derating factor be applied to the capacitor.

Tolerance

Although tolerances are not of major importance in most applications, common usage has resulted in the adoption of certain standards as representative of good engineering practice. These are shown in Table 4-1. Other tolerances are commercially available but are not recommended except for special applications.

Voltage Rating

Voltage ratings have also been standardized by general usage as shown in Table 4-1. These are based on the supposition that the dielectric will withstand 250 percent (d-c) of normal rated voltage for a period of not more than one minute with a maximum charging current of 50 ma.

Insulation Resistance

From a practical standpoint insulation resistance is generally unimportant since modern manufacturing methods are such that the minimum value rarely is less than 250 megohms under rather extreme operating conditions. When it is considered that in most applications the capacitor bypasses resistors of not more than three to five megohms, and usually a much lower value, the effect of normal insulation resistance is neglible. Typical values for the various commonly used impregnants are given in Table 4-2.

Power Factor

The primary function of a capacitor is to provide a low impedance path for alternating currents of a definite frequency. This requirement is satisfied as long as the impedance is below a specified value, which incidentally is substantially dependent on the capacitive reactance and not the power factor. For this reason the power factor is of little importance except as it affects the operating temperature of the unit.

Most fixed paper capacitors are wound or rolled non-inductively; that is, the foil extends to the edge of the paper and the connecting

Design continued

leads are soldered to the entire edge of the foil instead of to one end. Such construction is preferable for high frequency operation since the inductance is minimized; the result is a higher resonant frequency.

High frequency applications require a high series resonance. With ordinary type construction a 0.1 mfd capacitor with $1\frac{1}{2}$ inch leads may resonate as low as two megacycles. Resonance may be practically eliminated by the use of a three-terminal type construction as shown in Fig. 4-1.

Characteristics - Paper Dielectric Capacitors

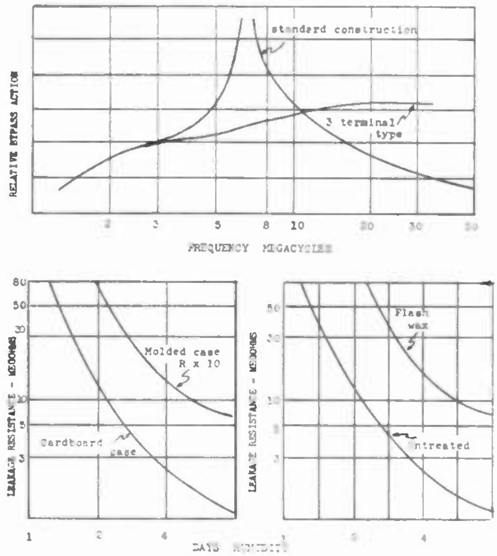


Fig. 4-7

Three-Terminal Capacitors

The three terminal type of anti-resonant capacitor physically resembles the ordinary commercial design except for the third lead. The design is such that it simulates a long transmission line by making one conducting foil inductive (ground terminal) and the other non-inductive. Capacitors of this construction exhibit a uniformly decreasing impedance characteristic up to at least 100 megacycles. Normal circuit current flows through the non-inductive winding and therefore must be considered in the design of the unit. Typical characteristics are shown in Fig. 4-7.

Metalized Paper

The metalized paper capacitor is characterized by its small physical size. Instead of the conventional paper and foil construction a metalized paper is employed which is obtained by applying aluminum to the dielectric by means of a high-vacuum vaporization process. The use of an aluminum film, which will upon breakdown form aluminum oxide, (an excellent insulator) makes the unit self-healing. However if the unit is subjected to voltage breakdown long enough the capacitance would eventually disappear. To prevent this from occurring it is necessary to derate the working voltage for applications involving high temperatures. Two working voltages are generally specified, one at normal ambient temperature and the other at maximum operating temperature with the latter depending on impregnation.

Insulation resistance and power factor are comparable to conventional paper-foil designs.

APPLICATION

The application of fixed paper capacitors involves the choice of a suitable type to satisfy the following major requirements.

1. Small physical size.
2. Low impedance at the operating frequency.
3. Adequate safety factor against breakdown under all operating conditions.

Non-inductive capacitors should be wired with the outside foil (usually marked) connected to ground or the low potential part of the circuit. This takes advantage of the possible shielding effect afforded by the outside foil and is good engineering practice.

In many instances, particularly where the capacity required is greater than 1000 mmf it is feasible to employ a paper tubular capacitor instead of a mica without degrading performance. Obviously this is advantageous from a cost standpoint.

Typical applications are summarized in Table 4-3 and shown schematically in Fig. 4-8.

SPECIFICATIONS

Specifications are outlined on the specification data sheet and in general are self-explanatory. It is not necessary to specify each item since some do not apply for all applications and others when established for a particular design do not vary with production. The following are generally accepted as standard by the industry.

Dielectric strength is measured at 250 percent of rated working voltage and must withstand applied voltage for a period of not more than one minute.

Insulation resistance is seldom a factor to be considered for most applications. It should however exceed 5000 megohms at 25°C as measured with a minimum of 100 volts d-c at a relative humidity of less than 80 percent.

Power factor at 1000 cycles should be one percent or less for capacitors having a mineral oil impregnation and two percent or less for other impregnants.

SPECIFICATIONS CAPACITORS—fixed

PHYSICAL

- **Type**
  - Paper
  - Mica
  - Ceramic
- **Dimensions**
  - Overall
  - Mounting
- **Terminals**
  - Leads
    - Length
  - Lugs
    - Type
- **Impregnation**
  - Wax
  - Oil
    - Mineral
    - Synthetic
    - Vegetable
- **Hermetic Seal**

GENERAL

- **Temperature**
  - Range
- **Humidity**
- **Life**
- **Altitude**

ELECTRICAL

- **Capacitance**
  - Tolerance
- **Power Factor - Q**
  - Frequency
- **Insulation Resistance**
  - Terminal to terminal
  - Terminal to case
- **Compensation**
  - Range
- **Stability**
  - Temperature coefficient
  - Retrace
- **Voltage Breakdown**
  - Temperature
  - Humidity
  - Altitude

Table 4-5

VARIABLE CAPACITORS

DESIGN

VARIABLE CAPACITORS

General Considerations

Variable air-dielectric capacitors are characterized by relatively low losses or high Q at radio frequencies. This may be attributed to the fact that air is a nearly perfect dielectric medium and since the major portion of the dielectric is air the losses are low. There are, however, other factors which contribute to the losses and these will be discussed with particular reference to variations with frequency.

In addition to the variations with frequency other characteristics such as curve shape, tracking between sections, stability with changes in temperature and humidity, low rotational torque, smooth action, mechanical strength and non-microphonic construction are desired. Although not a characteristic, cost is a very important item and should be carefully considered in any design. Factors influencing these characteristics, particularly with reference to operating frequency are basic in design.

Electrical Considerations

Capacitance

The capacitance of a parallel plate air-dielectric capacitor can be calculated from the equation:

$$C = 0.2246 \frac{(N-1)A}{d} \text{ mmf}$$

where A is the effective area of one plate in square inches, d the spacing between adjacent plates in inches and N the total number of plates. The equation holds for any plate shape as long as both rotor and stator plates are equal in area. It should be pointed out that calculations of plate shape for a specific capacity curve are only approximate due to so called "fringe effect" which varies with the spacing between plates. After a preliminary sample is completed according to the design equation the judicious use of a file to correct small variations in the curve is generally required before the final plate design is obtained.

Typical capacitance versus angular rotation curves are shown in Fig. 5-1.

Typical Curve Shapes—Capacitance versus rotor rotation.

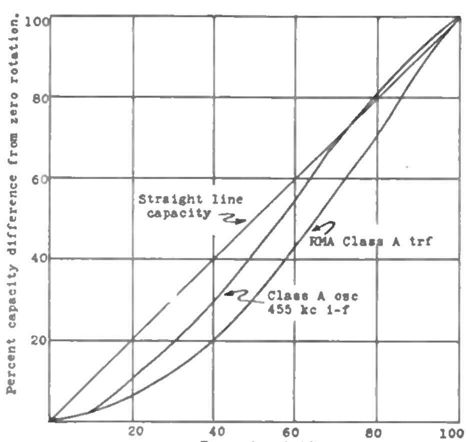


Fig. 5-1

Figure of Merit (Q)

The figure of merit, commonly expressed as Q, is inversely proportional to the resistance or loss determining quantity of a capaci-

Design continued

tor and can be represented by the equation $Q = 1/\omega CR$. From this it is evident that the resistance or loss-determining factor should be minimized for good design.

Residual Parameters

Two residual parameters, inductance (due to the magnetic field set up by conduction currents) and resistance (a combination of losses caused by eddy currents in the metallic structure and hysteresis loss in the dielectric) determine to a large extent the magnitude of the Q over a range of frequencies.

Residual Inductance

The residual inductance is the result of current dividing at the stator plate support and flowing out through the stator plates and back to the rotor plates. Since the current sets up a magnetic flux an inductive reactance results. The current in and between the plates contributes little to the inductance (the area involved is relatively large). It would appear then that the residual inductance might be a constant at a given angular degree of rotation for a particular design, but as the angular rotation changes (assume capacitance decreases and frequency increases) the inductive reactance obviously increases which results in an apparently higher capacity than that ordinarily expected.

The inductance may be decreased by the use of additional rotor wipers. Standard practice is to specify a spring brass wiper for each section in the capacitor. They should preferably be short in length and soldered to the frame for maximum effect. Some designers prefer the so called "V" type wiper which provides a short ground path between the rotor sections and the frame or internal shields. External connections are then made directly to a convenient spot on the shield.

Residual Resistance

As mentioned previously the residual resistance is the result of eddy current loss in the metal parts and hysteresis loss in the dielectric. The former occurs in the plates, plate staking, rotor shaft, bearings, wipers, in fact in any part of the metallic structure in which current flows. The major portion is contributed by the contact resistance at the rotor wipers and in the case of grounded rotor designs the resistance through the shaft bearings. Being essentially constant for any angular degree of rotation these losses remain fixed for a particular design. The variable eddy current losses (variable with frequency) are attributed to skin effect and can be minimized by silver plating of the metal parts. These are usually negligible for low and medium operating frequencies.

Because the insulating supports required in a variable capacitor are of necessity within the electric field a hysteresis loss occurs. Assuming the dielectric is in a field which does not vary with the rotor setting (most designs are essentially thus) the loss is constant at any given frequency. Obviously as the frequency increases the loss increases depend-

Proposed Capacitance Characteristics Class A Capacitors

Rotor Position (Percent rotation)	Change in Capacitance from zero — TRF Plates	Oscillator Plates
0	0	0
10	9.4	7.3
20	33.7	29.1
25	47.9	41.8
30	63.6	55.1
40	101.9	84.5
50	154.6	119.0
60	222.6	157.5
70	299.9	196.8
75	340.1	215.4
80	380.4	232.4
90	461.3	262.5
100	530.0	285.2

Values are for 24 dielectrics: 12 stator and 13 rotor plates TRF; 20 dielectrics: 10 stator and 11 rotor plates Oscillator. The capacitance for other dielectrics may be obtained by the proportionality of capacitance to the number of dielectrics. The mechanical maximum position is considered 100 percent rotation. For zero rotation the rotor is displaced 180° from its 100 percent position.

Number of Plates	Minimum Capacitance (not more than uuf below) TRF	Oscillator
25	15.0	
23	14.0	
21	13.5	13.0
19	13.0	12.0
17	12.5	11.5
15		11.0
13		10.5
11		10.0

Table 5-1

ing upon the quality of the material. In the choice of a suitable insulating material several factors such as dielectric constant, power factor, mechanical stability and variations with temperature and humidity and physical strength are significant. It is not always advisable to choose the lowest loss material unless the material also has good mechanical properties.

In other words the effective insulation of a variable capacitor cannot be judged solely by the electrical quality of the material. Some materials, although relatively poor electrically but because of their good physical characteristics make excellent capacitor insulators. This apparent contradiction to theory is due to the fact that the volume of the insulation required is smaller than if the higher electrical grade material was employed. The loss per unit of volume may be higher but since less material is required the total loss may actually be less. Mechanically strong insulation permits the use of designs having long leakage paths which result in low surface leakage.

The surface of the material has a direct bearing on its characteristics when subjected to high humidity. Porous materials not only absorb moisture but under certain conditions tend to "wet" easily. This is an undesirable condition since the conductivity of even a thin film of moisture is appreciable. The problem is to obtain a surface which will not wet.

Wax and some of the silicone resins are excellent examples of surfaces that do not wet easily. Here the water vapor collects in small discrete globules which do little harm. The application of moisture repellent substances is therefore advisable. Any leakage resulting from

Design continued

the use of inferior insulating materials or lack of treatment represents a loss which when subjected to high frequency currents decrease the Q.

Mechanical Considerations

Three major mechanical requirements should be satisfied in the design of a variable capacitor, (1) the frame should be sturdy to prevent distortion when mounted, (2) the action should be smooth and have low rotational torque, (3) means should be provided for aligning the capacity curve to a predetermined standard with a specified tolerance between sections.

Frame Structure

The first requirement is satisfactorily accomplished by using a bar type construction. In such a design a relatively heavy bar of either round, square or flat stock is securely staked to the end plates or frame. A bent, one-piece frame is sometimes employed but this lacks the necessary desired rigidity for good design.

Torque

The second requirement, smooth action and low rotational torque depends mainly on the bearing design and number of rotor wipers. Usually the front bearing design is of the ball type, while the rear is of the thrust type with a single ball adjustable for torque.

Plate Structure

Alignment of the capacity curve is readily accomplished if the spacing between plates is adequate and radial slots provided in the outside rotor plates. Plate spacings less than 0.010 inches are definitely not recommended because of the difficulty in alignment and the greater possibilities for microphonism.

Aluminum is nearly always employed as the plate material although brass, steel and copper are sometimes

Characteristics - Typical Variable Capacitor showing effects of temperature and humidity

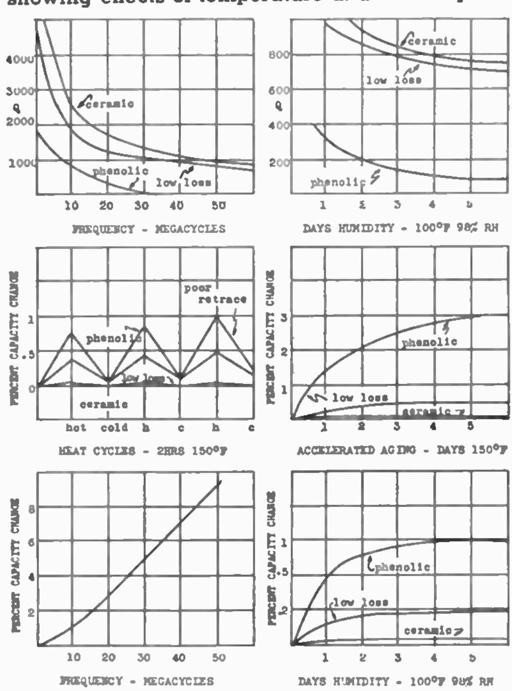


Fig. 5-2

Design continued

used. Aluminum and copper because of their deadness are generally preferred from a microphonic standpoint.

Characteristics

In general a well designed air-dielectric capacitor has an excellent temperature characteristic. Several factors influence this, probably the most important being the choice of materials. The coefficient of expansion or elongation of the metal parts, for instance, is of prime importance. No fixed rules exist whereby specific materials should be employed for specific parts. Each design must be individually studied to determine the source of error and corrective measures taken to either minimize or compensate for the deficiency.

Typical characteristic curves under normal and various operating conditions of temperature and humidity are shown in Fig. 5-2. The figure of merit curve shows how the Q varies over a wide range of frequencies. Note particularly the rather abrupt change above ten megacycles and the variations between capacitors employing different insulating materials. Obviously the quality of the insulation is of prime importance. The same conclusion will be reached by inspecting the Q versus humidity curve.

The capacitance change versus temperature illustrates two effects: the change due to temperature alone and the retrace characteristic. These variations, as pointed out previously, are the result of minute changes in physical dimensions, that is variations in plate area, spacing and dielectric. The retrace characteristic has intentionally been exaggerated to show the effect of aging of the dielectric. This is particularly important when the capacitor is used in a mechanical or electric driven push button tuner.

APPLICATION

Most receiver applications require that several circuits be tuned simultaneously and that the resonant frequency of the circuits align or track properly throughout the entire angular rotation of the unit. Furthermore the capacity versus angular rotation must follow, within reasonable tolerances, a prescribed curve shape and be capable of being reset to any desired point with accuracy.

Good and Bad Practice

Assuming the capacitor is according to specifications when received; unless it is mounted correctly in the chassis the curve shape and alignment may be affected. The application of a variable capacitor to a new design requires the observance of a few simple precautions.

Never solid mount a variable capacitor at both ends of its frame. Unavoidable production tolerances make it highly improbable that the mounting surfaces will be absolutely parallel or plane and with all mounting holes centered. In mounting, either the chassis or the capacitor or both will be under a strain and any twisting of the capacitor frame will shift the plate alignment.

Application continued

Mounting the capacitor with three screws into one plane surface (bottom, first choice; front end, second choice) is recommended to avoid any possible frame distortion. Even this may not always be satisfactory so it is standard practice to include a "horseshoe" or "U" cutout in the chassis around one mounting hole. This intentionally weakens the chassis at the third mounting point so that only two screws are effective in locating and establishing the plane of the capacitor with respect to the chassis. The third screw serves only as a hold-down and does not distort the frame because of the flexibility of the mounting. Frame distortion can also be minimized by the use of rubber grom mets and spacers to mechanically isolate the unit from the chassis. This also decreases the possibility of microphonism and is to be recommended.

Microphonism may be further decreased by the use of dead soft copper for the plate material in place of aluminum. Steel and brass are definitely not recommended as plate materials.

Vertical mounting, particularly where an appreciable load is applied to the shaft, is to be avoided. Such a mounting subjects the rear bearing to extra pressure which eventually may shorten its life. Applications which require long drive shafts are not recommended where there is a possibility for high side thrust on the bearings.

High frequency operation may require the specification of additional rotor wipers to reduce the residual inductance of the unit. These should not be too heavy or the drive torque will be increased to an unsatisfactory value. High frequency operation also requires a better grade of dielectric than ordinarily specified for frequencies up to 10 megacycles.

In general the application of variable capacitors requires the specification of a sturdy low-loss design and means for mounting which do not distort the plate alignment.

Specifications

The specification data sheet outlines the information required for the specification of a variable capacitor and is in general self-explanatory. A few items however should be more detailed and are discussed below.

Mechanical

Radial slots are specified only for the rotor end plates.

Rotor torque is generally maintained from two to six inch ounces.

Both rotor and stator plates should be securely fastened mechanically and preferably soldered .

Stator insulators should be riveted, staked or attached to the frame with screws, lockwashers and nuts. Vibration tests during heat cycling will indicate whether the stator sections are securely fastened.

Electrical

The capacitance of the reference section is usually checked against

Specification continued

a specified curve (Table I) at 0, 25, 50, 75 and 100 percent rotation with an allowed tolerance of ± (1 mmf + 1%) of the curve value.

The matching of other identical sections to the reference section at 25, 50, 75 and 90 percent should be within ± (1 mmf + ½%) of the reference section value.

The matching of sections not identical with the reference section should be within ± (1 mmf + ½%) of the specified value for the particular number and type of plate employed. Tests are made where the reference section is exactly as specified for its 25, 50, 75 and 90 percent rotation. The larger tolerance on the reference section is allowed because it only affects the scale calibration and is not as important as matching between sections.

The specification of a minimum Q at a given frequency is sometimes desired according to the application. No difficulty is experienced in obtaining a Q of 1000 at one megacycle.

The specification of allowable capacitance change with temperature and humidity as well as retrace after repeated thermal cycling is seldom required since these characteristics are usually uniform for a given design.

Standard voltage breakdown is 400 volts RMS 60 cycles at 25°C and 50 percent relative humidity at less than 1000 foot altitude. Voltage breakdown tests are useful as an indication of proper plate spacing. Poor alignment or incorrect spacing is a common source of microphonism.

ADJUSTABLE CAPACITORS

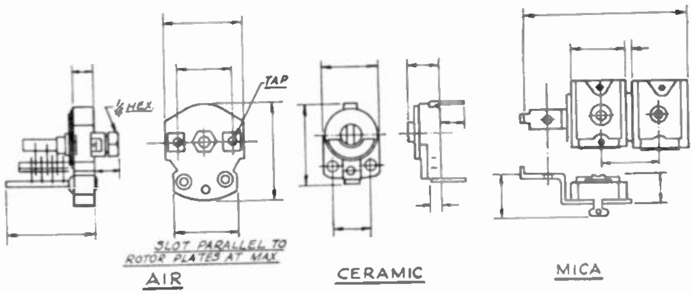
DESIGN

Several types of adjustable capacitors (Fig. 5-6) are commercially available for use in antenna, r-f, i-f and oscillator circuit applications.

SPECIFICATIONS Variable Air-Dielectric Capacitors			
PHYSICAL	**Type**	ELECTRICAL	GENERAL
	Bent frame		
Dimensions	Bar	**Capacitance**	**Finish**
Overall	Bearings	Curve shape	Plating
Mounting	Front	Tolerance	Special treatment
Shaft	Rear	Reference section	
	Compensators	Compensators	**Life**
Sections	Location		Cycles
Number	**Stator**	**Q at Operating Frequency**	**Microphonic**
Location	Type terminals	Normal	
Plates	Insulation	Humidity	
Material	Treatment		
R-F	**Mounting**	**Voltage Breakdown**	
Oscillator	Tapped holes	Normal	
	Brackets	Altitude	
Rotation	Studs		
Increase capacitance	**Wipers**	**Drift Characteristic**	
Torque	Long, short, V	Temperature	
	Location	Retrace	

Table 5-2

Specification—Variable Air Capacitor



PART Nº	CAPACITY MAX.	CAPACITY MIN	Q AT MC	VOLTAGE BREAKDOWN	HUMIDITY	ALTITUDE	TEMP	DIMENSIONS MOUNTING	DIMENSIONS OVERALL

INSULATED ADJUSTMENT	SECTIONS	STABILITY TEMP COEFF	STABILITY RETRACE	STABILITY VIBRATION	MICROPHONICS	TORQUE

Fig. 5-3

Because of the large variety of designs available only three will be considered; (1) mica, (2) miniature air and (3) ceramic.

Mica Compression Type

The most common adjustable capacitor is the mica dielectric compression type wherein the electrode plates are separated by thin sheets of mica (0.0015 to 0.003 inches thick) and held under tension by means of an adjusting screw and the general shape of the plate. The mechanical design varies to a certain extent with the manufacturer and with its particular application but in general the basic principles of construction are similar.

Mechanical Considerations

The method of mounting should be so designed that movement of the mount will not cause mechanical shifting of the plates, mica films, adjusting screw and nut. The adjusting means should be firm and have no backlash throughout the entire operating range. The capacity-turn curve should be smooth and without negative slopes within the usable range of the capacitor. The armature plates should be under tension through the full operating range to ensure stability and freedom of microphonics.

Electrical Considerations

Stability with temperature, humidity and life; low losses and adequate capacity range are the primary electrical considerations. Such

Design continued

factors as the coefficient of thermal expansion of the materials, plate tension and dielectric losses become of paramount importance.

Due to thermal expansion of the plates the capacity increases with an increase in ambient temperature. This effect is offset somewhat by the elongation of the adjusting screw, which holds the plates together, but unfortunately the two opposite effects do not balance. The design can be centered to provide optimum performance over a narrow capacitance range.

Characteristics

Temperature characteristics as shown in Fig. 5-4 indicate a gradual decrease in capacity change with each succeeding temperature cycle. This is the result of relieving stresses set up during the manufacturing process. The effect can be minimized by specifying the unit to be heat treated or aged after fabrication. Another type of temporary instability occurs after each adjustment to a new capacitance value. This is due to the relatively high coefficient of friction between the plates. A graphite film treatment applied to the plates will usually provide sufficient lubrication to improve the condition.

The dielectric films (mica) between the plates have an important bearing on the Q and the ability of the capacitor to withstand high humidity. Due to the nature of mica, which is composed of many very thin layers, it can absorb a considerable amount of moisture, under con-

Comparative Characteristics - Compression (Mica), Compensating (Ceramic) and Air Dielectric Adjustable Capacitors.

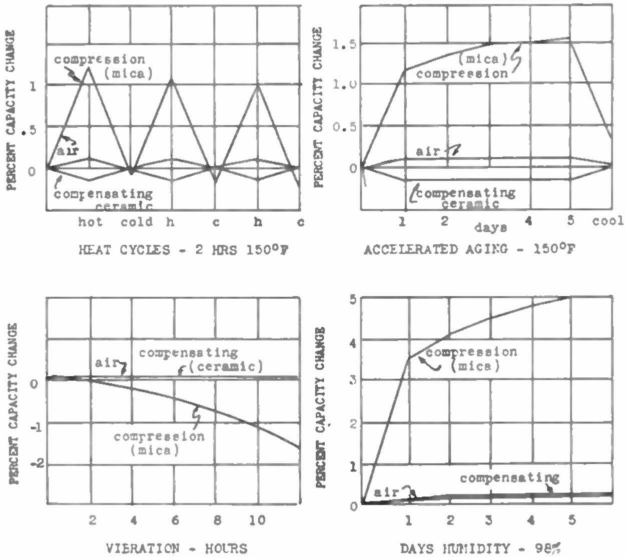


Fig. 5-4

Design continued

ditions of high humidity, if flaws or other defects are present. Treatment of the mica films to seal the edges against moisture penetration is sometimes desirable.

In addition to the dielectric between the plates the insulating material of the base must be considered. The coefficient of expansion and the dielectric loss should be small and the mechanical strength adequate. Some designs employ a metal instead of a dielectric material as the base plate. The basic design problems, however, remain unchanged.

Air Dielectric Type

Like the compression type capacitor the air dielectric type is manufactured in many varied designs.

Mechanical Considerations

The miniature type tuning capacitor closely resembles a regular tuning capacitor except for frame and bearings. Usually only one bearing (front) of the sleeve type is employed and the plate structure instead of being supported to the frame is supported on rods which are securely fastened by soldering to eyelets in a ceramic or other insulating front plate. Bearing surfaces should be smooth and have close tolerances to prevent side play in the shaft.

This type possesses unusually good characteristics and when properly designed to withstand mechanical shock are especially desirable for high quality equipment.

Another version of the air dielectric trimmer consists of cylindrical plates intermeshed by means of an adjusting screw or nut. While not quite as stable mechanically they are usually smaller physically and therefore desirable in many applications where space is limited. Mechanical tolerances must be held quite close to insure smooth action and prevent any tendency to microphonism.

Electrical Considerations

The Q and stability depend essentially on the quality of the dielectric employed and in general the same factors involved in the design of tuning capacitors prevail. This assumes of course the mechanical design is sturdy and not subject to excessive variations due to temperature and vibration effects. Comparative characteristics are shown in Fig. 5-4.

Capacity Range vs. Turns Rotation - Typical compression type variable capacitor.

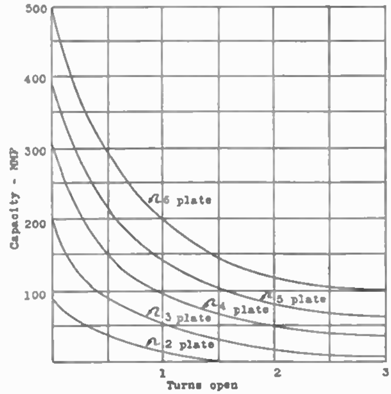


Fig. 5-5

Design continued

Ceramic Type
Mechanical Considerations

Adjustable ceramic capacitors because of their excellent mechanical design are ideal from an ease of adjustment standpoint. Constant rotational torque and vibration proof operation through 360 degrees is achieved by the use of a non-ferrous spring which holds the rotor in intimate contact with a silver coated lapped and burnished ceramic base. Capacitance to ground when mounted against a metal chassis depends upon the base material. Most designs employ a low dielectric-constant steatite for this purpose. The conducting electrode (silver) is fired on to the ceramic rotor thus insuring an intimate contact at all times (similar to plated mica construction). Mechanical protection of the conducting electrodes is necessary to prevent dust and other foreign particles from affecting the operation. This is obtained by using a circular rotor plate which completely covers the active electrodes.

Electrical Considerations

Like other adjustable capacitors stability with temperature and life as well as high Q are desired. Stability and Q are dependent upon the quality of the dielectric, assuming the mechanical design is satisfactory. Positive, negative or zero temperature coefficients are available according to the percentage of titanium dioxide in the rotor insulation.

APPLICATION
Compression Type

The mica compression type capacitor is noted for its low cost, small physical size, wide capacity range, ease of adjustment and fair stability. It is recommended for all low frequency applications (up to two megacycles) where stability is not of primary importance. When necessary an effective increase in stability can be obtained by designing the circuit to minimize the variable capacity in the circuit in favor of more stable components. For instance where a capacity of 555mmf is required (oscillator series tracker) specify a good quality 470mmf fixed or compensating capacitor to be connected in parallel with the trimmer thereby decreasing its effectiveness in the circuit. This is seldom necessary for most low frequency applications if the compression trimmer has been located away from high heat radiating components or tubes.

Medium frequency applications are also permissible if the same precautions are observed. For frequencies above 50 megacycles the compression type capacitor is not recommended except for low Q circuit applications where frequency stability is not of prime importance.

The useful range (Fig. 5-5) should be limited to the portion of the capacitv curve from 1/7 to 2 turns from tight. When it is necessary to adjust the capacity to a point beyond ⅛ turn from tight the ability to adjust to a specified point is decreased. With some designs

Application continued

the capacity versus turn curve at this point shows a negative slope and is obviously undesirable. At the minimum capacity end of the tuning range the correct adjustment point is rather difficult to determine and because the plates are under very light tension microphonics are likely to result. From an ease of adjustment standpoint and comparative freedom from microphonism the ideal range of adjustment lies between $\frac{1}{2}$ to 1 turn from tight.

There is nothing fundamentally wrong with the compression type capacitor if its application is confined within the capabilities of the component.

Air Dielectric Type

Miniature tuning or concentric type adjustable capacitors, because of their small capacity range, are usually specified only for medium and high frequency applications. The Q and stability are essentially the same as discussed for standard tuning capacitors.

Ceramic Dielectric Type

Ceramic type adjustable capacitors because of their relatively high cost are recommended only where a high order of frequency stability is required. Positive, negative or zero temperature characteristics are available which widens their field of application. Like the air dielectric type capacitor the maximum operating frequency is determined by the Q of the circuit and component.

SPECIFICATIONS

The specification data sheet outlines the information required for the specification of adjustable (trimmer) capacitors and is in general self explanatory. A few items however should be more detailed and are discussed below.

Mechanical

Rotor torque is usually specified between 10 to 25 inch ounces.

Rotor and stator plates (miniature tuning type) should be soldered into position.

Silver plating is generally specified only for high frequency applications.

Additional mechanical details are shown in Fig. 6.

Electrical

It is important to specify the capacitance range (compression type) in turns from tight to insure ease of adjustment and a certain degree of freedom from microphonism.

Q is an important factor only when the circuit losses are low. It is sometimes desirable to specify a minimum value at a particular operating frequency although for a particular design it will seldom vary in production.

Specification continued

Voltage breakdown is seldom specified since it depends in general on the particular design and once established needs no further attention.

Stability requirements, especially with variations in temperature are often specified. Usual requirements are of the order of:

+300 parts/million/°C Compression type (mica).

+100 parts/million/°C Miniature type (air).

+250 to –750 parts/million/°C Ceramic type.

Retrace characteristics are also of importance but depend so much on the particular application that no general values can be given.

SPECIFICATIONS

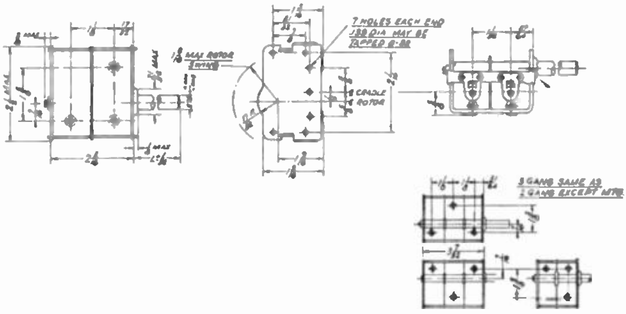
Adjustable Capacitors

PHYSICAL	ELECTRICAL
Type	**Capacitance**
Miniature tuning	Range
Concentric plate	Tolerance
Compression	
Ceramic	**Q - Operating Frequency**
	Normal
Dimensions	Humidity
Overall	
Mounting	**Voltage Breakdown**
	Normal
Adjustment	Altitude
Screw	
Hex nut	**Stability**
Slot	Temperature
	Retrace
Terminals	
Location	**Microphonics**
Dimensions	
GENERAL	**Dielectric**
Torque	Air
Finish	Ceramic
Plating	Mica

Table 5-3

Design continued

Typical Adjustable Capacitor Specification

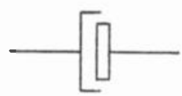


PART No	No SECTIONS	REFERENCE SECTION	ROTATION	CAPACITY EFFECTIVE	CURVE	COMPENSATORS	WIPERS	Q AT MC

SHAFT DIAMETER LENGTH	DRUM OR PULLEY TYPE	LOCATION	PLATE MATERIAL	GRADE INSULATION	VOLTAGE BREAKDOWN	HUMIDITY	STABILITY mmf/°C	PLATING	OPERATING TORQUE

Fig. 5-6

CAPACITORS
ELECTROLYTIC



DESIGN

General

The electrolytic capacitor depends upon a polarizing voltage for operation and because of this the characteristics are quite different from the ordinary paper capacitor. The equivalent circuit of the component as shown in Fig. 6-1 will therefore be briefly discussed.

The film capacity C_1 varies with the surface area and is inversely proportional to the formation voltage. (A commonly used method of increasing this capacity is to process or etch the surface of the plate which results in greater surface area). R_1 the leakage resistance varies with the polarizing voltage and depends also on the method of formation and type of electrolyte employed. The electrolyte capacity C_2 is directly proportional to the area of the electrodes and inversely proportional to the spacer thickness and dielectric constant of the solvent. R_2 the electrolyte resistance, is dependent upon its viscosity, concentration and temperature.

Equivalent Circuit - Electrolytic capacitor

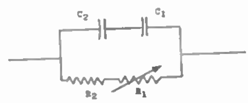


Fig. 6-1

Present day designs make use of two types of foil; (1) etched and (2) plain. Etched foil capacitors are recommended where economy of space and cost are of prime importance and where the temperature requirements are not stringent. Plain foil capacitors are to be recommended where high values of ripple current must be handled or the temperature requirements are abnormally high but not over 85°C. The etch ratio is defined as the ratio of the increase in capacity of an etched plate to that of a plain plate when formed at the same d-c potential. In practice this is of the order of 7 to 8 times.

Series Resistance

The equivalent series resistance is substantially determined by the surface area of the anode and the specific resistivity of the electrolyte. Unfortunately the ratio of the electrolyte resistivity to anode surface area is not uniform for all working voltages because of the possibility of corrosion due to ionization on the one hand and the possibility of voltage breakdown on the other. For this reason multiple units, having sections rated at different voltages are not the equivalent of separate

Leakage Current Characteristics Showing Effect of Temperature and Forming Time.

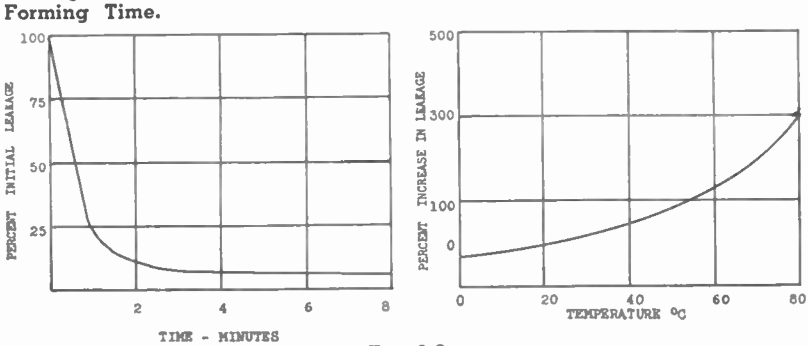


Fig. 6-2

Design continued

sections since it is necessary to employ an electrolyte which is designed for the highest voltage specified in the unit. This results in a higher than normal equivalent series resistance for the low voltage sections and is sometimes undesirable. In such cases the designer can either increase the capacity of the low voltage section or specify a separate capacitor for the particular application.

Leakage Current

The magnitude of the d-c leakage current is dependent upon the ratio of the applied working voltage to the formation voltage, the operating temperature and the duty cycle. This is shown in Fig. 6-2 along with other typical characteristics. Leakage current and series resistance have an indirect bearing on the life of an electrolytic capacitor in that they both contribute to total watts loss and therefore the operating temperature of the electrolyte. (The total watts loss equals the leakage current times working voltage, plus ripple current squared, times the equivalent series resistance).

Ripple

While an electrolytic capacitor is usually considered as a direct current device, most circuit applications involve an alternating current potential which is generally superimposed on the d-c. Capacitor-fed filter networks are particularly vulnerable in this respect. (The approximate ripple current is equal to 1¼ and 2½ times the d-c drawn from a full wave and a half wave rectifier respectively). When an alternating current flows through a dry electrolytic capacitor an a-c potential difference is set up across the electrolyte. During one half of the cycle the cathode plate is negative with respect to the electrolyte while on the other half cycle the polarity is reversed. This latter condition is favorable for the formation of an anodic film (assuming the material is suitable) which simulates another capacitor in series with the original as shown in Fig. 6-3. The net result is a reduction in the effective capacitance. This effect is only of importance with etched anode capacitors; when both the cathode and anode plates are of etched construction this difficulty is eliminated.

Effect of Ripple Voltage Forming Dielectric Film on Cathode Plate

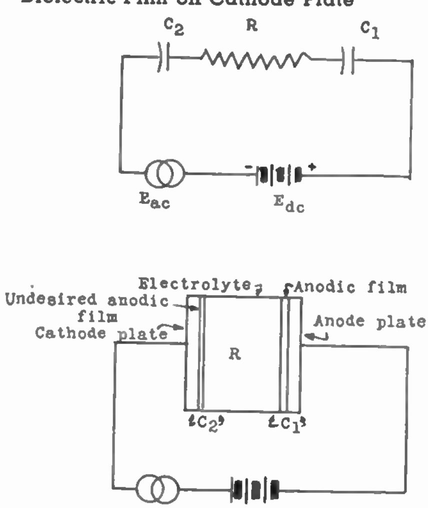


Fig. 6-3

Working and Surge Voltage

The operating require-

Design continued

ments for an electrolytic capacitor should be predicated upon such abnormal conditions as high line voltage and high ambient temperatures. Surge voltages should be ascertained with paper capacitors in the circuit, to eliminate errors due to normal voltage-current characteristics, when an electrolytic capacitor is employed. This provides a factor of safety and is extremely important; when an electrolytic capacitor must act as a voltage regulator its life is materially shortened.

Characteristics

Typical characteristics and design factors are given in Tables 6-1 to 6-5 and Figs. 6-2, 6-4 and 6-5.

APPLICATION

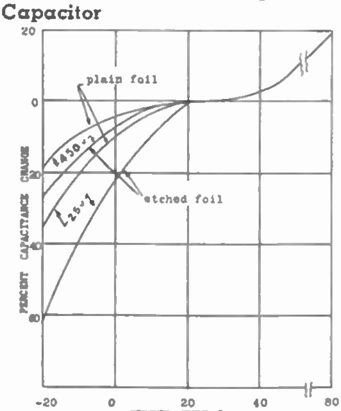
Electrolytic type capacitors are specified almost without exception for all applications where a capacity of over one microfarad is required. There are two reasons for such a choice: (1) the physical size per microfarad is extremely small and (2) the cost is relatively low.

In applications of metal cased capacitors where the container is not the cathode connection, the container should never be grounded. When a "floating" container is grounded the internal insulation is likely to fail prematurely because of the presence of the electrolyte. For this reason insulated metal containers are not recommended.

Electrolytic capacitors are not suited for r-f applications since they have a high impedance. The specific resistivity of the electrolyte increases with frequency until it eventually acts as an insulator.

Applications involving high ripple current result in heating due to power loss and formation of a film on the cathode which reduces the effective capacitance of the unit. Since the heat tends to dry out the electrolyte,

Characteristics - Electrolytic Capacitor



Capacitance versus temperature showing effect of working voltage and type foil.

Fig. 6-4

Characteristics - Typical Electrolytic Capacitor

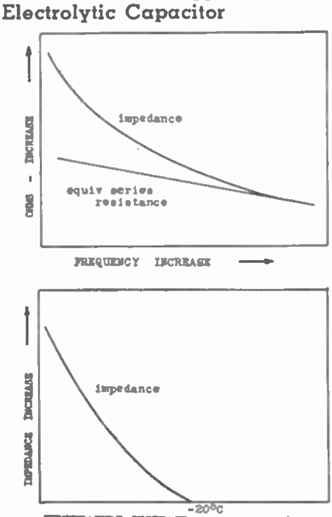


Fig. 6-5

Application continued

cardboard containers are not recommended for such applications.

Etched foil capacitors are recommended for practically all applications except where ripple currents or temperatures are extremely high. High temperatures and over-voltage often result in the generation of gas which makes it necessary to provide some means for venting to prevent possible rupture of the container; after venting occurs the unit is subject to moisture leakage through "breathing." For most applications this is not serious although it does have a slight effect on the life of the capacitor. The importance of adequate voltage ratings and suitable operating temperatures is thus evident.

Extremely low temperature applications in general require the use of a plain foil capacitor to maintain a reasonable impedance. On a per microharad basis at –40°C the impedance of an etched foil unit will increase from two to three times as much as a similar plain foil unit. This is of little importance except for airborne or automotive equipment since the average home receiver is rarely required to operate at such temperatures.

D-C LEAKAGE CURRENT

Working Voltage	Leakage Current Maximum Milliamperes
3 to 100	0.3 + 0.01 x capacitance
101 to 250	0.3 + 0.02 x capacitance
251 to 350	0.3 + 0.025 x capacitance
351 to 450	0.3 + 0.04 x capacitance

NOTE: Maximum leakage current measured after application of rated voltage for at least five minutes. Capacitors may require an initial forming if units have not been in service for an extended period of time.

RIPPLE CURRENT

Maximum ripple current in milliamperes at 120 Cycles 60°C

Microfarads	D-C Working Voltage 0 to 50	51 to 150	151 to 450
5		45	95
10		75	150
15		85	170
20		90	180
30		100	200
40		190	200
50		200	200
80	200	200	200
100	200	200	200
500	625		
1000	850		

Table 6-1

EQUIVALENT SERIES RESISTANCE

Maximum equivalent series resistance in ohms 120 cycles 25°C

Working Voltage	Resistance in Ohms
0 to 15	1000/capacitance (mfd)
16 to 25	500/capacitance
26 to 50	400/capacitance
51 to 150	300/capacitance
151 to 250	230/capacitance
251 to 300	210/capacitance
301 to 450	200/capacitance

NOTE: Low voltage sections of multi-section units will have two times series resistance shown in table.

STANDARD TEMPERATURE RANGE

-20 to 85°C
0 to 85°C
0 to 65°C
-20 to 65°C

CAPACITANCE TOLERANCE

Rated Voltage	Tolerance
0 to 35	-10 + 250%
36 to 150	-10 + 150%
151 to 150	-10 + 100%
351 to 450	-10 + 50%

STANDARD VOLTAGES

D-C Working	D-C Surge
3	4
10	12
15	20
25	40
50	75
150	200
250	300
300	350
350	400
400	450
450	500

STANDARD CASES

Metal:	Twisted lug mounting (tabs)
Metal:	Tubular
Paper:	Tubular (humidity resistant)
Paper:	Tubular

Table 6-2

Capacitor Ripple (Current and Voltage) Versus Capacity and Load for Capacitor Input Filter. (1st capacitor).

D.C. across 1st capacitor	Load (current)	Ripple Current	Peak ripple volts at 120 cycles. 10 mfd	20 mfd	30 mfd	40 mfd
250	50	44.5	8.3	4.2	2.8	2.1
	100	86	16	8	5.4	4
300	50	49	9.2	4.6	3.1	2.3
	100	92	17.2	8.6	5.7	4.3
350	50	52	9.7	4.9	3.2	2.4
	100	99.5	18.6	9.3	6.2	4.6
400	50	55	10.3	5.1	3.4	2.6
	100	110.5	20.7	10.3	6.9	5.2
	125	128.5	24	12	8	6
450	50	59.5	11.1	5.6	3.7	2.8
	100	114.5	21.4	10.7	7.1	5.3
	125	142	26.5	13.2	8.9	6.6

NOTE: Other values may be calculated from:
Ripple current x capacitor impedance (at filter frequency) = RMS ripple voltage.
Peak ripple = RMS x 1.41.
Peak ripple voltage is added to d-c volts to obtain peak voltage. Values are all determined with maximum input voltage. Peak ripple volts for 25 cycle supply (50 cycle filter frequency) = Ripple x 120/50 — Er peak x 2.4

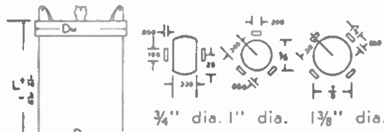
Table 6-3

Size Factors

Micro-farads	Rated Voltage 10	25	50	150	200	250	300	350	400	450
10				10	14	17	20	23	28	31
15				15	20	26	30	35	42	47
20		8	10	19	27	34	40	46	56	62
25		10	12	24	34	43	50	58	70	78
30		11	15	29	40	52	60	69	84	94
40		15	19	38	53	69	80	92	112	125
50	9	18	22	48	67	86	100	115	140	156
80	14	25	35	77	107	138	160	184	224	250
100	17	28	40	96	134	172	200	230	280	312
500	83	140	200							
1000	167	280								

Table 6-4

Standard Twisted Lug Mounted Case



Chassis Layout for Direct Mounting

DIMENSIONS

D	DM	L
1	1⅛	2, 2½, 3, 3½
1⅜	1½	2, 2½, 3, 3½
¾	55/64	2

Insulated sleeves and bakelite mounting plates are available for all diameters.

SIZE INDEX

Size	Single	Dual	Triple	Quad
¾ x 2	36			
1 x 2	83	79	75	
1 x 3	158	150	142	
1⅜ x 2	172	168	164	160
1⅜ x 3	336	328	320	312

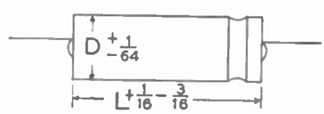
MARKING

Voltage	All Diameters Single	1⅜" dia. Dual	1⅜" dia. Triple	1⅜" dia. Quad	1" dia. Dual	1" dia. Triple
Highest (ripple)	Blank	⌓	⌓	⌓	▭	▭
Intermediate (1st)				▭		△
Intermediate (2nd)			▭	△		
Lowest		△	△	Blank	△	Blank

Common Negative always to can

Table 6-5

Standard Metal Tubular Case

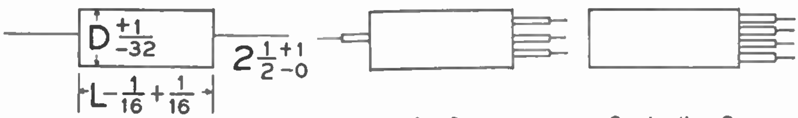


DIMENSIONS / **SIZE INDEX**

Diameter	Length		Maximum Size Index Single		Maximum Size Index Dual
⅝	1⅝		16		
¾	1⅝	2⅛	30	50	
⅞	1⅝	2⅛	48	66	
1.0	1⅝	2⅛	64	86	62

Table 6-6

Paper Tubular Case



Construction A (Single) | Construction B (Dual or triple) | Construction C (Single, dual or triple)

DIMENSIONS

Diameter	Length in Inches A	B	C
9/16	2.0		2.0
5/8		2.25	2.25
3/4	2.5		2.5
7/8		2.75	2.75
1.0	3.0		3.0
1 1/8		3.25	3.25
1 1/4	3.5		3.5
1 3/8		3.75	3.75

CODING

Color	Voltage
Orange	Highest
Red	Intermediate
Blue	Intermediate
Yellow	Lowest
Black	Negative

LEADS

Single sections — #20 AWG — 10 strands #30 bare
Multiple sections — #20 AWG — 10 strands #30 insulated

Table 6-7

SPECIFICATIONS

CAPACITORS—electrolytic

PHYSICAL

- **Type**
  - Etched
  - Plain
    - Single unit
    - Multiple unit
- **Case**
  - Metal
  - Cardboard
- **Dimensions**
  - Overall
  - Mounting
- **Terminals**
  - Leads
  - Lugs

GENERAL

- **Temperature**
  - Range
- **Humidity**
- **Altitude**

ELECTRICAL

- **Capacitance**
  - Tolerance
- **Power Factor**
- **Insulation Resistance**
- **Working Voltage**
- **Surge Voltage**
- **Ripple Current**
- **Leakage Current**

Table 6-8

RESISTORS
FIXED

The resistor family as indicated in Table 7-4 represents only those resistive components ordinarily specified in radio equipment design. Large power type rheostats of the wire wound or carbon-pile variety, slide-wire voltage dividers and precision resistors for laboratory use will not be discussed since these items are seldom specified by the design engineer.

DESIGN

Wire Wound

Characteristics of wire wound resistors depend on the specific resistivity and temperature coefficient of the wire, dimensions of winding form, type of winding and the external coating material.

Resistance

A choice of wire material (Table 7-1) should be made which permits high resistance per circular mil foot, low magnetic content and a low temperature coefficient. To facilitate production and decrease normal breakage the wire should not be less than 0.002 inches in diameter. This normally will limit the maximum resistance to values as shown in Table 7-2. Heavy duty (bare) resistors of the crimped ribbon type are limited to a maximum resistance value of approximately 50 ohms. Since this type of construction is seldom employed in general radio applications the data given in Table 7-3 should be sufficient for most design requirements.

Power Dissipation

Wire wound resistors are noted for their ability to dissipate relatively high power. This characteristic depends upon the winding form, coating if any, and wire size.

An inorganic coated ceramic tube resistor is rated such that the hot spot temperature rise over an ambient temperature of 40°C, does not exceed 300°C under free space conditions (suspended in air at least one foot away from nearest object).

Organic coated resistors under the same conditions are limited to a maximum temperature of 125°C. Ceramic form resistors without coatings (bare) may be subjected to a 375°C temperature rise, assum-

TYPICAL MATERIAL CHARACTERISTICS

Material	Resistivity (Ohms/CMF)	Temperature Coefficient (Ohms/ohm/°C)
Silver	9.75	0.00381
Copper	10.37	0.00393
Nickel-Copper 45/55	294.0	±0.00002
Chrome-Nickel 80/20	650.0	0.00014
Nichrome V	675.0	0.00023

Actual values depend on specific composition of alloys.

Table 7-1

Design continued

ing of course that the winding is not subject to shift which might result in shorted turns.

Voltage Rating

In addition to power dissipation as limited by temperature rise, the voltage rating must also be considered. This is limited by the insulation between turns which is influenced by the overall winding length and the desired resistance. Obviously the greater the resistance for a given length of form the closer the spacing between turns. Representative voltage ratings for cylindrical winding forms are given in Table 7-2.

High Frequency Characteristic

The high frequency characteristic of wire wound resistors is in general relatively poor due to skin effect, residual inductance and capacitance. These parameters however can be controlled to a certain extent where special applications make it necessary. **Skin effect**, for example, is influenced by the diameter and iron content of the wire. Fig. 7-1 shows the recommended maximum wire diameter as a function of the operating frequency which will result in negligible skin effect.

GENERAL DESIGN DATA—STANDARD WIRE WOUND RESISTORS

Power Rating Watts	Maximum Voltage Rating	Core Size Dimensions — Inches L	I.D.	O.D.	Recommended Maximum Resistance[1] Standard	Non-reactive
5	200	1	5/32	5/16	1360	
10	300	1¾	5/32	5/16	5400	1000
20	400	2	⅜	9/16	12,000	1500
25	500	2½	⅜	9/16	18,000	
40	700	3½	½	¾	35,000	3500
50	1000	4½	½	¾	48,000	
80	1500	6½	½	¾	75,000	7500
100	1500	6½	¾	1⅛	110,000	
160	2000	8½	¾	1⅛	150,000	15,000
200	2500	10½	¾	1⅛	190,000	

Note 1. Based on 0.002" diameter wire.

Table 7-2

Inductance and capacitance is a function of area, number of turns, type winding and the configuration of the winding form. Obviously a flat strip or straight sided oval form will result in less inductance than the ordinary cylindrical tube. Several non-inductive windings (Ayrton Perry, bifilar and pie) are commercially available for special applications, however, the Ayrton Perry winding on a ceramic form is generally employed. This consists of two windings, opposite in direction and connected in parallel. It is important that the winding cross-over points occur 180° apart on the form to minimize the inductance and distributed capacitance. Special flat sided cylindrical cores have been developed

Maximum Wire Size for Negligible Skin Effect. Material vs. Frequency.

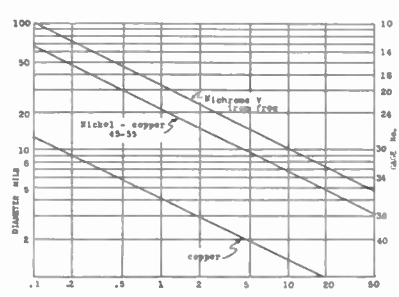


Fig 7-1

Design continued

which make this commercially possible. See Fig. 7-2.

Vitreous enamel coatings are generally supplied and non-magnetic mounting brackets are recommended for this class of resistor.

APPLICATION

The choice of the proper resistance value and power rating is only a small part of the problem in resistor application. Climatic conditions, tolerances, overload and physical dimensions are also factors to be considered. Each specific type is particularly suited to certain applications and therefore should not be specified indiscriminately unless it is known that the operation of the equipment will not be adversely affected. Although a resistor may be rated to dissipate 10 watts of power under ideal free-air conditions most applications necessitate that a derating factor (Fig. 7-3) be employed to compensate for actual operating conditions, where the air circulation is not perfect. It is not good practice to operate resistors at maximum rated temperatures. They should be further derated in instances where proximity to other components may damage the latter.

GENERAL DESIGN DATA—CRIMPED RIBBON RESISTORS (bare)

Power Rating Watts	Nominal Length	Outside Diameter	Resistance (Ohms) Minimum	Maximum
75	3½	1	0.04	6.0
110	4½	1	0.05	9.0
160	6½	1	0.08	15.0
300	8½	1⅜	0.15	33.0
375	10½	1⅜	0.20	40.0

Table 7-3

Wire Wound Resistors

Wire wound (power) resistors are commercially available in several types of construction as shown in Table 7-4. In general, the vitreous enamel coated resistor is recommended for high wattage dissipation. The cement coated types wound on phenolic forms should be limited to low and medium power applications since their thermal conductivity is rather poor and safe operating temperature is limited to approximately 125°C.

Wire wound units are seldom employed where the power dissipation is under one or two watts. The type of mounting and type lugs are important since the unit is generally mounted securely to the chassis and thus affects the general layout. In a-c/d-c applications where the chassis is not conductively coupled to the power line the leakage resistance (between element and ground) and voltage breakdown are essential considerations. The leakage resistance should not be less than 10 megohms after 100 hours of 95 percent relative humidity at an ambient temperature of 40°C, and the unit should withstand 900 volts RMS between resistor element and ground at room temperature.

Application continued

Some enamel and cement coated resistors are subject to deterioration under excessive (continuous) humidity. For such applications a careful study of available types should be made.

The principal uses of wire wound resistors are voltage dividers, voltage dropping, bias and filter applications. Taps may be provided at little cost.

SPECIFICATIONS

The specification of resistors, like other components, should only include those items necessary for the particular application.

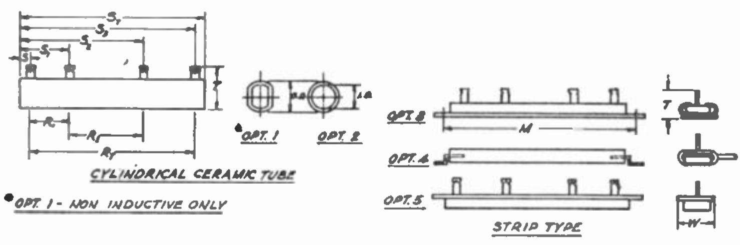
Mechanical

Under this classification the important items are (1) permissible dimensions, (2) mounting and (3) type terminal. Care should be taken to provide adequate clearance in the design of the equipment so that decimal tolerances will not be required.

Electrical

Resistance and tolerance, both overall and each step if tapped, are the main considerations for all applications. Power rating, taking into account the physical location of the unit, is next in importance. Insulation resistance under specified operating conditions, voltage breakdown and impedance are only specified when definitely required, since their specification is usually unnecessary for most applications. The specification data sheet, Table 7-8, outlines the items normally checked before releasing final specifications and drawings.

Specification—Wire Wound Resistors



PART No	RESISTANCE - OHMS				DIMENSIONS IN INCHES								TERMINALS		TYPE	
	OVERALL	R_1	R_2	ETC.	O.D.	I.D.	S	S_1	S_7	T	W	M	TYPE	LOCATION	STRIP	TUBE
	±%															

INSULATION		TEMPERATURE RISE	NOMINAL WATTS DISSIPATION	LEAKAGE RESISTANCE TO CASE OR MTG.	IMPEDANCE AT MC.	VOLTAGE BREAKDOWN	HUMIDITY TEST
FORM	COATING						

Fig 7-2

FIXED RESISTORS—CLASSIFICATION & RECOMMENDED APPLICATION

Type	Usual Power Dissipation Watts	Recommended Max Temp °C	Notes—Recommended Application
WIRE WOUND			
Metal strip	Up to 15	125	Phenolic strip and insulation. Voltage dropping, voltage divider, bias and filter circuits.
Molded strip	Up to 10	125	Same as metal strip type.
Vitreous enamel	Up to 200	300	Fired vitreous enamel on ceramic tube. General medium and high power applications. Good humidity characteristics.
Cement coating	Up to 25	300	Cement coating on ceramic tube.
	Up to 10	125	Cement coating on phenolic strip. Voltage divider, voltage dropping, bias and filter circuits.
Bare	Up to 375	375	Crimped ribbon or wire on ceramic tube. High power applications only.
Flexible core	Up to 5	275	Glass textile core and covering. Textile fuses at high temperatures with no serious effects. General low and medium power applications.
Glass sealed	Up to 50	275	Ceramic tube, glass case with ferrule ends. Good humidity characteristics. Untapped ferrule units.
Precision	Up to 1	50	Instrumentation
COMPOSITION			
Carbon	Up to 2	85	Carbon-graphite resin binder. Phenolic insulated case. General purpose. 10 ohms to 10 megohms.
Metal film	Up to 1	85	General purpose, fair high frequency.
Wire element	Up to 2	85	Low noise, high inductance, stable. 5000 ohms max, 470 recommended max.
Compensating	Up to 5	200	Resistance decreases approx. 3rd power of impressed voltage. Voltage limiting surge control.

Table 7-4

Composition Type

Composition type resistors consist of a finely divided carbonaceous material mixed with a suitable resinous or equivalent binder combined in the proper proportions to obtain the specific resistance required. The resistor element (insulated type) is suitably enclosed in a molded case for mechanical strength and to protect it against the effects of humidity. It should have high thermal conductivity, high heat radiation efficiency, and ability to operate over a temperature range of —20 to +50°C with a minimum of chipping or flaking when subjected to intermittent heating and cooling. Axial wire leads having a minimum length of 1½ inches are usually provided. Electrical connections must be mechanically secure and electrically continuous.

Composition type resistors are subject to variations due to voltage, current, humidity and temperature. The degree to which each affect the nominal value obviously depends upon the magnitude of the variable.

Voltage Characteristic

The voltage characteristic (instantaneous effect of voltage applied to a resistor) is usually inappreciable, being of the order of minus one to minus three percent. Measurements are made the instant voltage is applied to prevent any temperature rise affecting the results. The

Design continued

change is temporary since the resistance value returns to normal after the voltage is removed.

Load Characteristic

In actual operation as the voltage is increased the power dissipated is likewise increased which brings the load characteristic into effect. The resistance change under this condition is due to both voltage and load but, since it simulates actual operation, it is not necessary to determine the change due to load alone. Load curve characteristics (Fig. 7-4) are made after the resistor temperature has reached a steady state for any given load (approximately 10 minutes). The resistance decreases due to the negative resistance coefficient of carbon and is usually of the order of five to ten percent, according to the magnitude of the load and the value of the resistor.

Derating Curve - Wire Wound Resistors

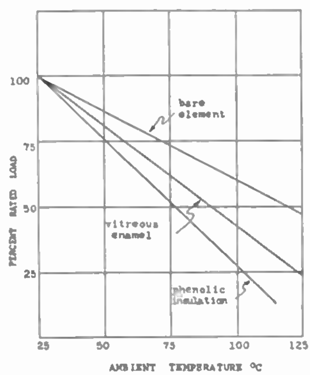


Fig. 7-3

Load Characteristic - Composition type one half watt resistor

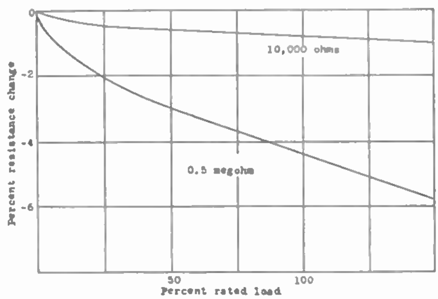


Fig. 7-4

High Frequency Characteristic - Representative composition resistor.

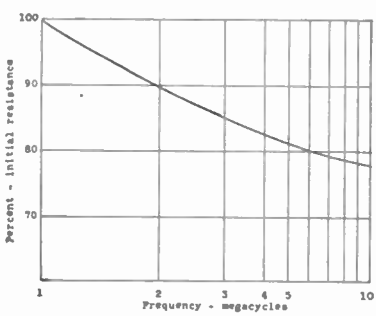


Fig. 7-5

Temperature Characteristic - Typical Composition Resistor

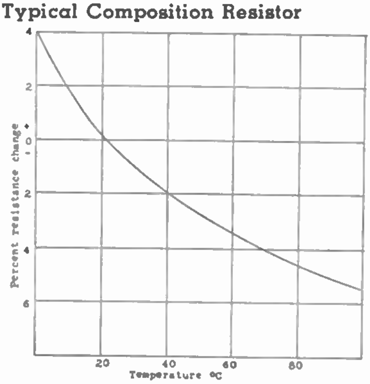


Fig. 7-6

Humidity Characteristics

The humidity characteristic (effect of high humidity over long

Design continued

Resistor Rating	Maximum Temperature
1/4 watt	65°C
1/2 watt	65°C
1 watt	80°C
2 watt	85°C

Maximum temperature rise versus wattage dissipation. Composition type resistors.

Table 7-5

Resistor Rating	Maximum Resistance
1/4 watt	1 megohm
1/2 watt	2 megohm
1 watt	3 megohm
2 watt	5 megohm

Recommended maximum value of resistance versus power rating for high humidity applications.

Table 7-6

Resistor	Length	Diameter	Working Volts
1/4 watt	0.406	0.170	250
1/2 watt	0.468	0.249	350
1/2 watt	0.655	0.249	350
1 watt	0.718	0.280	500
1 watt	1.28	0.310	500
2 watt	1.41	0.405	500
2 watt	1.78	0.405	500

Maximum working voltage versus power and physical dimensions.
Composition Type Resistor

Table 7-7

SPECIFICATIONS Resistors - fixed			
PHYSICAL	Closure	ELECTRICAL	Temperature Coefficient
Type	Insulated	Resistance	Voltage Coefficient
Wire wound	Non-insulated	Value	Humidity
Composition	Metal	Tolerance	Noise
Dimensions	Cement	Insulation	Impedance
Overall	Vitreous	Voltage breakdown to ground	Operating frequency
Leads	GENERAL	Leakage (element to ground)	
Lugs	Soldering Test	Rating	
Mounting	Thermal Shock	Power	
	Mechanical Construction	Voltage	
	Treatment		

Table 7-8

periods of time) is generally of little importance unless the resistance value is quite high. Since it is a function of the physical length and surface protection of the unit it can be controlled by the proper choice of specifications. Salt water immersion and thermal shock tests are not required for general design applications.

Shelf Life

The shelf life of present day resistors is relatively good because of the controlled curing methods used during the manufacturing process. An improperly cured resistor (moisture not excluded) will gradually dry out over a long period of time and consequently change in value. The probability of this occurring is so slight that shelf life is seldom a factor to be considered. (Approx. 2%).

High Frequency Characteristic

High frequency characteristics as shown in Fig. 7-5 seldom present any problems since in most applications the unit is bypassed for these frequencies. The change in resistance may be appreciable and is mainly the result of internal capacitance and capacitance between leads. Typical capacitance values are 1.0 mmf for a 1/2 watt unit and 0.5 mmf for the 1 watt size.

Design continued

Temperature Characteristic

The temperature characteristic (Fig. 7-6) must be taken into account with carbon type resistors. The resistance decreases with an increase in temperature, either ambient or that due to power dissipation and is often a controlling factor in the choice of ratings. In addition to the normal temperature characteristic, a further change is likely to be experienced due to soldering. Small (1/4 watt) resistors are subject to as much as a three percent change (approximately one half of which may be permanent) while larger units usually are not affected more than one percent.

Rating

The rating or power handling capacity is determined by the amount of power the unit can dissipate without showing signs of deterioration. The heat dissipation varies with the construction, physical size and thermal conductivity of the case, type of lead joint and type of resistor element. The maximum recommended temperature rise for a composition type of resistor of representative design is indicated in Table 7-5.

Since there are so many variables affecting the power handling capacity of a resistor the only conclusive test is a life test at recommended maximum continuous working voltage, on 1 1/2 hours, off 1/2 hour, for a period of 1000 hours. An accelerated test which simulates the normal life characteristic consists of operating the resistor for 100 hours with 150 percent of normal rating, for nominal ratings of less than two watts. More uniform results are obtained if the initial and final measurements are made at two percent of normal rating. At the completion of the test the resistance should not be changed more than plus or minus ten percent from the initial value.

Noise

Due to fluctuations in the contact resistance, when d-c flows through the unit, noise is generated. A typical 1/2 watt unit will develop a noise voltage of the order of two microvolts at rated load. Standardized noise measurements are made by comparing a known 1000 cycle source with the noise developed at normal ratings. A special Standardized RMA test setup consisting of an amplifier, filter and vacuum-tube voltmeter is employed.

Derating Curve - Composition Type Fixed Resistor

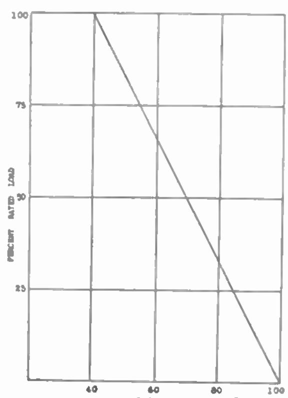


Fig. 7-7

APPLICATION

Composition Type Resistors

Carbon

Composition carbon-resin type resistors are the generally accepted standard for practically all low power applications. Recommended practice limits the power dissipation to 60 percent of normal rating for long troublefree life (after derating for ambient conditions). Non-insulated composition resistors are not recommended for high speed production designs because of the danger of shorting to other components.

High humidity (95%) for long periods results in the formation of a moisture film which is effectively in parallel with the resistor element. The maximum value should therefore be limited when humidity is a factor. Recommended maximum values for various power ratings are given in Table 6. Wax or other moisture resistant treatment may be specified to improve this condition when necessary.

Maximum working voltages depend essentially on the physical dimensions (and power) and should be limited as shown in Table 7-7.

Metalized Film

Metalized film type resistors are generally limited to special high frequency applications where low capacitance is desired.

Wire-wound Composition Case

Composition wire wound element resistors are usually limited to circuit applications requiring values under 470 ohms. They are generally more stable than the carbon type and have exceptionally low noise characteristics. Due to the relatively high inductance of this type resistor it is good practice to limit its application to audio frequencies and d-c.

Compensating

This composition type resistor is recommended for circuit applications requiring low surge voltage or limited regulation. An extensive range of compensation is available commercially.

SPECIFICATIONS

The specification of composition type resistors in general follows that of the wire wound type and reference should be made to this subject as previously discussed.

Composition Type Resistor Standard Color Code

Color	Represents
1st	First significant figure of resistance value in ohms.
2nd	Second significant figure
3rd	Multiplier
4th	Tolerance (if used). No color indicates ± 20%

Color	Significant Figure	Multiplier	Tolerance
Black	0	1	
Brown	1	10	
Red	2	100	
Orange	3	1000	
Yellow	4	10000	
Green	5	100000	
Blue	6	1000000	
Violet	7	10000000	
Gray	8		
White	9		
Gold	—	0.1	± 5%
Silver	—	0.01	±10%
No-Color	—	—	±20%

Table 7-9

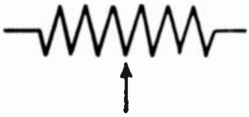
**Composition)
Preferred Resistors (Fixed**

Resistance	Tolerance 5%	10%	20%
1	·	·	·
11	·		
12	·	·	
13			
15		·	·
16	·		
18	·	·	
20	·		
22		·	·
24			
27		·	
30			
33	·	·	·
36	·		
39	·	·	
43	·		
47	·	·	·
51			
56	·	·	
62	·		
68	·	·	·
75	·		
82	·	·	
9.1	·		

Resistance values may be multiplied by any multiple of 10 up to 20 megohms.

Table 7-10

RESISTORS
VARIABLE



DESIGN

Two types of variable resistors are commonly employed in radio applications; (1) composition and (2) wire wound. The latter can be subdivided into low and high power units having a wattage dissipation of four and twenty-five watts respectively. (Higher power units are available but are seldom required).

For all practical purposes the characteristics of the wire wound and the composition types are so similar that they can be discussed concurrently.

Electrical Considerations

Resistance

Practical production designs are limited in resistance to maximum values of approximately five megohms for the composition type and 10,000 ohms for the wire wound. The use of higher values results in more difficulty in manufacturing and consequently more rejects (assuming standard tolerances) thereby increasing the cost per unit.

Tolerances are normally $\pm 20\%$ of the stated maximum; closer tolerances can be supplied if necessary although this will increase the cost because of special testing and the necessity for selecting units to meet specifications. Tolerances at intermediate points on the resistance curve should allow for the accuracy in setting the control. This amounts to $\pm 3\%$ of the rotation and is in addition to the $\pm 20\%$ specified resistance value.

Curve Shape

A wide variety of resistance curves are available with the composition type control and it is advantageous to specify one of these rather than a "special" even though special curve shapes are possible. Wire wound controls generally have a linear characteristic, although, here again a taper can be manufactured at an increased cost if necessary. Typical curve shapes are shown in Fig. 8-5.

Derating Curve - Wire Wound Variable Resistor

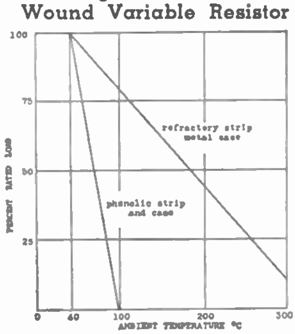


Fig. 8-1

Derating Curve - Composition Type Variable Resistor

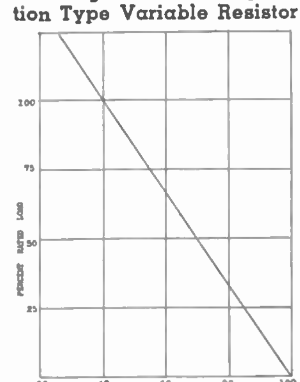


Fig. 8-2

Design continued

Leakage Resistance

The normal leakage resistance of case to ground (for composition type units) is important in certain AC/DC applications. This does not impose any particular hardship on the manufacturer with present day designs and can be met without difficulty. The effect of humidity on leakage resistance is sometimes serious and if this is a factor it may require special recessed terminal arrangements and completely enclosed sealed cases. These effectively keep out dust or other harmful foreign matter which might otherwise decrease the useful life of the unit. Humidity effects are seldom serious as far as overall resistance is concerned. A $\pm 10\%$ change is reasonable and can usually be tolerated.

Because of the low resistance values of the wire wound type, factors such as leakage resistance and humidity effects become relatively unimportant.

Noise

The generation of electrical noise is particularly obnoxious in any variable resistance control. Its magnitude and objectionable quality are dependent upon the circuit application and the design. Noise is often a function of the curve shape and resistance; any irregularities in the resistance versus angular rotation curve are likely to be a source of trouble. This also applies if the "hop-off" resistance is too high (point where the contact leaves its end position).

Improved operation from a noise standpoint can be achieved by eliminating metal to metal contact, that is, through the use of a spiral rotor connection instead of the usual metal sliding contact. In the composition type unit a molded element is to be preferred to the coated phenolic construction although the latter is entirely satisfactory for most applications.

Variable Resistor Applications

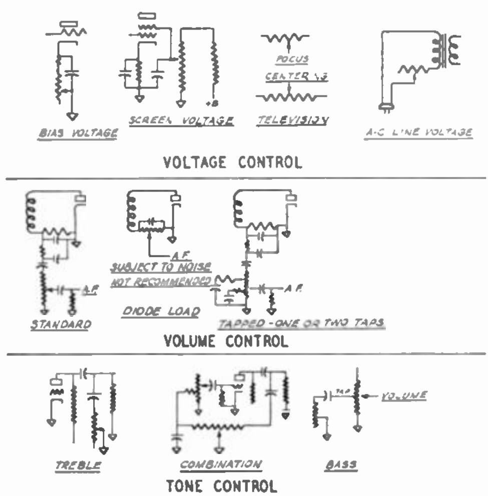


Fig. 8-3

Ratings

The rating of a wire wound unit depends on the material employed for the winding form. The maximum operating temperature for phenolic should be limited to 110°C in free space at an ambient of 40°C, while temperatures of 1000°C are permissible when a refractory form is employed.

General practice limits the phenolic type to a power dissipation of 4 watts with a maximum surface temperature of 60°C. Higher temperatures result in a gradual disintegration of the phenolic strip. It should be noted these temperatures are for free space conditions which rarely exist in actual practice, therefore for practical applications the units should be derated as shown in Fig. 8-1. Full ratings apply down to 75% of maximum resistance; below this point 90% of full rating should be used.

Refractory winding strips are designed on the basis of a 300°C hot-spot temperature (again in free space). Since actual practice never duplicates this condition, derating should be applied.

The power handling capacity of composition type controls is usually limited to a maximum of one-half watt or 500 volts, whichever is the smaller. Like the wire wound type they are subject to considerable derating as recommended in Fig. 8-2. A further derating of approximately 50% should be applied for resistance curves having a taper.

Typical Curve Shapes - Composition Type Controls

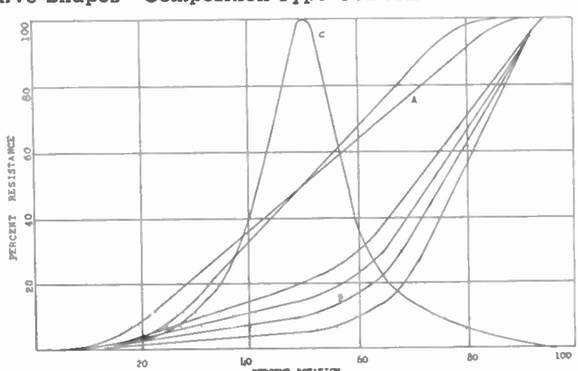


Fig. 8-5

Mechanical Considerations

Mechanical dimensions often vary between manufacturers and for this reason it is standard practice to specify the control by maximum permissible dimensions. Of course the location of the locating pin should be given although this dimension has been generally standardized. Other important mechanical items are:—length, thread and diameter of the mounting bushing; length, diameter and type of shaft; terminal type and location, when important; and any special grounding requirements. Mechanical details are shown in the outline drawing of Fig. 8-4.

Life

Life requirements are generally specified as the number of cycles which the control must withstand without undue mechanical wear and

Design continued

with a specified maximum noise voltage. This varies from 10,000 to 25,000 cycles at not greater than 10 complete cycles per minute.

Rotation

The specification of the degrees rotation (clockwise or counter-clockwise) is only important in special cases, as for instance where a knob has an indicator which must be located with respect to markings on the cabinet, or where the control shaft must operate a separate switch or other mechanism at some specific point of rotation. It should be noted that when an internal or built-in switch is an integral part of the control the effective degrees of resistance change is decreased. This will vary between manufacturers and, like the total rotation, is only important in certain applications.

Torque

The operating torque is another item seldom specified unless for special applications where severe vibration is encountered.

APPLICATION

The application of variable resistors can be divided into three groups; (1) voltage, (2) volume and (3) tone control; typical schematic diagrams of which are shown in Fig. 8-3.

Voltage

Voltage control applications require the dissipation of a certain amount of power. In order to keep the physical size of the control to a minimum the unit should be located in such a manner that good ventilation and good thermal conductivity is obtained. If necessary chassis ventilating openings (louvres or holes) may be employed, although if not properly designed these may violate the requirements of the Underwriters. It is good practice to mount such controls against a large metal surface rather than on a small bracket since the latter does not effectively conduct the heat away from the resistance element. The choice of metal cased-refractory form units is to be preferred over phenolic materials for good heat conductivity.

The actual rating is determined by a combination of the extent of the thermal conduction, ventilation and actual operating temperatures. Units are then derated accordingly. Adequate allowances should also be made for maximum voltages taking into account all possible variations of tolerance.

Volume

Volume control applications usually require special resistance curves to give the effect of a linear increase in volume with equal increments of angular rotation. Such curves are fairly well standardized as shown in Fig. 8-5 and can be obtained in either a clockwise or a counter-clockwise rotation. The danger of departing from one of the standardized curves lies in the fact that the control is likely to be noisy because

Application continued

of abrupt changes in resistance or too high a hop-off value. Of course it is possible to deviate from the curves now being manufactured but the minor change in performance attainable and the chances of not obtaining as smooth a control are factors that make it inadvisable.

Resistance values of course depend upon the circuit requirements and are not ordinarily critical. The use of a tap for bass boost circuits also depends on the circuit requirements. One or two taps are available in a variety of positions depending on the requirements. The main precaution in the use of taps is to prevent any great discontinuity in the curve shape which will result in noisy operation.

Tone

Many methods of adjusting the tone of a receiver or amplifier have been proposed but general practice has narrowed the field to the variable-resistor-fixed capacitor type circuit.

The degree of tone compensation varies of course with the circuit constants and the tubes employed. The higher the load resistance, the more effective a given value of capacitance can be. Curve shapes are chosen to obtain a linear variation in tone with a linear rotation of the control. Curve B in Fig. 8-5 is recommended for most applications (either clockwise or counter-clockwise) where separate bass and treble controls are employed. Curve C is recommended for combination bass-treble applications.

Line switches are included in many tone control applications so the unit can be turned on or off without disturbing the volume level.

SPECIFICATION

In general, variable resistors are quite similar in physical appearance and mechanical construction, but because of the many possible circuit applications and diverse operating conditions, their specification often becomes quite involved. The major items to be considered are resistance value and curve shape, noise, and mechanical dimensions.

SPECIFICATIONS Resistors - variable			
PHYSICAL	Knurl	**Bushing**	**Leakage Resistance**
Dimensions	Slot	Length	To case
Overall diameter	Insulated	Thread	Humidity
With terminals	Non-insulated	**ELECTRICAL**	**GENERAL**
Without terminals	**Locating Pin**	**Resistance**	**Life**
Maximum depth	Angular position	Value	Cycles
With switch	Dimensions	Tolerance	**Torque**
Shaft	**Rotation**	Tap or taps	Ounce-inches
Length	Minimum degrees	Location	**Line Switch**
Diameter	With switch	Hop-off	Type
Flat	Without switch	**Curve**	Off position
Position		Shape	Cover
		Tolerance	

Table 8-1

Specification continued

Of lesser importance (in most applications) are life, leakage resistance, temperature and humidity requirements, operating torque and degrees rotation.

The specification data sheet and outline drawings are, in general self-explanatory. A few items, however, should be more detailed and are discussed below.

Mechanical

General

Overall dimensions should be specified as the maximum allowable, not including terminals. These should be given separately as shown. The maximum alowable depth should include any switch lugs if employed and is measured from the front mounting surface.

Shaft

A shaft diameter of 0.250 inches +0.001, —0.003 inches is standard. Lengths up to 2¾ inches in steps of 1/16 inch are standard. Flats for knobs ⅝ inches long may be obtained at any desired angular position, with widths of 0.218 or 0.156 inches. Knurling may also be specified as shown in the outline drawing.

Mounting

Locating pins are generally located on a radius from the axis of 7/16 inches for controls up to 1-1/16 inch diameter, and 17/32 inches for controls over 1-1/16 inch diameter. Bushings are standardized with a ⅜-32 thread in lengths of ¼ or ⅜ inches. This dimension is measured from the mounting surface. The ¼ inch length is not recommended for shafts longer than 1¾ inches.

Other mechanical items such as torque, life and degrees rotation are not generally specified unless special applications make them critical.

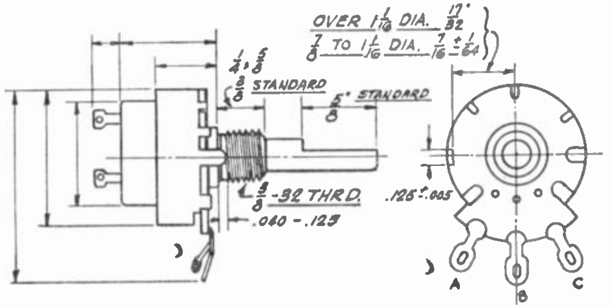
Electrical

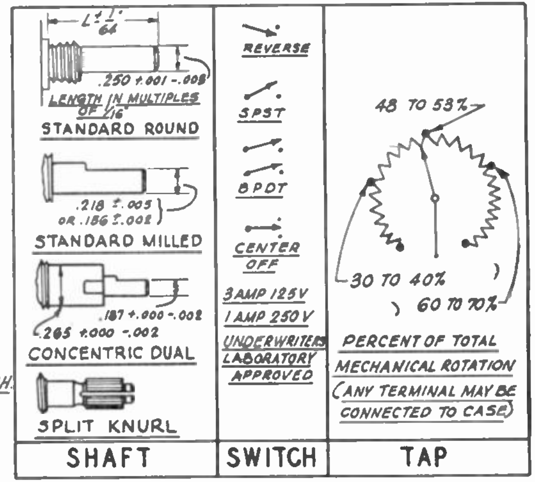
Tolerance

A tolerance of ±20% is considered standard practice for the overall resistance and intermediate points. In addition a ±3% tolerance is assumed as the accuracy of setting the angular rotation. Hop-off resistance and degrees rotation are only important in certain applications and are specified as a minimum allowable value.

Noise

A maximum permissible noise voltage specification is important when the unit is employed as a volume control and should be specified under certain test conditions.

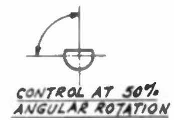




TYPES:-
SINGLE, DUAL TRIPLE WITH OR WITHOUT SWITCH.

GENERAL NOTES:-
RESISTANCE CURVE SHALL BE GRADUAL AND SMOOTH THROUGHOUT RANGE. ALL FERROUS PARTS MUST WITHSTAND NORMAL HUMIDITY. IN ALL RESPECTS NOT INDICATED PART SHALL BE EQUIVALENT TO APPROVED SAMPLE.

TYPE	DIMENSIONS			SHAFT				BUSHING	SWITCH			LIFE	
PART NO.	DIAMETER	WITH LUGS	DEPTH	TYPE	INSULATED VOLTS BRKDWN	LENGTH	FLAT LOCATION	LENGTH	TYPE	TORQUE	DEGREES ROTATION	CYCLES	RATE

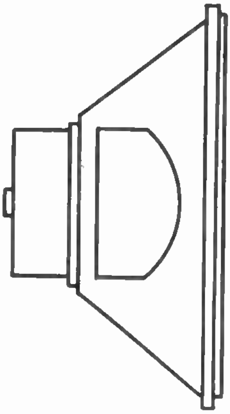


FLAT LOCATION

RESISTANCE								POWER	TOLERANCE
OVERALL	TAP 1	TAP 2	TAP 3	CURVE	MIN DEGREE ROTATION	WIRE-COMPOSITION	HOP OFF	WATTS	±3% ROTATIONAL AND ±20% AT INTERMEDIATE POINTS ±20% OVERALL. HOP OFF-MAX. 0.02% OVER .25 MEGOHM 0.02% OR 10Ω UNDER .25 MEGOHM.

Fig. 8-4

LOUD SPEAKERS
PERMANENT MAGNET
ELECTRO-DYNAMIC



DESIGN

General Considerations

Dynamic speakers may be divided into two classes according to the type of field structure employed. The designs are so similar however that it is convenient to discuss the factors influencing their characteristics together.

Fidelity and Range

Tonal balance in many respects is more important than obtaining good high or low frequency response. Without tonal balance a receiver may sound "boomy" or "thin," yet with a good balance the frequency range may be quite limited and still be satisfactory. A general rule is to design so that the product of the low frequency and high frequency cutoffs equal 500,000 to 650,000 as shown in Fig. 9-1. Unless the frequency response falls reasonably close to the curve shown the fidelity lacks a certain naturalness and is often objectionable to the ear.

Spatial Distribution

The ordinary speaker usually has a poor spatial distribution curve which results in an apparent change in reproduction as the listener moves about the room. A typical polar characteristic, together with sound pressure curves which illustrate the effect, is shown in Fig. 9-2.

There are several methods (Fig. 9-3.) of improving such a characteristic; (1) by the use of a diffuser element, (2) the design of the cabinet grille, (3) the use of a multi-cellular horn type tweeter and (4) a combination coaxial speaker with diffuser for the high frequency unit. Incidentally, in the coaxial type speaker the tweeter improves the polar characteristic of the low frequency unit at the high end of its range.

Effect of Cabinet

Of equal importance in obtaining good speaker response is the design of the cabinet. Fortunately most radio cabinets are designed such that the speaker is not located at the center of a square housing. Such a design would result in an appreciable discontinuity in the response curve as shown in Fig. 9-4. The frequency and amplitude of the dip being determined by the physical dimensions of the cabinet and occurring at the point where the radiation from the

Tonal Balance Curve - Showing Recommended High and Low Frequency Cutoff

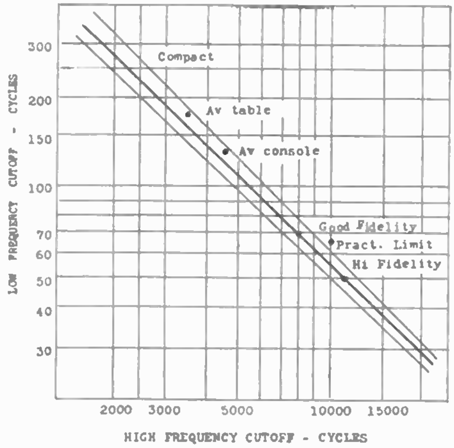


Fig. 9-1

Design continued

front and back of the cone cancel. Radiation from the front and back are 180 degrees out of phase. The front to back distance should be at least one-quarter wavelength for the lowest frequency desired. In the usual cabinet where the paths are unequal this does not occur.

Another common error, when two similar speakers are used is to mount them equally spaced from the edges of the baffle and as far apart as possible. Instead the two speakers should be located close together and somewhat off center. The cones, which are in phase of course then load each other more effectively and a more efficient coupling to the air is obtained. The result—a better low frequency response.

Improved low frequency response can also be obtained by the use of acoustical labyrinths and bass reflex* enclosures. It should be noted that the thickness of the wood is also a factor in obtaining good reproduction. Cabinets built with thin materials have a tendency to vibrate along with the speaker cone, which obviously is not desirable.

Cones

The frequency response due to the speaker cone depends upon several factors, namely; size, shape, material, treatment and constructional features. Because the response depends on so many factors it is very difficult to analyze or predict with any degree of accuracy, although from past experience several general tendencies can be indicated.

Spatial Distribution - Typical Speaker Without Sound Diffuser

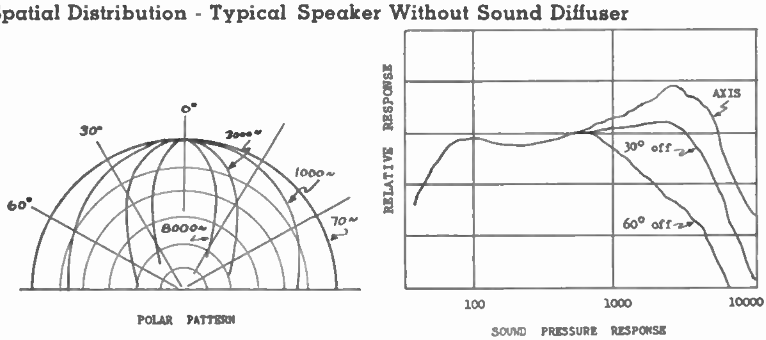
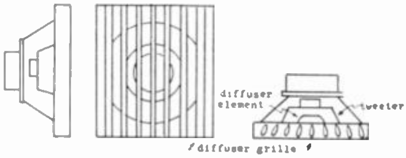


Fig. 9-2

The apparent increased efficiency in the vicinity of 2500 cycles in most speakers is due to reflections of the propagated sound wave (radially) from the outer edge of the cone back to the apex in a period of one half cycle. This effectively decreases the mass reactance which obviously results in increased efficiency or effective output. The intensity of the effect may be controlled by the choice of "soft" cone materials, the use of corrugations to break up the wave or a decrease in cone rigidity by specifying a shallow cone. Some designers use a combination cone where the center section is made of a fairly stiff paper which retains its rigidity, and the outer section is made from a soft paper to break up cone resonance effects.

* Reg. trade mark Jensen Manufacturing Co

Coaxial Speakers with Diffusers



Multicellular Horn - Speaker Combination
Typical Speaker Arrangements for High Fidelity Applications

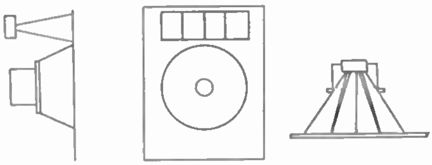


Fig. 9-3

The diameter of the cone determines to a large extent the useful limit of the low frequency response. Fig. 9-5 shows a typical comparison for cones of various diameters. The example shown does not take into consideration resonance effects due to the voice coil support but does indicate the general increased low frequency response to be expected with an increase in cone diameter. Cones having a diameter greater than 12 inches are seldom specified, for cost reasons, in the average design. It should be pointed out that the mass of the cone must be kept as low as possible otherwise no advantage is obtained in the use of a larger diameter, in fact with a poor design the low frequency response of a 12 inch speaker is inferior to that of an 8 or 10 inch diameter cone.

The efficiency of a cone type speaker is relatively low, being of the order of two to five percent. This may be tremendously improved (approximately to 40 or 50 percent) by the use of a horn to increase the radiation resistance or ability to "take hold" of the air.

Field Coils and Magnets

The industry standardization program has recommended the use of three weights of magnets for each of the three pole piece diameters. The design engineer thus has a choice of magnet size which permits a control over the sensitivity and output level. Each increase in magnet weight represents an increase in output level of approximately three decibels. The choice of magnet size therefore becomes a problem in economics; whether the increased magnet cost is justifiable from a performance standpoint or whether it might be more economical to increase the electrical output of the audio amplifier.

No standardization has been proposed for electro-dynamic field coils since the application of this type of speaker is so varied. Filtering and voltage requirements differ so greatly between de-

Effect of Baffle Shape on Response Curve

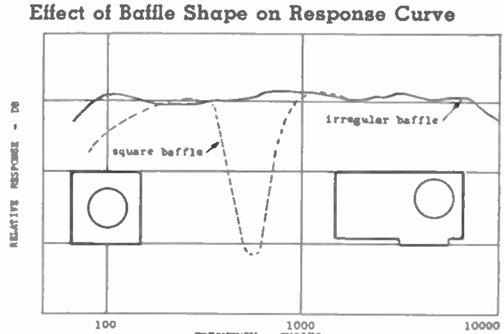


Fig. 9-4

Design continued

signs that it is quite difficult for even a single manufacturer to standardize his entire line. A general rule of thumb used by many designers is to specify the field coil dissipation equal to the electrical power output of the receiver. In other words one watt in the field for each watt of power output to be handled by the speaker. This ordinarily provides sufficient flux in the air gap for efficient operation. Of course the wire size determines the ampere-turns in the field and therefore must be given due consideration. Never exceed a current density of 1200 circular mils per ampere, in fact 900 circular mils per ampere is considered by many as a maximum.

The temperature rise in the winding is the final criterion and should be checked under actual operating conditions before final specifications are released. As an aid in deciding changes in wire size the following information is useful.

With a given resistance a change of one wire size results in a change in turns by a factor of 1.16.
With a fixed number of turns a change of one wire size changes the resistance by a factor of 1.20.

Care should be taken to provide for adequate flux in the gap otherwise the low frequency resonance of the voice coil-cone will be quite pronounced and may even result in mechanical damage to the unit. The response curve Fig. 9-6 shows the effect of insufficient flux to damp the low frequency resonance (apex support) of a typical speaker. There is an optimum flux density for each particular design which can best be determined experimentally. A certain degree of undamped resonance is sometimes desirable and is commonly used to enhance the low frequency response.

Voice Coils, Air Gaps and Pole Pieces

The mechanical dimensions of the air gap structure has been

Standardized Air Gap and Magnet Dimensions

Air Gap Dimensions

Center Pole Diameter	Air Gap Length	Annular Hole Thickness
9/16"	0.029"	0.156"
¾"	0.033"	0.187"
1"	0.038"	0.250"

Magnet Weight & Length

Center Pole Diameter	Air Gap Length	Weight of Magnet	Length of Magnet
9/16"	0.029"	0.68 oz	0.430"
		1.00 oz	0.522"
		1.47 oz	0.626"
¾"	0.033"	1.47 oz	0.535"
		2.15 oz	0.648"
		3.16 oz	0.765"
1"	0.038"	3.16 oz	0.633"
		4.64 oz	0.748"
		6.8 oz	0.970"

Table 9-1

standardized by the industry as shown in Table 1. (Small and medium speakers only). These dimensions confine the structure of the voice coil to rather narrow limits with respect to thickness. However, they represent the results of years of intensive research, manufacturing experience and field operation and for this reason it is standard practice to accept them without further questioning. Experience has shown that smaller air gaps which would increase the sensitivity are definitely not recommended because of the greater possibilities of slightly distorted voice coil forms striking the pole face or center piece.

Speaker Response Curves - Showing Effect of Cone Diameter on Low Frequency Characteristic. Amplitude of Low Frequency Resonance Depends on Air Gap Flux.

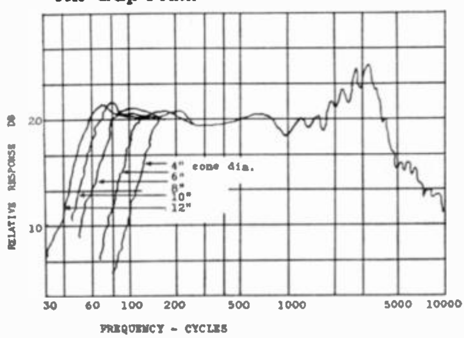


Fig. 9-5

The impedance of the voice coil has been standardized at 3.2 ohms for all speakers having a maximum pole piece diameter of not over one inch. Since this includes the majority of speakers the main consideration resolves itself into what diameter pole piece or voice coil should be employed for a given application. In general a 9/16 inch diameter pole piece is satisfactory for handling one to two watts of electrical output. Power outputs up to four or five watts require a pole piece diameter of ¾ inch. Above five watts and up to a maximum of ten a one inch pole piece is recommended. Many engineers prefer to specify two speakers at this level, particularly in a high quality design. Power output above 10 watts require a more substantial design as shown in Table 2 where the field excitation may be of the order of 20 watts with a voice coil diameter of 1½ to 2 inches.

Underwriters Requirements

Two separate groups of requirements are specified for speakers; (1) applications where the receiver is not conductively coupled to the power supply circuit and (2) applications where the receiver is conductively coupled to the power supply circuit. The first refers to a-c operated devices and the second to a-c/d-c operation.

Effect of Field Excitation on Low Frequency Response. Normal excitation damps low frequency resonance.

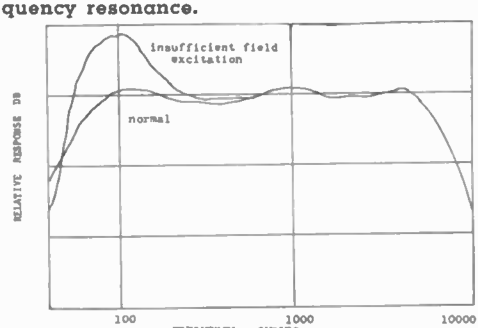


Fig. 9-6

Design continued

Isolated (A-C) Applications

The speaker field and output transformer leads if spliced over the outside winding must be protected with an insulating wrapper of not less than 1/32 inch in thickness. If the leads terminate in a plug the insulation should extend to the prong of the plug. Insulation having a minimum thickness of 1/64 inch should cover all otherwise exposed exterior conductors.

Coupled (A-C/D-C) Applications

Insulation having a minimum thickness of 1/32 inch should be employed around the outside of the speaker field. Both the field and the output transformer must withstand operation for seven hours on either 120 volts A-C or D-C (whichever produces maximum temperature rise) without the maximum temperature exceeding 175° C (ambient temperature of 25°C). In lieu of satisfying these requirements the field and output transformer must be completely enclosed in an non-combustible enclosure.

APPLICATION

The choice of a specific type and size of speaker for a particular application depends on many factors, some of which are not of a strict engineering nature. For example, the cone diameter may be chosen because competition in the same price field feature a certain size.

From an engineering standpoint only a few basic facts need be considered.

1. Provide adequate power handling capacity by the choice of the correct voice coil diameter.

2. Select the field excitation (whether electro-magnetic or permanent magnet) to provide sufficient flux in the gap for the power output to be handled. Cone excursions that force the voice coil out of the constant flux area should be avoided. As mentioned previously a good rule of thumb is to make the field power approximately equal to the output power of the amplifier.

3. Choose a mechanical design that is sturdy and satisfactory from a mechanical layout standpoint.

4. Provide for adequate hum bucking and phasing where required.

5. Set up sufficient test specifications to insure uniformity and quality as represented by an approved sample. Recommendations for such tests are given in Fig. 9-7.

Standard Speaker Test Methods

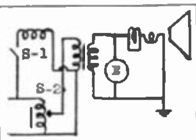
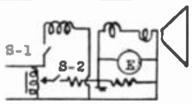
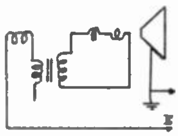
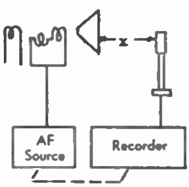
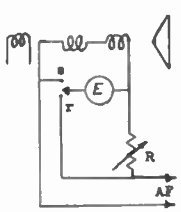
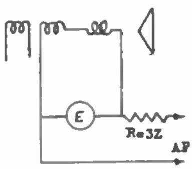
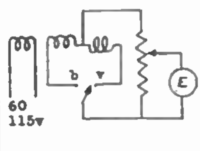
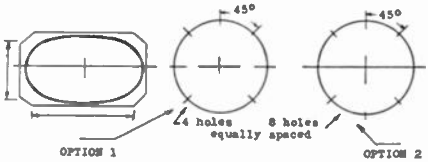
MEASUREMENT	SCHEMATIC	NOTES
Phasing - (field coil, voice coil and output transformer.		With bucking coil shorted, close switch S-1 (switch S-2 open) and note reading of E. Reverse switches (S-1 open, S-2 closed) and adjust input voltage to indicate same voltage as previously noted. Close switch S-1 and the voltage E will increase if phasing is correct.
Phasing - (field coil and voice coil)		Measure same as above. With both switches closed E will increase if phasing is correct.
Voltage Breakdown		Apply 60 cycle test voltage between frame and field winding for a period of 10 seconds. If output transformer is mounted on speaker connect one side of primary to field as shown. Insulation must withstand specified voltage for period indicated.
Frequency Response (sound pressure)		Apply constant amplitude variable frequency input to speaker mounted on a specified baffle and spaced at a specified distance from a calibrated microphone. Speaker field should be energized with rated current. Recorder and AF source should be suitably coupled mechanically to correspond with recorder graph paper. Recorder adjustment is varied to keep recorder output constant as frequency is varied over the range. See typical sound pressure curves in text.
Voice Coil Impedance		Field should be energized with rated current. No baffle or reflecting surface nearby which will affect the impedance. Adjust input from a low impedance audio source (having a relatively uniform amplitude-frequency response at the low frequency end of the range) to 0.5 volt across voice coil-bucking coil combination at first frequency above fundamental resonance of the moving system at which E is minimum. Adjust R until E is equal when switch is thrown. Impedance is then equal to d-c resistance of R.
Resonance		Field coil should be energized with rated current. No baffle or reflecting surface nearby. Adjust audio input for low reading on Voltmeter E and vary frequency until maximum voltage is indicated. Readjust input to 1.0 volt and recheck frequency adjustment for maximum. Repeat if necessary until voltmeter indicates 1.0 volt maximum; frequency of input is then resonance of speaker.
Hum Bucking		Field coil should be energized with 60 cycle 115 volts (approximate) and induced voltage in voice coil measured on a high impedance sensitive a-c volt-meter. With switch set for measuring indicated voltage across voice coil adjust potentiometer until meter reads 100 divisions. Throw switch and measure induced voltage across bucking coil. $\% \text{ Hum bucking} = 100 \dfrac{\text{volts induced in b}}{\text{volts induced in v}}$ Plus 100% indicates overbucking, minus 100% underbucking. Commercial tolerance is ± 15%.

Fig. 9-7

Standard Commercial Speaker Mountings

Nominal Speaker Size	Hole Option	Mounting Diameter	Minimum Hole Diameter
3½	1	3 15/16	3/16
4	1	4 11/16	0.200
5	2	4 11/16	0.200
5¾	2	5⅜	0.200
6½	2	6⅛	0.200
8	2	7⅝	7/32
10	1	9⅝	7/32
12	1	11 9/16	¼
15	2	14 9/16	17/64
4x6		3⅝x4⅝	0.200
5x7		4½x4 11/32	0.200
6x9		4¾x6⅝	0.200



NOTE: Where radial slots are used in place of circular holes they should include in their cross-section the equivalent circular hole indicated under minimum hole diameter.

Fig. 9-8

Random Wound Field Coils - Enameled Wire

AWG Size	Turns per square in.	Ohms per cubic in.	Pounds per Ohms
20	794	0.672	0.305
21	987	1.05	0.192
22	1255	1.69	0.121
23	1525	2.59	0.0758
24	1933	4.14	0.0477
25	2428	6.55	0.0299
26	3080	10.48	0.0188
27	3891	17.6	0.0119
28	5001	27.3	0.00746
29	6200	42.4	0.00470
30	7797	67.1	0.00295
31	9800	106.2	0.00186
32	12210	166.9	0.00117
33	15740	271.5	0.000735
34	19520	425.	0.000461
35	24680	677.	0.000290
36	31280	1082	0.000183
37	38500	1681	0.000115
38	49350	2720	0.0000721
39	63400	4370	0.0000454
40	67500	5910	0.0000285

Allow approximately 1/16" on all sides of gross winding space for insulation.

NOTE:

Normal space factor without insulation between layers is assumed. When "hum bucking" coil is used allow approximately ⅛" winding space. Values are average and are representative of commercial practice. For cost purposes weight of copper may be calculated by:

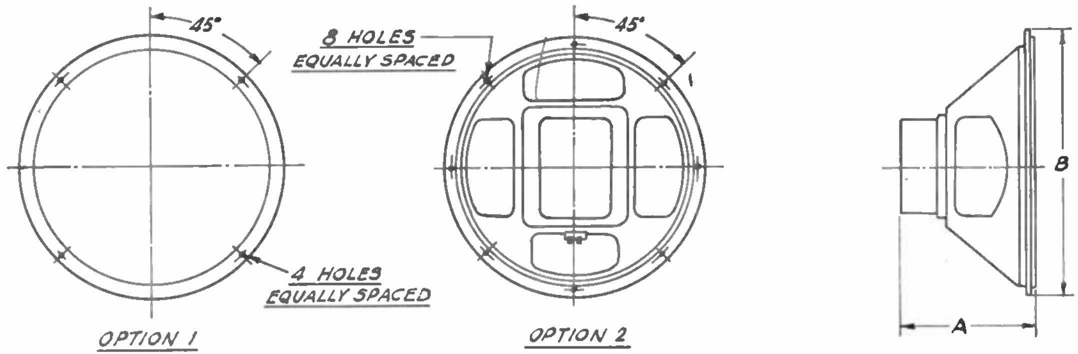
Pounds = resistance x lbs/ohm.

Table 9-3

SPECIFICATIONS Loud Speakers - electro-dynamic / permanent magnet			
PHYSICAL	Plug	ELECTRICAL	Resonance
Dimensions	Coding	**Field**	Cycles
Overall	Location	Electro-magnetic	Tolerance
Mounting	Type	Resistance	**Output Transformer**
Pole piece	**Finish**	Wire	Primary inductance
Terminals	Plating	Size	D-C current
Lugs	Paint	Insulation	Matching impedance
Type	GENERAL	Watts dissipation	Core size
Location	**Tests**	Permanent magnet	Material
Coding	Buzz	Material	Efficiency
Leads	Rattle	Weight	Leads
Length	Frequency range	**Voice Coil**	Terminals
Location	Voltage	Impedance	
Coding	**Impregnation**	Bucking	
	Temperature	Percent	
	Humidity	Test voltage	
	Underwriters		

Table 9-4

Specifications - Loud Speakers



SPECIFICATIONS :-

PART NO.	FIELD			VOICE COIL			DIMENSIONS					RESONANCE
	RESISTANCE ± %. MAGNET WEIGHT OZ	WIRE SIZE MATERIAL	WATTS	IMPEDANCE OHMS ± 10%	TEST VOLTS	POLE PIECE DIAMETER	A	B	MOUNTING OPTION	MOUNTING HOLE SIZE	MOUNTING DIAMETER	FREQUENCY CYCLES ± %

TERMINALS (CODING AS INDICATED)						OUTPUT TRANSFORMER						TESTING				
LEAD LENGTH (INCHES)				PLUG TYPE LOCATION	LUGS TYPE LOCATION	MIN. L. PRIMARY	D.C.	MATCHING IMPEDANCE	LOCATION	APPROX. CORE SIZE	EFFICIENCY	HUM BUCKING % TOTAL	PHASING	UNDERWRITER	RESPONSE	VOLTAGE BREAKDOWN
C	D	B	A													

GENERAL :-
SPEAKER MUST CONFORM TO APPROVED SAMPLE IN ALL RESPECTS NOT INDICATED.
ALL FERROUS PARTS TO BE PLATED OR PAINTED. ALL PAPER AND COIL TAPE TO BE CHEMICALLY NEUTRAL.
SPEAKER MUST BE DUSTPROOFED. TESTING SPECIFICATIONS INDICATED BY SPEC. NO. AVAILABLE ON REQUEST.

Fig. 9-9

Frequency Range - Speech and Musical Instruments

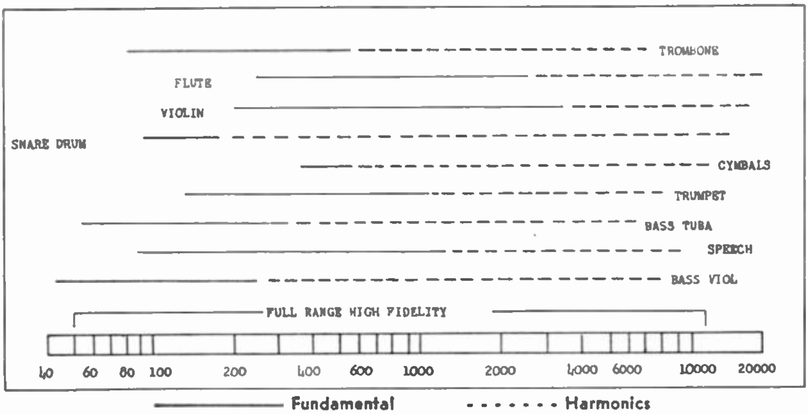


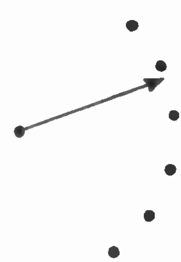
Fig. 9-10

Data: Typical Commercial Designs with Suggested Applications

Size Inches	Nominal Excitation Field Watts	Magnet Ounces	Power Output Recommended	Voice Coil	Resonance	Application
4	2-4	.68-1.47	1.5 watts	9/16	150-250	AC-DC, farm, portable
4 x 6	2-4	.68-1.47	2 watts	9/16	150-250	AC-DC, farm, AC, auto, portable
5	2-4	.68-1.47	2.5 watts	9/16	150-250	AC-DC, farm, AC, auto, portable
5 x 7	4-6	1.47-3.16	4 watts	¾	125-180	AC-DC, farm, AC, auto, portable
6	4-6	.68-1.47	4 watts	9/16	125-180	AC-DC, farm, AC, auto
	4-6	1.47-3.16	6 watts	¾	125-180	AC-DC, farm, AC, auto
6 x 9	5-9	1.47-3.16	4 watts	¾	80-150	Auto, AC
	5-9	3.16-6.8	8 watts	1	80-150	Auto, AC
7	5-9	1.47-3.16	5 watts	¾	100-150	Auto
	5-9	3.16-6.8	8 watts	1	100-150	Auto
8	5-9		5 watts	¾	80-150	AC
	5-9		8 watts	1	80-150	AC
10	9	3.16-6.8	10 watts	1	75-125	AC-DC, AC
12	9	3.16-6.8	10 watts	1	65-100	
12	15	1 lb.	15 watts	1½	65-100	High Quality AC
12	20	2.2-3.2 lb.	25 watts	2	55-100	High Quality AC
14-12	9	3.16-6.8	10 watts	1	65-100	12" cone in 14" frame AC-DC, AC
15	20	1-1.57 lb.	18 watts	1½	55-90	High Quality AC
15	20	2.2-3.2 lb.	30 watts	2	50-90	High Quality AC

Table 9-2

SWITCHES
PUSH-BUTTON
ROTARY
SLIDE



DESIGN

Switches perform a very important function and unless they are properly designed and adequately specified for a particular application the overall performance of the unit will undoubtedly be compromised. Unlike many components a switch must have excellent mechanical as well as electrical characteristics.

They are usually classified in three general design types: (1) rotary, (2) pushbutton and (3) slide, as shown in the outline drawings of Figs. 10-1, 10-2 and 10-3.

Mechanical Considerations

Mechanically a switch should withstand approximately 10,000 cycles of operation without undue signs of failure. The mechanical life (including contact resistance) depends mainly on quality of the design and the proper choice of materials together with their finish. For example, the silver plating on a switch contact would show excessive wear in less than a thousand cycles if the wiping action was not correct, either through improper design or choice of materials.

Switches subject to operation where high humidity is encountered are likely to show excessive corrosive action on the metal parts which require special consideration. Ordinary commercial practice is to employ cadmium plated steel or terne plate for the shaft, end plates and general hardware; the contact clips and rotor blades are usually silver plated brass. Extra protection can be afforded by the use of a water dip lacquer on all cadmium plating or by specifying stainless steel.

Electrical Considerations

Electrically the following items are of major importance; high insulation resistance between adjacent lugs and from lugs to frame, low-loss dielectric, low capacity between lugs and low contact resistance. Most of the electrical items depend upon the quality of the dielectric employed and are therefore controllable to a certain extent. Some improvement in leakage resistance can be obtained by impregnation or similar treatment of the dielectric materials. More often a higher grade material is specified since treatment of the switch wafer before actual fabrication of the switch makes subsequent operations more difficult. Fig. 10-4 indicates typical leakage resistance versus humidity for a variety of wafer materials. It should be noted that the insulation resistance may become quite low, in fact, in some applications where both sides of the wafer is used, the leakage between circuits may be of the order of a few megohms.

APPLICATION

Rotary Type

Rotary type switches are commercially available in from one to six or more sections with or without a-c power switch. The a-c switch may be arranged to operate at any given position.

Application continued

Contacts

Switch contacts are generally of the shorting type in which connection is maintained with one contact until after the next contact is made. In most circuit applications this is desirable. Non-shorting contacts are available, however, if required.

Avoid locating contacts directly opposite one another (both sides of the wafer) unless they are at the same potential. If not at the same potential the contacts must obviously be insulated. This is undesirable because the leakage path is necessarily short (low leakage resistance) and capacitive coupling, which may often be objectionable, will be high.

Only one wiring connection should be made to each lug contact and this should be flexible if possible. An exception to this rule is where the lug contact is fastened by two eyelets in place of the usual one. Twisting of the lug after continued use is thereby eliminated even though the dielectric material shrinks due to aging.

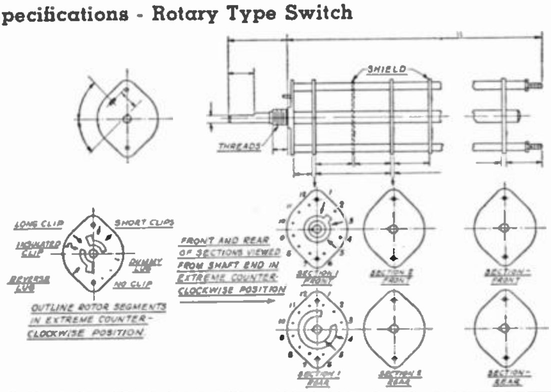
The number of contacts should be kept to a minimum to maintain low actuating torque or pressure requirements.

Contact lugs connecting the grid circuit and high d-c potentials should be separated, preferably on different wafers. When it is absolutely necessary to use the same wafer, a grounded lug should separate the circuits.

Wafers

Wafers should be spaced far enough apart physically to allow access to all wiring connections. Where more than three wafers are required, or the length of the switch exceeds three inches a support bracket should be specified to insure positive switching of the end section. Long switches tend to twist with the result that the rear section often does not function properly.

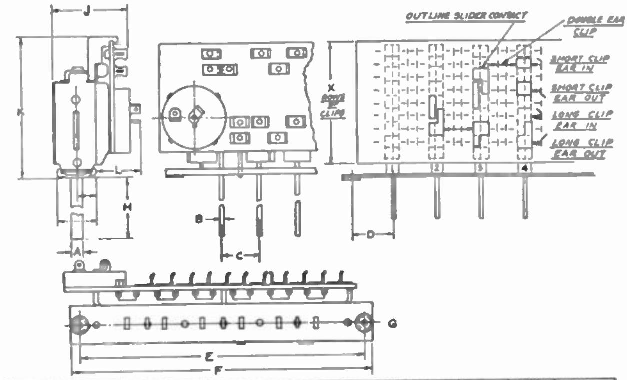
Typical Specifications - Rotary Type Switch



PART NO	SECTIONS	POSITIONS	AC SWITCH TYPE POSITION	TORQUE	LIFE CYCLES	INS RESISTANCE ADJACENT LUGS	DIMENSIONS	VOLTAGE BREAKDOWN CONTACT TO ROTOR

Fig. 10-1

Specification - Push Button Switch



PART №	POSITIONS	SWITCH LOCATION TYPE	INSULATION RESISTANCE CONTACT-CONTACT & TO FRAME	VOLTAGE BREAKDOWN	LIFE CYCLES	TORQUE	HUMIDITY SPEC	GRADE INSULATION

Fig. 10-2

Multi-section switches may be provided with electrostatic shielding between wafers when desired.

General

Standard mounting is 3/8-32 thread bushing either 1/4 or 3/8 inches long. A locating key is available at any angle in steps of 15 degrees from normal center line.

Shafts lengths are available in any length; however, long shafts should be avoided especially with 1/4 inch bushings. Shafts may be specified with a flat, knurl or slot. In the case of a flat it may be positioned at any angle desired.

With the wide variety of rotor contact segments (see Fig. 10-5) and both long and short stator contacts available, practically any circuit switching requirement can be obtained.

Pushbutton Type

Pushbutton switches are quite flexible in so far as unusual combinations of operation are concerned. Each button can be operated independently, each button can be arranged to automatically release all other buttons, or a combination of latching and non-latching buttons can be specified. Two groups of independent interlocking buttons can also be provided. In addition a-c power switches with or without terminal covers can be included on either end position.

Standard center to center spacing of buttons is 5/8 or 3/4 inches with push rods up to six inches in length. From one to 12 or more buttons are available depending on the particular basic design.

Up to 32 contacts per button are readily obtainable; however, as in the rotary type switch, contacts should be kept to a minimum to insure low operating pressure. With a wide variety of rotor contacts available the pushbutton switch is adaptable to practically any circuit requirement.

Application continued

The application suggestions for rotary type switches are also recommended for pushbutton and slide action switches where conditions are applicable of course.

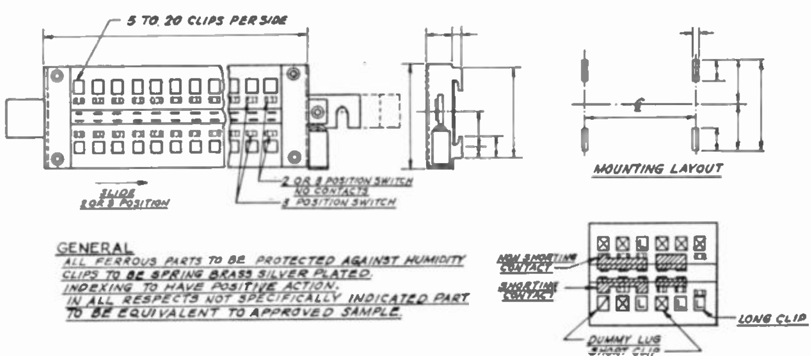
A limitation of the standard pushbutton switch is the difficulty of isolating or shielding contacts and rotors sufficiently to permit switching of high gain stages, or locating circuits of markedly different level on the same section. Also, it is frequently necessary to wire circuits of all pushbutton positions in multiple or series, thus increasing the stray capacities, the number of contacts and wiring operations. Consequently, these switches are not most suitable for r-f band switching, but are more applicable for station selection, phono-radio switching and the like.

Slide Type

Two general types of slide switches are available to the design engineer. One, the simple button type, is supplied with shorting or non-shorting contacts and with or without spring return. These may be ganged together where a single switch does not fulfill the circuit requirements. Principal applications are for tone control, pilot light, phonograph or similar circuits with suggested contact arrangements as shown in Fig. 10-5.

The other type slide switch is especially suited for r-f applications where short, low inductance leads are important. The contacts are spaced on a flat strip in such a manner that the self-inductance of the leads being switched tend to cancel one another. This type of design, besides saving space, permits switching of widely separated circuits with a minimum of long leads. It is particularly adaptable to AM-FM designs.

Specification - Slide Type Switch



PART NO.	POSITIONS		INSULATION		VOLTAGE BREAKDOWN		HUMIDITY	ALTITUDE	OPERATING PRESSURE
	NO.	MOVEMENT PER INDEX	TYPE	RESISTANCE BETWEEN ADJACENT CONTACTS	BETWEEN CONTACTS	CONTACT TO FRAME			

Fig. 10-3

Application continued

Additional information is shown on the outline drawing in Fig. 10-3.

SPECIFICATIONS Switches

PHYSICAL

- **Type**
  - Rotary
  - Slide
  - Pushbutton
- **Dimensions**
  - Overall
  - Mounting
  - Bushing
  - Shaft
    - Flat location
- **Contacts**
  - Short
  - Long
- **Rotor Segments**
  - Non-shorting
  - Shorting
- **Insulating Material**
  - Grade
  - Treatment
- **Shields**
  - Location
- **AC Switch**
  - Location
  - Type

ELECTRICAL

- **Insulation Resistance**
  - Between contacts
  - Contacts to ground
- **Voltage Breakdown**
  - Humidity
  - Altitude
  - Temperature

GENERAL

- **Life**
  - Cycles
    - Rate
- **Torque-Operating Pressure**
- **Switching**
  - Sections
    - Layout
  - Positions
    - Spacing

Table 10-1

Leakage Resistance - Typical Rotary Waveswitch Wafer. Measured Between Adjacent Lugs.

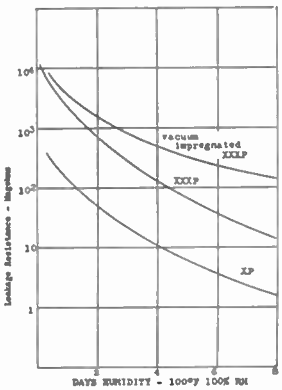


Fig. 10-4

Typical Switch Rotor Segments

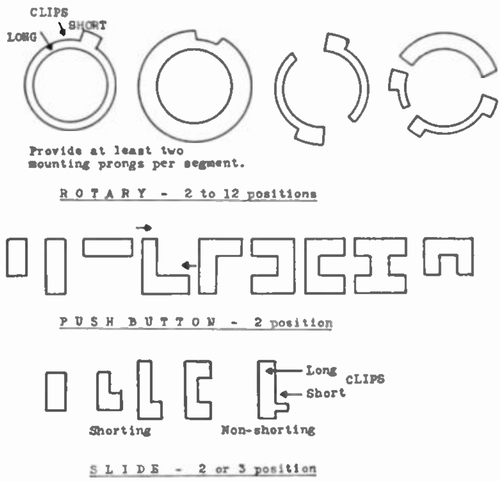
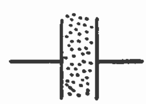


Fig. 10-5

INSULATING MATERIALS and COMPONENTS

TERMINAL PANELS
TUBE SOCKETS
CABLES
WIRE



General Considerations

There are two general types of solid insulation used in radio and electronic applications; the plastics and the ceramics.

Theoretical considerations will show under what circumstances dielectric loss in an insulator may be expected, and how the properties of a material can to some extent be predicted from a knowledge of its molecular structure and chemical composition. In general a low-loss material has a low dielectric constant. (See Table 11-1).

Dielectric Constant

The dielectric constant of an insulating medium may be considered as a measure of electrical displacement for a given electric force. It is equal to the ratio of the capacitance of two capacitors of equal size, one using the particular dielectric and the other using air as the dielectric. Properties of dielectrics are explained on the assumption that matter contains positively and negatively charged particles. These are bound together by the forces of attraction and when they are under the influence of an electric field there is a tendency for the charges to move in opposite directions against these restoring forces of attraction. In the case where the charges tend to become concentrated at opposite ends of the molecule there is a tendency for the molecule as a whole to rotate and set itself in the direction of the field. These are termed "polar molecules" and may be thought of as tiny dipoles which try to set themselves in the direction of the field at any instant. The charged portions do not separate but only tend to rotate as a whole depending on the magnitude of the charge, the size of the molecule, viscosity of the medium, temperature etc.

The behavior of any dielectric as the frequency is varied depends upon the polarization of the molecules existing in that dielectric. The frequency at which maximum loss factor occurs, called the relaxation frequency, and the rates at which both loss factor and dielectric constant change with frequency depend as to whether it is polar or non-polar.

Highly polar molecules have high dielectric constants while non-polar molecules have low dielectric constants. A hydrocarbon (non-polar) group reduces the polar properties of the material into which it is introduced, while the introduction of the–OH(polar) group increases the polar properties and likewise its dielectric constant. As an example, take ethyl alcohol, C_2H_5OH, with a dielectric constant of 26.8, add a hydrocarbon radical and we have butyl alcohol, C_4H_9OH with a dielectric constant of 17.8. Thus it is seen that the molecular structure of a material determined its dielectric characeristics.

In an alternating field the movement of charged electrons or the rotation of the polar molecule follow the alterations of voltage, and since the molecular and ionic movements are opposed by the forces of attraction between molecules and viscosity influences of the material, there is in general a lag behind the electric field which causes a power loss in the material. As the frequency increases the loss becomes greater up to a point where the particles cease to respond to

General Considerations continued

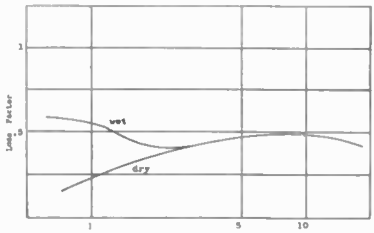
the alternating field. Above this point the dielectric constant decreases. If the internal friction is low the peak takes place at high frequencies, while if it is high as in glasses and many crystalline solids the peak occurs at low frequencies.

The Loss Factor

The loss factor of an insulating material is roughly the product of the dielectric constant and the power factor, providing the power factor is less than 0.1. Actually, the loss factor of an insulating material is the product of its dielectric constant and the cotangent of its phase angle; and is an expression of the power loss per unit volume at a given frequency. The typical curve of power loss versus frequency (Fig. 11-1) does not show any well defined maximum as would be expected if one factor alone were responsible for loss. (Usually the maximum is broad and not well defined, and often there is more than one maximum.) The laminated bakelites, for example, show a maximum just above ten megacycles when quite dry, but when moist a low frequency maximum also appears. This is attributed to ionization in the absorbed water. The maximum at ten megacycles appears to be common to all bakelites containing cellulose filler, whether paper, wood flour or fabric. The urea resins show the same effect. Undoubtedly the absorption is a function of the cellulose as it largely disappears when the cellulose is replaced by a mineral such as mica or talc, the introduction of which also renders the material less sensitive to moisture pickup, thereby reducing the low frequency absorption. This forms the basis of many of the low-loss materials now on the market.

Even though direct absorption of moisture is negligible the formation of a film on the surface lowers the insulation resistance, and when subjected to alternating potentials introduces a material loss. Therefore in selecting an insulating material it is necessary to consider the effect of moisture on the dielectric properties. If the material has a tendency to absorb an appreciable amount of moisture the power loss may be increased to such an extent as to make the insulation worthless for use at radio frequencies. Roughness or pores of molecular dimensions are the important factors. Porosity sufficient to permit more than 0.01% water absorption results in poor humidity characteristics. An insulation which water will not wet is usually only slightly affected by surface moisture because the water collects in drops and does not cover the whole surface. Glazing helps only to a small extent, although it is often used where a self-cleaning surface is required.

Typical Loss Factor Characteristic - Showing Effect of Ionization Due to Moisture - Material Laminated Bakelite.

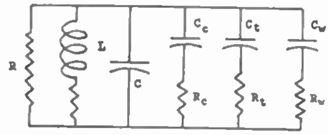


Frequency - Megacycles
Fig. 11-1

Loss Factor versus Mechanical Strength

The fact that the loss factor alone is not of major importance in

Typical Example of Effect of Components on Circuit Q



			Q	C/Q Ratio
C_c	Tuning capacitor supports . .	5mmf	500	1×10^{-14}
C_w	Terminal strip and wiring . .	2mmf	30	6.6×10^{-14}
C_t	Tube base and socket	3mmf	50	6×10^{-14}
C	Tuning capacitor	107mmf		
	$C' =$	117mmf	$\Sigma C/Q =$	13.6×10^{-14}

$\omega L = 1356$ $\quad C' = 117 \times 10^{-12}$ $\quad 1/C' = 8540 \times 10^{6}$

$\omega L/R_t = 1356 \times 10^{-6}$ $\quad 1/Q_L = 4000 \times 10^{-6}$ $\quad \frac{1}{C} \; \Sigma \; \frac{C}{Q} = 1161 \times 10^{-6}$

Circuit $Q = 153$

Fig. 11-2

choosing a dielectric is generally overlooked. The total power loss depends on the total volume of insulation in the high-frequency field, which brings the mechanical properties of the insulation into the picture. The strength of a material is therefore important not only from a purely mechanical standpoint, but also from an electrical point of view. It often happens that a dielectric material with comparatively poor electrical properties will produce a good insulator because its mechanical properties make possible a small volume and long dielectric path. Such a design produces low surface leakage because of its length and minimizes the loss because of its smaller volume. Choosing the proper insulator for a given application therefore becomes a compromise between electrical and mechanical properties. A small piece of higher loss factor insulation which has adequate mechanical strength for a given job may be preferable to a lower loss factor material which requires a greater volume because it has less mechanical strength.

Impregnation

A further improvement in design may be obtained by treating the insulator with wax or other suitable insulating material. Several of the more common impregnants are listed in Table 11-2. Note that the lowest values of dielectric constants are found in the saturated hydrocarbons, paraffin, ceresin and Superla wax. Halowax (chlorinated napthalene) which has a higher dielectric constant than any of the naturally occuring waxes, is an example of a saturated hydrocarbon to which has been added a polar group (chlorine).

It is generally known that most waxes absorb moisture when subjected to high humidities. This results in a change in dielectric which shows up as an additional power loss. Of the impregnants shown, with the exception of bayberry wax and shellac the absorption is not very great. After extreme exposure however, even the best impregnants permit moisture to penetrate. This can be readily demonstrated by observing the variation in Q of a treated and an untreated component after each has been immersed in water until the Q has been substantially reduced, and then noting the time required for the Q to return to normal. The untreated component will return to its original value with-

Properties of Commonly Used Solid Dielectric Materials

(Values are average and subject to variations in production)

PHYSICAL				ELECTRICAL			
Strength Tensile	(psi) Compr.	% Water Absptn 24 hr.	Softens at °C	MATERIAL	Dielec-tric Con-stant	% PF 1 MC	Dielec-tric Strength v/mil
10000	85000	.02	1440	Alsimag 196	5.8		240
3500	40000		1430	Alsimag 202	5		100
3000	4000	4	70	Cellulose Acetate	7	3.9	450
4500		2.5	85	Cellulose Nitrate	5.5	5	
6000	11000	1.9	150	Ethyl Cellulose	4.1	2.8	600
10000	25000	30	130	Fibre	4.5	5	170
	40000	0	600	Glass-Pyrex	4.5	0.2	
		0	1500	Glass Corning 790	4	.05	
		.01		Glass Corning Multiform	4	.18	
			1200	Mica	5.4	.02	
9000	32000	.035	500	Mycalex	7	0.3	350
				Phenol-Laminate			
12500	35000	4	150	Class X	5.5	5	700
9000	34000	1.3	150	Class XX	5	4.5	700
8000	25000	1.3		Class XXP	4.8	4	700
7000	32000	1.0	150	Class XXX	4.8	3.5	650
7000	25000	1.0		Class XXXP	4.5	2.7	650
9000	36000	1.5	150	Class CE	5.5	5.5	500
9000	37000	1.2	150	Class LE	5	4.5	500
				Phenol-Molded			
6000	19000	.035		Mica filler	5.6	.5	450
7500	30000	.31	130	Wood flour filler	5.5	3.9	300
11000	35000	.68	140	Fabric filler	5.5	5.5	400
1800	1700	.005	110	Polyethylene	2.3	.03	800
285				Polyisobutylene	2.3	.03	
4500	40000	Nil	1610	Porcelain (wet process)	6.8	6	
8500	200000	0	1430	Quartz-fused	4	.03	1500
9000	8000	.02	70	Rubber-hard	2.5	.7	470
4000		.02	140	Rubber A10 filler	3.85	.59	
4000		.02	165	Rubber mica filler	3.54	.49	400
13000	14000	.63		Silicone-Laminate	2.88	.15	250
7500	14000	.01	90	Styrene-Polymerized	2.55	.03	600
9000		.15	60	Vinyl Resins	4	1.7	225

Table 11-1

in 24 hours, while the treated component may require several days to regain its original value. Were it not for the fact that impregnations when properly applied provide sufficient protection for most conditions it would be better to omit the treatment.

The usual treatment for components fabricated principally of insulating materials consists of a vacuum impregnation in wax. A "flash dip" of the same wax for additional protection both mechanically and electrically is often applied after the regular vacuum treatment. The treatment for flashing is somewhat critical and depends on the particular type of wax and the size of the part being treated. Obviously care must be taken to prevent pin holes from forming during this operation as these would nullify the effect of the heavy coating.

Characteristics of Common impregnants

Material	Dielectric Constant Initial	Dielectric Constant 2 month immersion	% Water Absorption	Acid Value	Melting Point °C
Carnauba wax	2.72	4.0	0.8	2.8	80
Bayberry wax	3.25	10.4	6.1	21.0	60
Beeswax	2.87	3.2	0.42	20.3	
Ceresin wax	2.2	2.3	0.04	Neutral	75
Parafin	2.2	2.4	0.045	0	52
Superla wax	2.33	2.36	0.015	0	74
Halowax	3.63	5.3	0.24		86
Shellac	3.68	15.0	4.7	0.2	

Table 11-2

General Considerations continued

The acid content of a wax must also be considered when used as an impregnant, especially when the part is connected to a positive d-c potential. In such cases any leakage to ground will be accompanied by an electrolytic action which will show up as a greenish salt deposit on the positive wire. This will eventually corrode the wire and a failure will result. If the component is connected to a negative potential no corrosion will take place.

The effect of extremes in temperature must also be considered. The melting point should be at least 10°C above the maximum operating temperature. To meet unusual temperature requirements it is sometimes necessary to specify materials other than waxes. Varnish or lacquer having a base of styrene has been found to give excellent results when properly applied. The use of the silicone family, particularly the methyl-chloro-silane treatment for ceramics, results in an increase in leakage resistance, when the component must operate under dewpoint condensation conditions.

Insulating Material Effect on Circuit Q

A high-Q tuned circuit is generally thought of as a high-Q inductor and a good air dielectric capacitor. Most practical circuits however include other components which must also be considered. The stator supports, the coil form, terminal strips, wire insulation, tube, tube base and socket all introduce losses. The higher the inductor and capacitor Q the more noticeable is the effect of the other components. This is demonstrated in Fig. 11-2 where L represents the inductor and RL its equivalent resistance. In parallel with this we have the assumed perfect air dielectric capacitor C and the tube resistance R. Next we have Ct, Cc and Cw in series with Rt, Rc and Rw respectively, which represent the capacitor solid dielectric, terminal strip, insulated wire, tube base and socket, the C being the capacity and R the equivalent series resistance.

Suppose we now measure the Q and C of each of the components. A typical example is shown (Fig. 11-2) where the tube resistance (a-c) is one megohm, the frequency 1000 kilocycles, the inductance 216 microhenries with a Q of 250. This includes all inductor losses. We can then readily determine the effect of any of the components in the circuit on the overall circuit Q by the equation shown. Thus it is seen that starting with a coil Q of 250 the losses contributed by the seemingly unimportant parts have reduced the circuit Q to 153. The effect of vacuum impregnation on component parts under conditions of high humidity can be calculated in the same manner.

While the characteristics of insulating materials is an interesting subject the information is of little practical value to the design engineer unless it is applied in the fabrication of component parts.

TUBE SOCKETS—DESIGN

General Considerations

The desirable electrical characteristics of tube sockets include such items as low capacitance, high leakage resistance, low-loss factor, low contact resistance, high rated working voltage and freedom from effects of high humidity. These depend to a large degree on the quality of the dielectric used in their construction, although the mechanical design can influence these characteristics to some extent. For instance the rated working voltage can be increased by the use of insulating barriers between contact clips. This also improves the leakage resistance because of the increased length of the leakage path. Capacitance and loss factor depend on the dielectric constant and power factor of the material as well as the volume between contacts.

Desirable mechanical characteristics include ease of inserting and extracting tubes, safe operating temperature, strength, ease of mounting and wiring. Outline drawings of typical tube sockets are shown in Fig. 11-3.

APPLICATION

In r-f or high impedance circuit applications, especially where humidity is a consideration, dielectric materials such as ceramic, low-loss bakelite or polystyrene are recommended.

Although electrically ceramic is the most desirable socket insulation it is seldom used because of its higher cost and possible production difficulties due to breakage. Polystyrene on the other hand is seldom specified because its low melting point presents quite a problem in wiring due to the heat encountered in soldering. The remaining material, low-loss bakelite, withstands rough handling and riveting, is not affected by ordinary soldering operations yet has excellent electrical characteristics. The leakage resistance can be improved somewhat by vacuum impregnation in a suitable wax, although when subjected to long periods of high humidity in excess of 100 hours very little improvement is noted. Silicone treatment is recommended for operating temperatures in excess of 150°F.

Ordinary wood flour filled bakelite sockets are recommended only where leakage resistance is not of primary importance, such as low frequency operation or where the circuit impedance is less than one half megohm. Laminated phenolic sockets when fabricated from high resin content materials are electrically satisfactory for most applications but from a mechanical standpoint breakage in riveting and repair operations is often excessive.

Typical characteristic curves of sockets under simulated operating conditions are shown in Fig. 11-4.

SPECIFICATIONS

The specification data sheet outlines the information required for the specification of tube sockets. Many items obviously do not apply to all applications and may therefore be omitted at the discretion of

Tube Sockets continued

the design engineer. Since the data sheet is self-explanatory no detailed discussion is required.

INSULATED WIRING PANELS

DESIGN

General Considerations

The design of electronic equipment without adequate insulated terminal panels or wiring strips would be quite difficult. As components they often receive little attention: never the less, without proper considerations they can cause trouble, especially where high humidity is encountered. Like other components dependent on insulating materials for their principal characteristics, the following factors should be considered: grade of dielectric, insulation resistance, C/Q ratio, voltage breakdown and mechanical strength.

Electrical Considerations

The use of terminal panels should be confined as far as possible to a-f or d-c applications; the loss factor and C/Q ratio are then of

Humidity Characteristics - Typical Octal Tube Socket

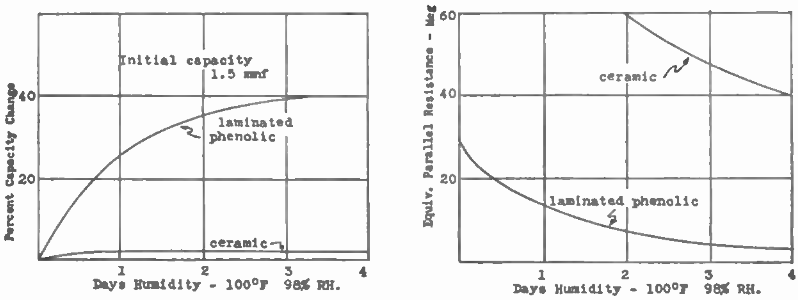
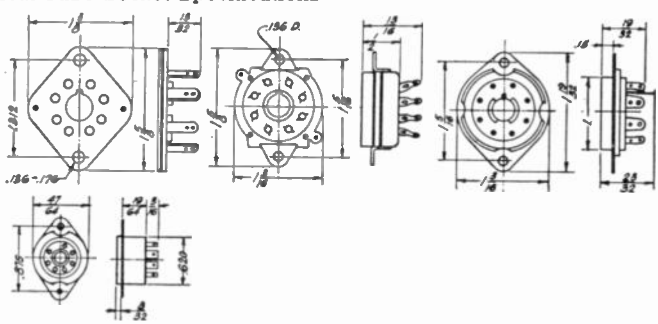


Fig. 11-4

Typical Tube Socket Specifications



PART NO.	TYPE	MATERIAL	WORKING VOLTAGE	CAPACITANCE	INSULATION RESISTANCE (ONE CONTACT TO ALL OTHERS)	CONTACT RESISTANCE	OPERATING TEMPERATURE

Fig. 11-3

SPECIFICATIONS TUBE SOCKETS			
PHYSICAL	**Mounting**	**Lugs**	**Capacitance**
	Above chassis	Feed-through	MMF one contact to all others
Type	Below chassis	Wrap around	**Loss Factor**
Octal	Riveted	**Pins**	Normal
Loktal	Ring	Number	Humidity
Acorn	Special		
Miniature		**ELECTRICAL**	
Material	**Class**	**Working Voltage**	**GENERAL**
Laminated phenol - Grade	Molded	Between contacts	**Operating Temperature**
	Ceramic	Contacts to ground	Maximum at rated voltage
	Wafer		
Molded plastic	**Treatment**	**Insulation Resistance**	**Insertion & Extraction**
Filler	Wax	One contact to all others	Pounds initial insertion
Ceramic	Silicone	**Contact Resistance**	**Contact Sliding Force**
Glazing	Fungus resistant	Maximum at one ampere with gage.	Minimum after 10 insertions

Table 11-3

little importance. The insulation resistance, voltage breakdown and mechanical strength however are still important and should be specified.

Leakage Resistance

The grade of dielectric employed depends on the application. Laminated material is usually satisfactory although molded stock may be employed where better insulating qualities are desired. The leakage resistance under conditions of high humidity is reduced by moisture absorption in the dielectric or by the formation of a moisture film on its surface. This effect can be retarded by the use of impregnants such as wax, lacquer and silicone treatments. Although 100% protection is not attained the improvement usually justifies the extra cost.

The best way to avoid leakage problems is to design around it. For example, avoid designs having a high potential terminal adjacent to a high impedance grid terminal. Any leakage across such points would affect the bias voltage and consequently the operating point, depending of course on the values of the coupling resistors. It is good practice to separate such points by a grounded lug, although in extreme cases leakage to ground with one half inch spacing and no impregnation has been known to approach one megohm after 100 hours exposure to continuous high humidity. Typical curves are shown in Fig. 11-5. The use of terminal strips for r-f circuit wiring should be discouraged because of the capacitance variations with temperature and humidity.

Voltage Breakdown

Spacing between adjacent lugs or to ground determines the voltage breakdown point. This is seldom a critical item since space requirements for convenience of wiring are such that voltage breakdown is minimized.

SPECIFICATIONS TERMINAL PANELS & WIRING STRIPS			
PHYSICAL	Mounting	**ELECTRICAL**	Temperature
Type	Spacing	**Insulation Resistance**	Altitude
Screw	**Material**	Between terminals	Humidity
Lug	Grade	Terminals to ground	**Capacitance**
Feed-through	**Treatment**	Normal	MMF between lugs
Wrap-around	Wax	Humidity	MMF lugs to mounting plate
Dimensions	Silicone	**Voltage Breakdown**	
Overall	Varnish		
	Fungus resistant		

Table 11-4

Mechanical Considerations

The main consideration in the mechanical design of terminal strips are strength (lack of brittleness), ease of mounting, adequate spacing between lugs and ground, and ease of wiring. Short strips having a minimum of lugs between mounting points are obviously desirable from the standpoint of mechanical strength. Overhanging lugs (beyond the mounting) are easily damaged during wiring and it is recommended that a maximum of one lug beyond the mounting be specified. Lugs should provide for both feed-through and wrap-around wiring. Provisions such as notching must be made to permit a mechanical joint when wiring to panels etc., otherwise connections are likely to be unsatisfactory when soldered due to so called "cold joints." These are caused by a slight movement of the wire which results in a crystallization of the solder while it is cooling.

Terminal strips of less than 1/16 inch in thickness are not recommended unless adequately supported at frequent intervals.

Specification

The specification data sheet lists the important items to be considered when specifying terminal panels and strips.

WIRE AND CABLES

Hook-up Wire

General Considerations

Insulated or hook-up wire plays an important part in the development of radio equipment. Several characteristics, such as insulation resistance (internal and surface), voltage breakdown, capacity to Q ratio, flexibility and the ability to withstand wide temperature variations are particularly important. Of these the insulation resistance is generally the most important. This is especially true in designs where the leads are dressed close to the chassis or where the insulation is actually in contact with other parts of the circuit.

Leakage Resistance vs Humidity - Typical Terminal Wiring Strip

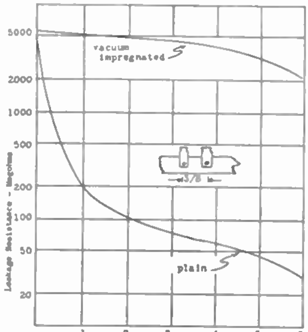
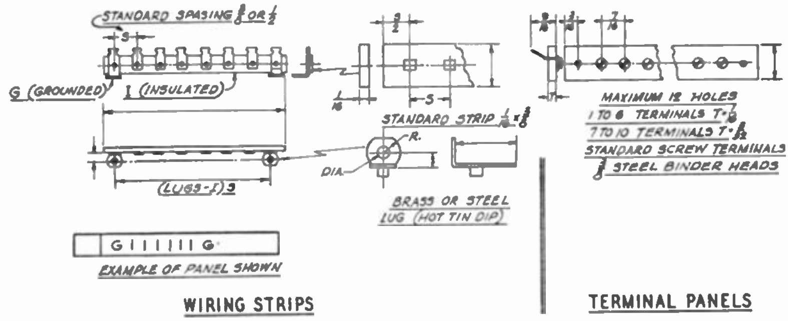


Fig. 11-5

Specifications Insulated Wiring Strips & Terminal Panels



PART NO.	INSULATION	TREATMENT	NO. OF LUGS	LUG ARRANGEMENT	INSULATION RESISTANCE BETWEEN TERMINALS

Fig. 11-6

Humidity Characteristics - Typical Hookup Wire

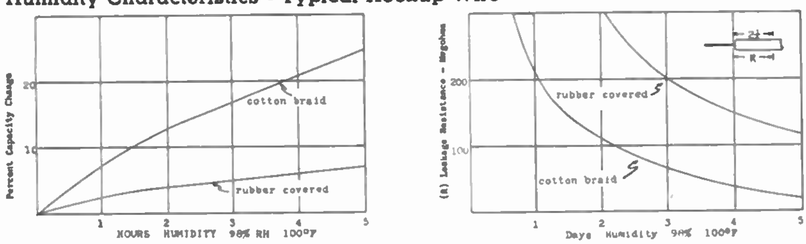


Fig. 11-7

In such cases it is evident that either internal or surface leakage will result in poor performance if high humidity is encountered. Typical leakage resistance versus humidity of two types of insulated wire is shown in Fig. 11-7.

The specification of voltage breakdown depends upon the application; high ambient temperatures, altitude, humidity and in some cases Underwriters' requirements must be considered. Flexibility is also of importance in certain applications, not only from the standpoint of wire breakage but of failure of the insulation due to cracking, cold flow, tearing or melting. Insulation having a low melting point is difficult to handle in high speed production where soldering time is at a minimum. For general wiring the capacity to Q ratio is relatively unimportant, however, in r-f applications this factor must be considered. The curves in Fig. 11-7 show the effects of humidity on capacity for representative samples. From this it is evident that the capacity change can appreciably affect the performance in high frequency circuits.

Size

Hook-up wire should not be smaller than #26 AWG because of danger of breakage. Recommended wire size for general chassis wiring,

Wire and Cable continued

except filaments, is #22 or #24 AWG. Filament wiring if in parallel should employ at least #20 AWG. Solid wire may be used wherever the part is solidly mounted and not subject to vibration. Unless adequate clamps or "dress lugs" are employed it is recommended that solid wire be used only for short jumper connections not exceeding three inches in length. In such cases bare wire is usually satisfactory although the use of spaghetti tubing to preclude the possibility of shorts is often required. In other words the use of stranded wire wherever possible is strongly recommended.

Properties of Some Commonly Used Wire Insulations

Insulation	Maximum °C Temperature	Notes
Cotton	90	Poor leakage resistance.
Cotton (impregnated)	105	Relatively high dielectric strength.
Cellulose acetate	105	Poor flexibility. Tough, moisture resistant. Supports combustion.
Vinylite	75	Chemically stable, fair dielectric, tough mechanically, moisture and flame resistant.
Fiber glass	130	Excellent heat protection. Poor mechanically.
Rubber (high temp)		Tough mechanically, good dielectric strength and moisture resistant. Subject to aging.
Polyethylene		Excellent flexibility, low loss for high frequency applications, excellent moisture resistance. Poor mechanically. Chemically stable.

Table 11-5

Suggested Color Coding for Hook-up Wire

Color	Wiring Application
Black	Grounds, grounded elements and returns.
Brown	Heaters or filaments off ground.
Red	Power supply, B plus.
Orange	Screen grids.
Yellow	Cathodes.
Green	Control grids.
Blue	Plates.
Violet	Not recommended.
Gray	Power line (a-c)
White	Above or below ground returns, AVC etc.

(Gray and violet are often omitted because of difficulty in distinguishing them under certain artificial lights.)

Table 11-6

Insulation

A wide range of insulating coverings are available which make the specification of wire particularly important since each insulation has its peculiar characteristics and is therefore not suited to general usage. A summary of the major insulation requirements would include, good dielectric strength, high insulation resistance, wide temperature range with high softening point and low brittle point, flexibility, color stability and resistance to abrasion, crushing, moisture, fungus, burning, corrosion, oil and acids.

An insulation wall thickness of not less than 0.013 inches is recommended for all wiring within the actual chassis or where suitable mechanical protection is provided. Where the wiring is exposed, but still within the confines of the cabinet, a minimum wall thickness of 0.025 inches is desirable.

Some of the more common insulations used for general hook-up wire include, lacquered cotton, high temperature rubber, butadiene styrene copolymers, Celanese, glass fiber textile, extruded polyvinyl chloride, cellulose acetate and polysthylene. These may be protected for improved abrasion resistance by a suitable braid covering which in turn should be lacquered. R-F wiring is usually confined to the use of rubber or polysthylene as the insulating material although other insulations are sometimes employed in special applications.

Wire and Cable continued

From five to ten coats of flexible, transparent, flameproof, moisture resistant lacquer may be employed according to requirements. Materials are usually specified to be non-toxic and non-corrosive and the finished wire should be relatively flameproof, at least to the extent that when held in a horizontal position in still air any self sustained combustion will not progress at a rate exceeding one inch per minute, nor will any burning particles fall during combustion.

Table 11-3 lists a summary of the more common types of insulation used on hook-up wire.

Transmission Line Design Data

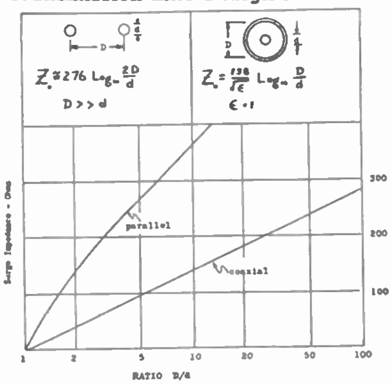


Fig. 11-8

Color Coding

The adoption of a system of standardized color coding has definite advantages such as, simplification of assembly wiring, inspection and servicing in the field. These are the major objectives of a color coding system and while they do not fulfill every need they are sufficiently applicable to the great majority of cases so that deviations for obscure circuit applications are of little consequence.

Where color coding is used for chassis hook-up and component-lead wire insulation the schedule in Table 11-4 is suggested.

Tests

Voltage breakdown or hi-pot tests are conducted with a minimum sample length of 52 feet. The entire sample except one foot at each end is immersed in tap water for a period of 24 hours, after which the test potential is applied between the conductor and the water for one minute.

Attenuation - Commercial R. F. Cables (Coaxial)

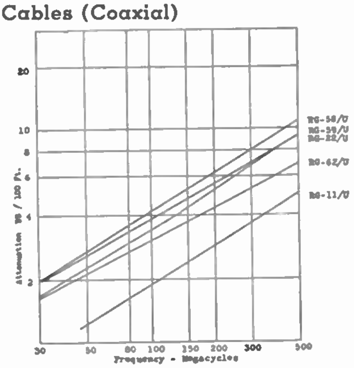


Fig. 11-9

Attenuation - Commercial Parallel Transmission Lines

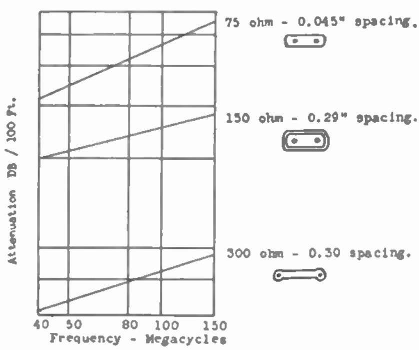


Fig. 11-10

Wire and Cable continued

SPECIFICATIONS HOOK-UP WIRE (INSULATED)			
PHYSICAL	Material	Lacquer	Maximum RMS
Conductor	Coding	Coatings	Temperature range
AWG number	**Protective Covering**	Flexible	Altitude
Solid	Braid	Transparent	Humidity
Stranded	Color	Flameproof	**Insulation Resistance**
Material	Material	Moisture resistant	Minimum per 1000 feet
Conductivity	Weave	Fungus resistant	**Figure of Merit**
Insulation	Shield	**ELECTRICAL**	Capacity to Q ratio
Wall thickness	Material	**Voltage Breakdown**	Operating frequency
	Covering (%)		

Table 11-7

Immediately after a successful hi-pot test with the sample still in the water the insulation resistance should be measured using a minimum of 100 volts d-c between the conductor and the water. The insulation should exceed 1.5 megohms per 1000 feet. Flexibility is determined by winding at least six turns of the sample wire on a mandrel having a diameter equal to the diameter of the wire under test. The sample is then subjected to a temperature of 120°C for one hour, after which inspection should disclose no cracks on the surface. A similar test for low temperature flexibility consists of subjecting the wire sample to a temperature of −10°C for one hour and immediately upon removal from the cold chamber wind six turns on a mandrel having a diameter of twice the diameter of the test sample. Again inspect for cracks or other defects.

Specifications

The specification data sheet lists the important items to be considered in the specification of hook-up wire. In general, it is sufficient to qualify wire size, voltage breakdown and temperature range with the other items being specified only for special applications.

Notes such as the following are often included as part of the specification.

1. Insulation to be non-toxic, non-corrosive and flame resistant.
2. Insulation shall be free stripping and show no evidence of cracking or other defects when subjected to temperatures specified for extended periods of time.
3. Material and workmanship on all points not specifically covered to conform to best commercial practice.
4. Conductor shall be tinned for easy soldering.

R. F. Transmission Lines

Coaxial or parallel (dielectric) spaced transmission lines have now substantially replaced the open-wire type of line. Since the newer lines have many advantages over those previously employed, the open-wire type will not be considered.

General Considerations

The major considerations in the choice of a suitable transmission line for receiver applications are not the same as those required for transmitter service. Voltage breakdown and power-handling capacity are of little importance. The main consideration is the choice of the proper impedance and more especially the attenuation at the desired operating frequency.

Impedance

The characteristic or surge impedance of a transmission line depends on the physical dimensions of the conductors, spacing and dielectric between them. Fig. 11-8 shows general design data for the most common lines available. Note that in the case of ceramic beads it is necessary to determine the percent space occupied in order to obtain an accurate impedance.

Attenuation

The attenuation (Fig. 11-9) is the total loss attributable to the sum of the resistance loss along the line and the dielectric loss between conductors. The resistance loss, which is largely due to skin effect, increases in direct proportion to the square root of the frequency while the dielectric loss is a function of the dielectric characteristic and varies considerably depending upon the material employed.

Insulation

Several types of core material are available depending upon the allowable dielectric losses. Rubber is the least desirable and polyethylene, ceramic beads, polyisobutylene combinations and vinyl chloride are the most desirable in the order named. So called air dielectric cable is not considered because of its inflexibility and inadaptability for most applications. Current designs of close spaced parallel type lines are reasonably free of radiation and are now extensively employed in home receiver and television applications.

Typical characteristics of some standard commercially available transmission lines, coaxial and parallel, are given in Table 11-5.

Characteristics of Typical Commercial Lines

AN Type #	Conductor Inner	Conductor Outer	Dielectric Polyethylene	Cover	O.D.	uuf/ft	Z	Notes
RG-58/U	20 AWG copper	T Cu braid	"	Vinyl	.195	28.5	53.5	Small general purpose cable
RG-59/U	#22 copper-weld	Cu braid	"	"	.242	21	73	General purpose, video cable
RG-11/U	7/26 T Cu	"	"	"	.405	20.5	75	Medium, flexible video & general
RG-22/U	2-#18 copper	T Cu braid	"	"	.405	16	95	Small twin conductor cable
RG-62/U	#22 copper-weld	Copper		"	.242	13.5	93	Small low capacity air spaced
			COXIAL TYPE					
Parallel	7/28	None	Polyethylene	None		23	75	General purpose
Parallel	7/28	"	"	Cu Braid		11.3	150	FM-Television Receiver
Parallel	7/28	"	"	None		4.8	300	FM-Television Receiver
			PARALLEL TYPE					

Table 11-8

SPECIFICATIONS—R. F. TRANSMISSION LINES

PHYSICAL

- **Type**
  - Coaxial
  - Parallel
- **Dimensions**
  - Overall
  - Conductors
    - Material
- **Dielectric**
  - Material
    - Solid
    - Beads
    - Spacers

ELECTRICAL

- **Impedance**
  - Ohms
- **Attenuation**
  - DB per 1000 feet
    - Operating frequency
- **Capacitance**
  - MMF per foot
- **Insulation Resistance**
  - Minimum per 1000 feet
    - Temperature
    - Humidity
- **Voltage Breakdown**
  - Temperature
  - Humidity
  - Altitude

GENERAL

The cable shall withstand twice normal voltage for a period of one minute, shall show no signs of cracking or loss of flexibility and the inner conductor shall not be displaced more than 15% due to bending at high or low temperature limits. Immersion for a specified time in tap water at room temperature shall not affect specified characteristics more than ±10%.

Table 11-9

R. F. Resistance of Copper Wire at 25°C

AWS Gauge	Diameter Inches	Ohms per foot				
		D.C.	5 MC	10 MC	100 MC	500 MC
10	0.1019	.00102	.0246	.0323	.0999	.228
12	0.0808	.00162	.0288	.0405	.1254	.284
14	0.0641	.00258	.0360	.0515	.1596	.358
16	0.0508	.00409	.0450	.0635	.2006	.451
18	0.0403	.00651	.0586	.0814	.2539	.569
20	0.0319	.01035	.0735	.0135	.3208	.719
22	0.0254	.01646	.0938	.1292	.4033	.907
24	0.0201	.02617	.1203	.1701	.5025	1.146
26	0.0159	.04162	.1540	.2123	.6451	1.446

Table 11-10

Diameter of Bare and Insulated Wires (In Mils)

AWG Size Wire	Bare	Enamel	Formex	Single Silk Enamel	Single Cotton Enamel	Single Silk	Double Silk	Single Cotton	Double Cotton
10	102	104	106		110			108	113
12	80.8	82.5	84.0		87.5			85.8	90.3
14	64.1	65.8	67.1		70.8			69.1	73.6
16	50.8	52.3	53.7	54.3	57.3	52.8	54.8	55.8	60.3
18	40.3	41.7	43.0	43.7	46.7	42.3	44.3	45.3	49.8
20	32.0	33.3	34.5	35.3	38.3	34.0	36.0	37.0	41.5
22	25.3	26.5	27.6	28.5	31.0	27.3	29.3	29.8	33.8
24	20.1	21.2	22.2	23.2	25.7	22.1	24.1	24.6	28.6
26	15.9	16.9	17.8	18.9	21.4	17.9	19.9	20.4	24.4
28	12.6	13.5	14.3	15.5	18.0	14.6	16.6	17.1	21.1
30	10.0	10.8	11.5	12.8	15.3	12.0	14.0	14.5	18.5
32	8.0	8.7	9.4	10.7	13.2	10.0	12.0	12.5	16.5
34	6.3	6.9	7.4	8.9	11.4	8.3	10.3	10.8	14.8
36	5.0	5.5	5.9	7.5	9.5	7.0	9.0	9.0	13.0
38	4.0	4.4	4.8	6.4	8.8	6.0	8.0	8.0	12.0
40	3.1	3.4	3.8	5.4	7.4	5.1	7.1	7.1	11.1

Note: These diameters are subject to variation due to variations in copper, enamel, silk, and cotton.

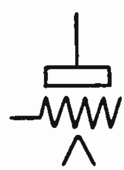
Table 11-11

Copper Wire Tables

AWG Wire Size	Diameter mils	Circular mils area	Ohms per 1000 ft. 25°C	Feet per lb.	Pounds per ft.	Fusing Current Amperes	Copper-weld Ohms/1000'	Stranded Equiv
10	101.9	10380	1.018	31.82	31.5	333	3.39	105/30
12	80.81	6530	1.619	50.59	19.8	235	5.40	65/30
14	64.08	4107	2.575	80.44	12.4	166	8.59	41/30
16	50.82	2583	4.094	127.9	7.81	117	13.65	26/30
18	40.30	1624	6.510	203.4	4.91	82.8	21.71	16/30
20	31.96	1022	10.35	323.4	3.1	58.3	34.52	10/30
22	25.35	642.4	16.46	514.2	1.94	41.2	54.88	7/30
24	20.10	404.0	26.17	817.7	1.22	28.9	87.27	4/30
26	15.94	254.1	41.62	1300	0.765	20.6		
28	12.64	159.8	66.17	2067	0.481	14.7		
30	10.03	100.5	105.2	3287	0.303	10.25		
32	7.95	63.21	167.3	5227	0.194	7.26		
34	6.305	39.75	266.0	8310	0.120	5.12		
36	5.000	25.0	423.0	13210	0.0757	3.62		
38	3.965	15.72	672.6	21010	0.0484	2.55		
40	3.145	9.88	1069	33410	0.0291	1.86		

Table 11-12

TUBES and METALLIC RECTIFIERS



Tubes and Metallic Rectifiers

Types Versus Service

The selection of tube types for a specific class of service is dependent upon several factors inherent in their design. These shortcomings or limitations should be carefully considered. For example, the characteristics of individual tubes of the same type may vary as much as plus or minus 25 percent from published data. It is therefore advisable to check all designs with "high" and "low" limit tubes. Designs based on "special characteristics" are unsound since service replacement is difficult.

Preferred types as listed by the manufacturer should be employed wherever possible. In this way the designer helps himself by selecting tube types currently available, thus expediting his requirements; at the same time he helps the manufacturers by permitting him to concentrate on a few types, thereby increasing manufacturing efficiency and reducing costs.

Table 12-1 has been arranged to assist in the selection of a tube for a specific application. While it by no means includes all available types, it does include those particularly adaptable to current designs.

R-F and I-F Amplifiers

R-f and i-f amplifiers usually employ pentode tubes with a remote cut-off grid characteristic. Such tubes permit the use of automatic volume control without serious cross-modulation effects. High gain without neutralization is possible because of the low grid-plate capacitance. For low and medium frequencies the load on the tuned circuit is relatively unimportant but at ultra high frequencies the input loading due to cathode-lead inductance and transit time effects makes the choice of a proper tube more difficult.

Converter Service

Conversion transconductance is the criterion in the choice of tube types for frequency conversion service. It is equal to the quotient of the i-f component of the plate current divided by the r-f signal grid voltage. The conversion conductance is largely dependent upon the strength of the oscillator which must be adequate over the entire operating frequency range.

Triodes are characterized by high conversion conductance, excellent signal to noise ratio, and low cost. Input loading due to feedback through the grid-plate capacitance is rather severe but can be compromised to a certain extent by increasing the value of the plate tuning capacitor across the i-f primary (or connecting the plate to a low impedance tap on the primary).

Pentodes have high conversion conductance, good signal to noise ratio with a minimum of loading due to low grid-plate capacitance.

Pentagrid converters, because of the low oscillator conductance, are not recommended except for low and medium frequency applications. Other disadvantages for high frequency operation are reduced gain due to variation of space charge when the oscillator frequency is

Tubes continued

above the signal frequency and poor oscillator stability with variations in signal input. Pentagrid mixers are an improvement as far as oscillator stability with signal is concerned. Both have poor signal to noise characteristics and are not recommended without an r-f stage.

Crystal mixers are particularly suited to very high frequency converter service where the ordinary tube is practically unusable. Their inability to handle large signals is overshadowed by the advantages of small physical size, high series resonant frequency, and simplicity of application. No heater or high voltage d-c with consequent hum problems are necessary.

Diodes, like crystals, have low conversion gain (less than unity), poor signal to noise ratio, and appreciably damp the tuned circuit. Circuit damping may be decreased by tapping the converter down on the tuned circuit. This results in less loading and thus higher Q which offsets the loss of gain due to transformer voltage step-down action. Compared with ordinary tubes at very high frequencies, both diodes and crystals are relatively satisfactory.

Detector Service

The choice of tube types for detector service has in general been narrowed down to one variety, namely the diode. Other types such as triodes, tetrodes and pentodes are occasionally employed in special applications but their use is so limited as to make them relatively unimportant. Typical schematic diagram for this application is shown in Fig. 12-1.

The choice of a diode detector depends mainly on the tube characteristics. Low capacitance and low voltage drop within the tube rating are desired. In a diode the parameter commonly known as Perveance, is the equivalent of transconductance insofar as desirability is concerned. An example of a typical design application will be cited.

A family of average characteristics is shown in Fig. 12-2 where each curve is obtained by varying the d-c load resistance and plotting the diode current while maintaining a constant input signal voltage. Assuming a load resistance of one megohm the load line (AB) is drawn by starting at zero voltage and current for one point and constructing the line to intersect the rectified current at 30 microamperes at a voltage of −30. (One megohm as 30 volts produces a current of 30 microamperes.) Assume an unmodulated carrier of 10 volts RMS is impressed on the diode. This would establish the operating point at the intersection of the load line and the 10 volt curve

Typical Diode Detector Schematic & Characteristic

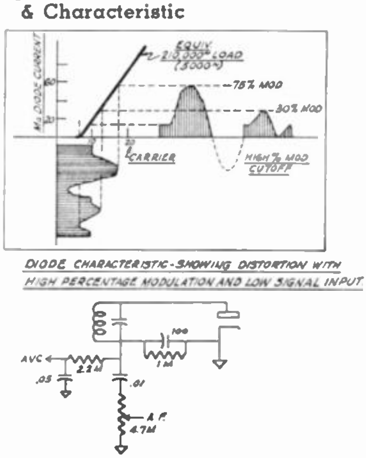


Fig. 12-1

Tubes continued

and is comparatively simple to determine. The complexity of operation occurs when the carrier is modulated with a varying audio frequency.

From the schematic (Fig. 12-1) it can be seen that in a typical circuit the load resistor is shunted by the AVC, diode capacitor and the input of the following audio stage. Because these components are not all resistive, it is evident that the effective load impedance will vary with a variation in audio frequency. Calculations at the extremes of the desired audio range show that the effective load resistance for 50 cycles will be of the order of 600,000 ohms while at 5000 cycles it will approximate 200,000 ohms. By constructing the new load lines on the family characteristic curves (dotted lines) sufficient points can be obtained to predict actual operation at a given audio frequency. As a typical example the operation at 5000 cycles has been plotted together with representative degrees of modulation. This indicates how at low signal inputs and high percentage modulation diode current cut-off exists, and distortion is obviously produced.

A-F Amplifier Service

Tubes for a-f amplifiers (particularly resistance coupled) should have a sharp cut-off and a high amplification factor. Triodes and pentodes are both satisfactory. Combination diode-triodes or diode-pentodes are often used as the second or audio detector-first audio amplifier, thus eliminating the use of a separate audio tube.

Beam type pentodes are generally recommended for audio power applications because of their high power sensitivity. Operation may be either Class A or B. For Class A operation the plate current flows during the complete a-c cycle and the output wave is essentially the same shape as the input signal. Grid bias should approximate one half cut-off value and grid current is not permitted. Plate efficiency is of the order of 25 percent.

Class B operation permits some grid current while operating at a bias of approximately twice cut-off. Plate current flows during a considerable portion of the a-c cycle. Plate efficiency is of the order of 60 percent.

Video Amplifier Service

Video frequency amplifier tubes require a high ratio of transconductance to tube capacitance. In general the transconductance is of the order of 5000 micromhos.

Rectifier Service

Tubes and metallic rectifiers are selected on the basis of the maximum d-c output current, maximum peak current and maximum peak inverse voltage. It is sometimes permissible to increase the d-c output voltage over the normal rated value if the output current is reduced proportionately. The tube manufacturer however should be consulted for all such applications.

Tubes continued

The maximum a-c voltage is generally given as an RMS voltage at a specified current. Maximum peak current is dependent upon the type of filter employed. With a choke input filter the peak current slightly exceeds the average load current, while with a capacitor input to the filter the current may easily exceed the tube rating, especially if the value of the capacitor is large. This obviously should be checked.

The peak inverse voltage for a halfwave rectifier circuit is equal to 1.41 times the RMS voltage applied to the plate while in a full wave circuit it is 2.82 times RMS per plate minus the voltage drop in the tube. The latter is usually negligible in comparison to the secondary voltage.

General Considerations
Electronic Tubes
Ratings

The selection of tube types for specific applications necessitates the determination of the basis of operation. Two methods are commonly employed; (1) absolute maximum and (2) design-center maximum.

The absolute maximum, as the name implies, is based on the maximum allowable voltage or current recommended under any possible operating condition. Unfortunately some tubes under this rating have a factor of safety which permits the use of higher than recommended values to be used. On the other hand many tubes do not have this margin of safety, so it is good engineering practice never to exceed the published values under any condition.

The design-center maximum ratings are predicated on average voltage supply conditions. In the United States this is 117 volts for a-c operated equipment, 6.6 volts for automobile storage battery and 1.35 volts for dry cell operation. A variation of plus or minus 10 percent from design-center is considered normal and can be tolerated without affecting anticipated tube life.

In addition to the absolute or design-center maximum some tubes are rated separately for continuous (CCS) or intermittent (ICAS) service. CCS ratings are chosen for reliability of performance under continuous operating conditions. ICAS ratings assume intermittent operation of approximately five minutes on and five minutes off, and are used where maximum power output with a minimum of physical size is more important than long

Diode Characteristic Curve Showing Various Load Lines

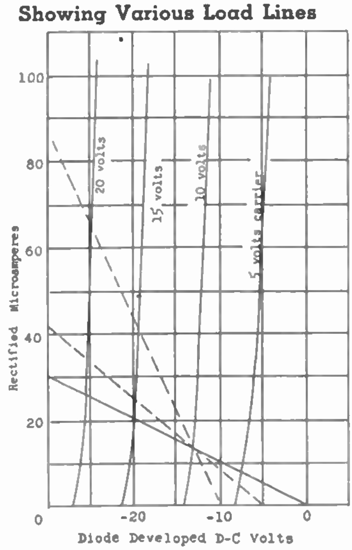


Fig. 12-2

Tubes continued

Noise

Shot noise — caused by the random flow of electrons from the cathode — can be a most prolific source of noise in an electronic tube. Since the effect is well known it needs no further discussion; however, there are certain conditions which aggravate the effect that are not too well known.

One factor is the effect of space charge around the cathode. When a tube is operated so that space charge exists, the total emission current does not reach the plate, in which case it is obvious that the shot noise will be diluted. It is evident that the filament should be operated at a temperature which will produce an abundance of electrons in order that the proportion of steady plate current to noise current be favorable. Conversely, with a low filament temperature limiting the emission, the noise is a more substantial part of the total. Operation at 60 percent of normal rating results in the plate current being limited by emission, so the noise is increased tremendously.

Another source of noise (in multi-element tubes) is the result of random variation in the division of currents between screen and plate. When the screen current is small compared to the plate current noise will be proportional to the screen current. The alignment of the screen with the other grids helps in this respect.

Input Resistance

Two factors, hot and cold input conductance determine the input resistance of a tube. The cold conductance, due chiefly to the dielectric loss in the envelope, insulating supports and tube base, is roughly 0.3 micromho per megacycle for most current octal designs.

The hot conductance depends more on the physical construction (cathode-lead inductance) and the electrode voltages (transit time effect). At low frequencies the hot conductance is negligible but as the frequency is increased it becomes increasingly important, since it is a function of the square of the frequency. At approximately 100 megacycles with ordinary tubes the input conductance equals the normal transconductance and the tube is practically useless since it will no longer amplify.

Determination of Plate Resistance from E_p - I_p Family.

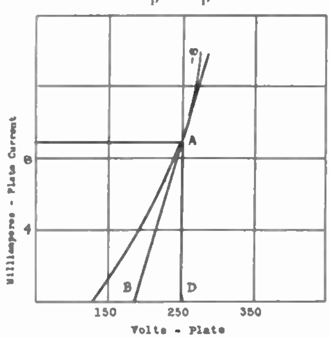


Fig. 12-3

Heating

Heat dissipation often becomes a factor, especially in small a-c/d-c applications. Insofar as the tube is concerned the main troubles are likely to be secondary emission or glass-to-metal seal damage. The latter is likely to occur at temperatures in excess of 200°C.

Determination of Amplification from E_p - I_p Family

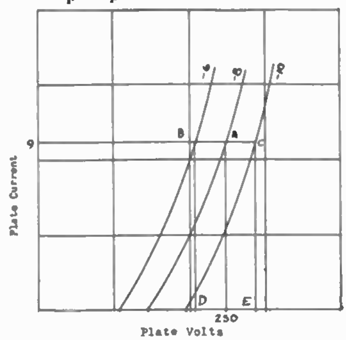


Fig. 12-4

Determination of Transconductance from E_p - I_p Family.

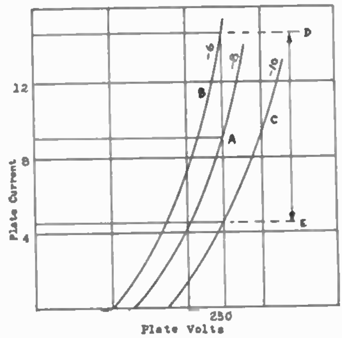


Fig. 12-5

U. H. F. Operation

The primary factors to be considered in the selection of tubes for UHF operation are low interelectrode capacitances, low cathode and other lead inductances, and high input resistance.

Determination of Operating Parameters

The family of plate characteristics is probably the most useful presentation of tube characteristics for overall design. Characteristic curves, however, represent only average results and therefore variations do exist between tubes which must be taken into account. Given a family of plate characteristics, it is possible to obtain operating parameters for any combination of voltage and current desired. For example, if it is desired to operate a tube as a Class B amplifier the zero plate current point at a desired plate potential is readily ascertained. (To obtain the correct operating point for Class C, it is simply necessary to read from the curve the grid bias for cut-off and multiply this value by two.)

Since the amplification factor, plate resistance and the transconductance are not constant over a wide range of operating voltages it is desirable to determine their actual values at a particular operating point. Such information is obtainable only from the characteristic curves.

Plate Resistance

The plate resistance can be determined by drawing a line tangent to the desired bias curve so that it intersects the curve at the operating point (A) see Fig. 12-3. Since the plate resistance is equal to the reciprocal of the slope of the curve it is only necessary to divide the plate voltage change (BD on the voltage axis) by the current change (AD on the current axis) to obtain the desired operating point.

$$rp = BD/AD = de_p/di_p = 69/0.009 = 7555 \text{ ohms}$$

Tubes continued

Because the slope of the curve is not a constant, precautions must be observed to confine the actual operation within the straight line region on the curve, otherwise the plate resistance will vary with changes in signal voltage.

Amplification Factor

The amplification factor is determined as shown in Fig. 12-4, where the desired operating point is (A). By definition it is equal to the ratio of a change in plate voltage to a change in bias voltage for a given constant plate current.

$$u = DE/BC = de_p/de_g = 80/4 = 20.$$

Transconductance

Transconductance (Gm) by definition is equal to the change in plate current for a given change in grid voltage with the plate potential remaining fixed. This is shown in Fig. 12-5.

$$Gm = DE/BC = di_p/de_g = 14.5 - 4.5/ 4 = 2500 \text{ micromhos.}$$

Because of curvature of the plate characteristic it is important to use points equidistant each side of the operating point in order to minimize errors.

Filament Operation

Tungsten filaments may be operated at five percent below normal when the emission requirements are not heavy. This will result in an approximate doubling of the tube life.

Thoriated-tungsten filaments should not be operated below normal. It slows down the diffusion of the thorium to the surface with the result that the emission is eventually lost.

Oxide coated filaments should also be operated at design-center ratings for long life. Inherently the oxide coated filament has a longer life than either of the other two types.

Metallic Rectifiers

Selenium Rectifiers

Selenium rectifier units consist of a series of barrier layer cells connected in series or parallel depending on the load and applied voltage requirements. Typical units are employed in half wave and voltage doubler rectifier power supply applications.

They are characterized by high efficiency, good regulation and relatively instantaneous operation. No heater power is required, which tends to minimize the operating temperature in many applications.

Selenium rectifiers form and reform rather quickly in comparison to other electro-formed components. The forming time is of the order of a few seconds while the deforming time is a matter of minutes.

Tubes continued

Because of this characteristic an initial surge of reverse current appears each time the unit is operated. This must be considered in the design of filters and it is recommended that protective resistors be employed to prevent damage. The fact that the internal voltage drop (approximately five volts) is low compared to most electron tube rectifiers must also be taken into consideration since this may require derating of the filter capacitors.

The maximum operating temperature should not exceed 75°C and in some applications it may be necessary to derate the unit for long life expectancy. Standard practice is to mount the units with the plates vertical in order to provide good air circulation. Typical operating characteristics are shown in the section on Power Supply Circuits.

Performance Characteristic - Crystal vs Diode

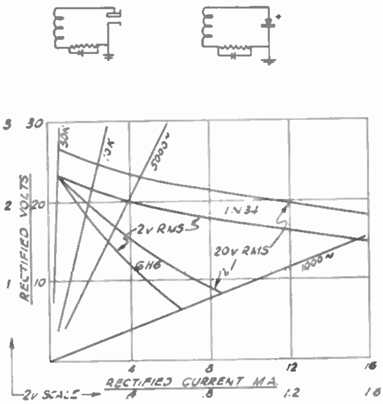


Fig. 12-6

Crystal (germanium) Rectifiers

Crystal rectifiers for present day radio applications consist of a semi-conductor (germanium plus dissolved tin) adequately mounted with a special tungsten shock absorbing contact in a ceramic insulating tube. Leads are provided for general usage although other type mountings are available for special applications.

They are characterized by their small physical size, low interelectrode capacitance and their ability to work into a comparatively low load resistance with reasonable efficiency. Applications include frequency conversion, relaxation oscillators and high frequency detection. Like other metallic rectifiers no heater current is required, which obviously is advantageous from a heat dissipation and hum pickup standpoint.

Typical characteristics (Fig. 12-6) as compared with a 6H6 diode show their superiority at low values of load resistance.

Recommended Tube Types versus Application

	Miniature	Lock-in	Octal	Application
TRIODES	6C4	1LE3 7A4 7B4 7E5	1G4GT 6J5GT 6F5GT/G	VOLTAGE AMPLIFIERS
DUAL TRIODES	3A5 6J6 12AU7	7F8 7AF7	6SN7GT	
PENTODES Sharp cutoff	1U4 12AW6 6AU6 6AG5	1LN5 7W7	1N5GT 6SH7	
PENTODES Semi-remote	6BA6	7H7	6GH7	
PENTODES Remote cutoff	6BJ6 1T4	7A7 7B7	6SK7	
PENTAGRID	1R5 6BE6	1LA6 7B8	1A7GT 6SA7GT 6A8GT	CONVERTERS
OCTODE		7A8		
TRIODE-HEPTODE		7J7		
TRIODE-HEXODE			6K8GT	
TRIODES	3A5 6J6	7F8 7AF7	6SN7GT	
DIODES	6AL5	7A6	6H6GT	DETECTORS
DIODES WITH VOLTAGE AMPLIFIERS	1U5 6AT6 6AQ6 12AT6	1LH4 7C6 7X7 7R7	1H5GT 6R7GT 6SQ7GT 12SQ7GT	
HALF WAVE	45Z3 35W4 117Z3	35Z3 35Y4	1B3GT 35Z4GT 35Z5GT	RECTIFIERS
FULL WAGE	6X4	7Y4 7Z4	6X5GT 5Y3GT 5U4G	
VOLTAGE DOUBLER		50X6	50Y6GT 117Z6GT	
BATTERY	1S4	1LB4	1A5GT	POWER AMPLIFIERS
AC/DC	3Q4	3LF4	3Q5GT	
AC AUTO	6AK6 6AQ5	7B5 7C5	6K6GT 6V6GT 6L6GA 6BG6G	
AC/DC	35B5 50B5	35A5 50A5	35L6GT 50L6GT	

Table 12-1

METAL

Type	Name	Dimen	Base	Cathode	Rating	Plate E	Plate I	Bias	Screen E	Screen I	Gm	Amp. u	Load	Po Watt	Capacitance G-P	In	Out
6AB7	TV Amp Pentode	E	8N	H6 3	45	300	12	-3	200	3 2	5000				015	8	5
6AC7	TV Amp Pentode	E	8N	H6 3	45	300	10	*	150	2 5	9000	*Cathode bias 160 ohms			015	11	5
6AG7	Video Pentode	G	8Y	H6 3	65	300	28	-10	300	7	7700				06	13	7 5
6C5	Triode	E	8Q	H6 3	3	250	8	8			2000	20			2	3	11
6H6	Twin Diode	A	7Q	H6 3	3	150 max RMS											
6SC7	Twin Triode	E	8S	H6 3	3	250	2	-2			1325	70			2	2	3
6SF7	Diode Pentode	E	7AZ	H6 3	3	250	14	-1	100	4 1	2050				004	5 5	6
6SS7	Pentode	E	8N	H6 3	15	250	9	3	100	2	1850				004	5 5	7
12SC7	Twin Triode	E	8S	H12 6	15	For other characteristics see type 6SC7											
12SF7	Diode Pentode	E	7AZ	H12 6	15	For other characteristics see type 6SF7											
12SG7	Pentode	E	8BK	H12 6	15	250	12	-2 5	125	4 4	4700				003	8 5	7
12SR7	Duplex Diode Triode	E	8Q	H12 6	15	250	9 5	-9			900	16			8	4 2	3 4

Table 12-2

Tube characteristics
MINIATURE

Type	Name	Dimen. Base	Cathode Rating	Plate E	Plate I	Bias	Screen E	Screen I	Gm	Amp. u	Load	Po Watt	Capacitance G-P	Capacitance In	Capacitance Out
1L4	Pentode Sharp CO	B 6AR	F 1.4 .05	90	4.5	0	90	2	1025				.01	3.6	7.5
1R5	Heptode Conv	B 7AT	F 1.4 .05	90	1.7	0	67	3	300					7	7.5
1T4	Pentode Remote CO	B 6AR	F 1.4 .05	90	3.7	0	67	1.2	900				.01	3.6	7.5
1U5	Diode Pentode	B 6BW	F 1.4 .05	90	1.6	0	90	.4	625						
3A4	Pentode Output	B 7BB	F 1.4 .2	150	13	-8.5	90	2.2	1900		8000	.7	.35	4.8	4.2
3A5	Dual Triode	B 7BC	F 1.4 .2	135	12	-1.5			2600	15			3.2	.9	1
3Q4	Pentode Output	B 7BA	F 1.4 .1 2.8 .05	90 90	9.5 7.7	-4.5 -4.5	90 90	2.1 1.7	2150 2000		10000 10000	.27 .24			
6AG5	Pentode Sharp CO	B 7BD	H6.3 .3	250	7	-1.4	150	2	5000				.025	6.5	1.8
6AK5	RF Pentode	B 7BD	H6.3 .17	180	7.7	-1.5	120	2.4	5100				.02	4	2
6AL5	Duo Diode	B 6BT	H6.3 .3	150RMS	9										
6AQ6	Duo Diode Triode	B 7BT	H6.3 .15	250	1	-3			1200	70			1.8	1.7	1.5
6AT6	Duo Diode Triode	B 7BT	H6.3 .3	250	1	-3			1200	70					
6AU6	RF Pentode Sharp CO	B 7BK	H6.3 .3	250	11	-1	150	4.3	5200						
6AV6	Twin Diode Triode	B 7BT	H6.3 .3	250	1.2	-2			1600	100					
6BA6	RF Pentode Remote CO	B 7BK	H6.3 .3	250	11	*	100	4.2	4400	*Cathode bias 68 ohm			.0035	5.5	5
6BE6	Heptode Conv	B 7CH	H6.3 .3	250	3	-1.5	100	7.1	475					7.2	8.6
6BH6	RF Pentode Sharp CO	B 7CM	H6.3 .15	250	7.4	1	150	1.4	4600				.0035	5.4	4.4
6BJ6	RF Pentode Remote CO	B 7CM	H6.3 .15	250	9.2	-1	100	3.3	3800				.0035	4.5	5.5
6C4	HF Triode	B 6BG	H6.3 .15	250	8	-8			2200	17			1.6	1.8	1.3
6D4	Gas Triode	B 5AY	H6.3 .25	450ma		100 ma peak, 25 ma av. Voltage drop 16.									
6J6	Duo Triode	B 7BF	H6.3 .45	100	8.5	*Cath. bias 50 ohms			5300	38			1.6	2.2	.4
12AT6	Duo Diode Triode	B 7BT	H12.6 .15	For other characteristics see type 6AT6											
12AU6	RF Pentode Sharp CO	B 7BK	H12.6 .15	For other characteristics see type 6AU6											
12AU7	Twin Triode	C 9A	H6.3 .3 H12.6 .15	100 250	12 10.5	0 -8.5			3100 2200	19.5 17			1.5	1.6	5
12AV6	Twin Diode Triode	B 7BT	H12.6 .15	For other characteristics see type 6AV6											
12BA6	RF Pentode Remote CO	B 7BK	H12.6 .15	For other characteristics see type 6BA6											
12BE6	Heptode Converter	B 7CH	H12.6 .15	For other characteristics see type 6BE6											
12BH6	RF Pentode Sharp CO	B 7CM	H12.6 .15	For other characteristics see type 6BH6											
12BJ6	RF Pentode Remote CO	B 7CM	H12.6 .15	For other characteristics see type 6BJ6											
35W4	HW Rectifier	D 5BQ	H35 .15	117	100 60	without pilot light with pilot light (no shunt)							Capacity input		
45Z3	HW Rectifier	B 5AM	H45 .075	117	55	Capacity input.									
50B5	Beam Output	D 7BZ	H50 .15	110	49	-7.5	110	4	7500		2500	1.9			
117Z3	HW Rectifier	D 4CB	H117 .04	117	75	Capacity input									

LOCK-IN

Type	Name	Dimen. Base	Cathode Rating	Plate E	Plate I	Bias	Screen E	Screen I	Gm	Amp. u	Load	Po Watt	Capacitance G-P	Capacitance In	Capacitance Out
1LA4	Pentode Output	F 5AD	F1.4 .05	90	4	-4.5	90	.95	875		25000	.11			
1LA6	Freq Conv	F 7AK	F1.4 .05	90	.6	0	45	.6	250					7.5	8
1LB4	Pentode Output	F 5AD	F1.4 .05	90	5	-9	90	1.1	925		12000	.2			
1LC5	Sharp Pentode	F 7AO	F1.4 .05	90	1.1	0	45	.2	775				.007	3.1	7
1LC6	Pentagd Conv	F 7AK	F1.4 .05	90	.75	0	35	.7	275					9	5.5
1LD5	Diode Pentode	F 6AX	F1.4 .05	90	.6	0	45	.1	575				.18	3.2	6

Table 12-2

Tube characteristics continued

LOCK-IN continued

Type	Name	Dimen. Base	Cathode Rating	Plate E	Plate I	Bias	Screen E	Screen I	Gm	Amp. u	Load	Po Watt	Capacitance G-P	Capacitance In	Capacitance Out
1LE3	Triode	F 4AA	F1 4 05	90	1 4	-3			760	14 5			1.7	1 7	3
1LH4	Diode Triode	F 5AG	F1 4 .05	90	.15	0			275	65					
1LN5	Sharp Pentode	F 7AO	F1 4 .05	90	1.6	0	90	.35	800				.007	3 4	8
3D6	Pentode Output	F 6BB	F1 4 .22	150	10	-4.5	90	1	2400		14000	.6			
3LF4	Beam Output	F 6BB	F2 8 .05 1 4 .1	90	10	-9	90	2	1750		6000	.32			
7A4	Triode	F 5AC	H6 3 .3	250	9	-8			2600	20			4	3 4	3
7A5	Output Beam	I 6AA	H6 3 .7	125	37	-9	125	3.2	6100		2700	1 9			
7A6	D Diode	F 7AJ	H6 3 .15	150 RMS 10MA Max.											
7A7	Pentode	F 8V	H6 3 .3	250	8 6	-3	100	2	2000				.005	6	7
7A8	Octode Conv.	F 8U	H6.3 .15	100	1 8	-3	75	2 7	375					7 5	9
7AF7	Twin Triode	F 8AC	H6.3 .3	100	5	-3			1900	16			2 3	2 2	1 6
7B4	Triode	F 5AC	H6 3 .3	250	.9	-2			1500	100			1 6	3 6	3 4
7B5	Output Pentode	I 6AE	H6.3 .4	250	32	-18	250	5.5	2200		7600	3.4			
7B7	Pentode Remote	F 8V	H6 3 .15	100	8.2	-3	100	1.8	1675				.007	5.25	6
7B8	Penteg'd Conv.	F 8X	H6 3 .3	250	3.5	-3	100	2.7	550					5	9
7C4	Diode	F 8XB	H6 3 .15	165	10 max.										
7C5	Output Tetrode	I 6AA	H6 3 .45	250	45	-12.5	250	4.5	4100		5000	4 5			
7C6	Duodiode Triode	F 8W	H6 3 .15	100	1	0			850	80			1.4	2.4	3
7C7	Pentode	F 8V	H6 3 .15	100	1 8	-3	100	.4	1225				007	5 5	6 5
7E5	HF Triode	F 8XA	H6 3 15	180	5 8	-3			3075	36			1 5	3 6	2 8
7E6	Duodiode Triode	F 8W	H6.3 3	250	9 5	-9			1900	16			1 5	3	2 9
7E7	Duodiode Pentode	F 8AE	H6 3 3	250	7 5	-3	100	1 6	1300				.005	4 6	4 6
7F7	Dual Triode	F 8AC	H6 3 .3	250	2 3	-2			1600	70					
7F8	Dual Triode	F 8BW	H6.3 .3	250	10	-2.5			5000	52			1 2	2 8	1 8
7G8	Dual Tetrode	F 8BV	H6 3 .3	250	4 5	-2.5	100	.8	2100				.15	3.4	2 6
7H7	Pentode Semi-R	F 8V	H6 3 .3	250	9	-2.5	150	2.5	3500				.007	8	7
7N7	Dual Triode	F 8AC	H6.3 .6	250	9	-8			2600	20			3	3 4	2
7Q7	Penteg d Conv.	F 8AL	H6 3 .3	250	3 4	0	100	8	450					9	9
7S7	Triode Heptode	F 8AR	H6 3 3	250	1.8	-2	100	3	525	Osc gr d leak 50000 ohms					
7T7	Pentode Sharp CO	F 8V	H6 3 .3	250	10 8	-1	150	4 1	4900				005	7 5	5 5
7W7	HF Pentode	F 8BJ	H6.3 .45	300	10	-2	150	3 9	5800				0025	9 5	7
7X7	Twin Diode Triode	F 8XE	H6.3 .3	250	1 9	-1			1500	100					
7Y4	FW Rect.	F 5AB	H6 3 .5	350	60										
7Z4	FW Rect.	F 5AB	H6 3 .9	325	100										
14A4	Triode	F 5AC	H12 6 .15	90	10	0			3000	20			4	3 4	3
14A5	Beam Output	F 6AA	H12 6 .15	250	30	-12.5	250	3.5	3000		7500	2 8			
14A7	Pentode	F 8V	H12 6 .15	100	8 9	-3	100	2 6	1900				.005	6	7
14AF7	Twin Triode	F 8AC	H12 6 .15	100	5	-3			1900	16			2 3	2 2	1 6
14B8	Pentagrid Conv	F 8X	H12 6 .15	100	1.1	-1 5	50	1 3	360					5	9
14C5	Beam Output	I 6AA	H12 6 22	For other characteristics see type 7C5											
14C7	Pentode	F 8V	H12 6 15	100	5 7	-1	100	1	2275				007	5 5	6 5
14E6	Duod ode Triode	F 8W	H12 6 .15	100	3 9	-3			1500				1.5	3	2 9
14E7	Duodiode Pentode	F 8AE	H12 6 15	100	10	-1	100	2 7	1600						
14F7	Dual Triode	F 8AC	H12 5 15	100	65	-1			1125	70					
14F8	Dual Triode	F 8BW	H12 6 .15	For other characteristics see type 7F8											
14H7	Pentode Semi R	F 8V	H12 6 .15	100	8 2	-1	100	3 3	3800				007	8	7
14N7	Dual Triode	F 8AC	H12 6 3	90	10	0			3000	20			3	3 4	2
14Q7	Pentagrid Conv.	F 8AL	H12 6 .3	100	3 3	-2	100	8 5	525					9	9

Table 12-2

Tube characteristics continued

LOCK-IN continued

Type	Name	Dimen. Base	Cathode Rating	Plate E	Plate I	Bias	Screen E	Screen I	Gm	Amp. u	Load	Po Watt	Capacitance G-P	In	Out
14R7	Duodiode Pentode	F 8AE	H12 6 15	100	5 5	-1	100	2 2	3000				.004	5 6	5 3
14S7	Triode Heptode	F 8BL	H12 6 15	100 100	1 9 3	-2	100	3	500 Triode Osc grid leak 50000 ohms						
14W7	HF Pentode	F 8BJ	H12 6 22	300	10	-2	150	3 9	5900						
35A5	Beam Output	I 6AA	H35 15	110	40	-7 5	110	3	5800		2500	1 5			
35Y4	HW Rect	I 5AL	H35 15	235	100										
35Z3	HW Rect	I 4Z	H35 15	235	100										
50A5	Beam Output	I 6AA	H50 15	110	49	7 5	110	4	8200		2000	2 2			

OCTAL

Type	Name	Dimen. Base	Cathode Rating	Plate E	Plate I	Bias	Screen E	Screen I	Gm	Amp. u	Load	Po Watt	Capacitance G-P	In	Out
OA4G	Gas Triode	E 4V		105-130 Max I 100ma Cont I 25ma											
OB3	V. Reg.	E 4AJ	Starting 127v d-c min Operating 90v Oper 5-30 ma d-c maximum												
1A5GT	Pentode Output	H 6X	F 1.4 .05	90	4	-4.5	90	1	940		25000	.11			
1A7GT	Pentagrid Conv.	H 7Z	F 1.4 .05	90	.55	0	45	.6	250					6.5	11
1B3GT	HW Rect.	K 3C	F 1.25 .2	Max peak inverse plate volts 40000 Max av plate ma 2 Max peak plate current 17 ma.											
1H5GT	Diode Triode	H 5Z	F 1.4 .05	90	15	0			275	65			1	1.1	4.6
1N5GT	Pentode Sharp CO	H 5Y	F 1.4 .05	90	1.2	0	90	.3	750				007	2.2	9
3Q5GT	Output Beam	H 7AP	F 1 4 .1 2 8 .05	90	9 5 7 5	-4 5	90	1 6 1	2100 1800		8000	27 25			
5U4G	FW Rect.	M 5T	F 5 3	450	225										
5V4G	FW Rect.	L 5L	H5 •2	375	175										
5Y3GT	FW Rect.	J 5T	F 5 2	350	125										
5Z3	FW Rect.	N 4C	F 5 3	500	250										
6A5G	Triode	N 6T	H6 3 1	250	60	-45			5250		2500	3.75			
6A8GT	Pentagrid Conv	H 8A	H6.3 .3	250	3 3	-3	100	3 2	500					9 5	12
6B4G	Pwr Triode	M 5S	F 6 3 1	250	60	-45			5250	4 2	2500	3.5			
6BG6G	Beam Out.	O 5BT	H6 3 .9	500	100	-50			6000				5	11	6 5
6J5GT	Triode	H 6Q	H6 3 3	250	9	-8			2600	20			3 4	3 4	3 6
6K6GT	Pentode Output	H 7S	H6 3 .4	250	32	-18	250	5 5	2200		7600	3 4	.5	5 5	6
6L6G	Beam Output	L 7AC	H6 3 .9	250	72	-14	250	5	6000		2500	6 5			
6SA7GT	Pentagrid Conv	H 8AD	H6 3 .3	250	3.4	-2	100	8	450					11	12
6SF5GT	Triode	H 6AB	H6 3 .3	250	.9	-2			1500	100					
6SG7GT	Pentode Semi R	H 8BC	H6 3 .3	250	12	-1	125	4.4	4700				.004	8.5	7
6SH7GT	Pentode Sharp CO	H 8BK	H6 3 .3	250	11	-1	150	4.1	4900				.004	8 5	7
6SJ7GT	Pentode	H 8N	H6 3 .3	250	3	-3	100	.8	1650				004	7	7
6SK7GT	Pentode	H 8N	H6 3 3	250	9 2	-3	100	2 4	2000				005	6 5	7 5
6SL7GT	Twin Triode	H 8BD	H6.3 .3	250	2.3	-2			1600	70			2 8	3	3 8
6SN7GT	Twin Tri.	H 8BD	H6 3 .6	300	9	-8			2600	20			3 8	3	.8
6SQ7GT	Duodiode Triode	H 8Q	H6 3 .3	250	.8	-2			1100	100			1 8	4 2	3 4
6SR7GT	Duodiode Triode	H 8Q	H6 3 .3	250	9.5	-9			1900	16			2 3	3 5	3.8
6V6	Beam Output	H 7AC	H6 3 .45	250	45	-12 5	250	4.5	4100		5000	4.25			
6X5GT	FW Rect.	H 6S	H6 3 6	325	70										
6Y6GT	Tetrode Output	H 7AC	H6.3 1.25	135 200	58 61	-13 5 -14	135 135	3.2 2.2	7000 7100		2000 2600	3 6 6			
12A8GT	Pentagrid Conv.	H 8A	H12 6 .15	100	1.1	-1 5	50	1.3	360					9 5	12
12SA7GT	Pentagrid Conv	H 8AD	H12 6 .15	100	3.3	-2	100	8 5	425					11	11
12SF5GT	Triode	H 6AB	H12 6 15	100	.4	-1			1150	100					
12SH7GT	Pentode Sharp CO	H 8BK	H12 6 .15	100	5 3	-1	100	2.1	4000				003	8 5	7
12SJ7GT	Pentode	H 8N	H12 6 15	100	2 9	-3	100	9	1575				005	6 3	1
12SK7GT	Pentode	H 8N	H12 6 15	100	13	1	100	4	2350				005	6 5	7 5
12SL7GT	Twin Triode	H 8BD	H12 6 15	100	65	1			1125	70			2 8	3	3 8

Table 12-2

Tube characteristics continued

OCTAL continued

Type	Name	Dimen.	Base	Cathode Rating		Plate E	Plate I	Bias	Screen E	Screen I	Gm	Amp. µ	Load	Po Watt	Capacitance G-P	Capacitance In	Capacitance Out
12SN7GT	Twin Triode	H	8BD	H12.6	.3	90	10	0			3000	20			3.8	3	8
12SQ7GT	Duodiode Triode	H	8Q	H12.3	.15	100	.4	-1			900	100			1.8	4.2	3.4
25C6G	Beam Output	L	7AC	H25	.3	For other characteristics see type 6Y6GT											
25L6GT	Beam Output	H	7AC	H25	.3	110	49	-7.5	110	4	9000		2000	2.1			
25Z6GT	VD Rect.	H	7Q	H25	.3	117	75										
35L6GT	Beam Output	H	7AC	H35	.3	110	40	-7.5	110	3	5800	80	2500	1.5			
35Z4GT	HW Rect.	H	5AA	H35	.15	235	100										
35Z5GT	HW Rect.	H	6AD	H35	.15	117	100										
50C6G	Beam Output	L	7AC	H50	.15	For other characteristics see type 6Y6GT											
50L6GT	Beam Output	H	7AC	H50	.15	110	49	-7.5	110	4	9000		2000	2.1			
50Y6GT	FW Rect.	H	7Q	H50	.15	117	75										
117Z6GT	FW Rect	H	7Q	H117	.075	117	60										

Table 12-2

Panel Lamp Characteristics

Type	Circuit Volts	Volts	Amp.	Color	Miniature Base	Usual Service	Bulb Style No.
S40	6-8	6.3	0.15	Brown	Screw	Radio dials	T-3¼
S41	2.5	2.5	0.50	White	Screw	Radio dials	T-3¼
S42	3.2	3.2	0.35	Green	Screw	Radio dials	T-3¼
S43	2.5	2.5	0.50	White	Bayonet	Radio dials	T-3¼
S44	6-8	6.3	0.25	Blue	Bayonet	Radio dials	T-3¼
S45	3.2	3.2	0.35	White	Bayonet	Radio dials	T-3¼
S46	6-8	6.3	0.25	Blue	Screw	Radio dials	T-3¼
S47	6-8	6.3	0.15	Brown	Bayonet	Radio dials	T-3¼
S48	2.0	2.0	0.06	Pink	Screw	Battery set dial	T-3¼
S49	2.0	2.0	0.06	Pink	Bayonet	Battery set dial	T-3¼
S50	6-8	7.5	0.20	White	Screw	Auto sets	G-3½
S51	6-8	7.5	0.20	White	Bayonet	Auto sets	G-3½
S55	6-8	6.5	0.40	White	Bayonet	Auto sets	G-4½

Table 12-3

Key to Tube Dimensions

Symbol	Length Maximum	Diameter Overall	Symbol	Length Maximum	Diameter Overall
A	1¾	1-5/16	I	3-5/32	1-3/16
B	2⅛	¾	J	3⅜	1-5/16
C	2-3/16	⅞	K	4-1/16	1-5/16
D	2⅝	¾	L	4⅝	1-13/16
E	2⅝	1-5/16	M	5-5/16	2-1/16
5	2-25/32	1-3/16	N	5⅜	2-1/16
G	3¼	1-5/16	O	5-17/32	2-1/6
H	3-5/16	1-5/16			

Table 12-4

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