The Aerovox Research Worker

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Fixed Capacitors in Modern Circuitry

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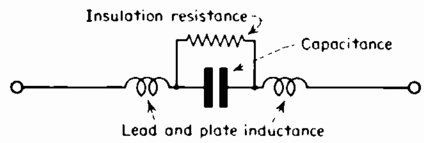
EDITORS NOTE: In response to numerous requests, this month's Research Worker is devoted to a review of capacitors and their characteristics, bringing up-to-date articles on this subject that have appeared in earlier issues of the Research Worker.

No other electrical component is called upon to perform such a wide variety of functions in electronic circuits as the capacitor. Most of these applications are based upon the ability of the condenser to differentiate between electrical currents of various frequencies. Such applications include; d.c. blocking, ripple filtering, r.f. and audio by-passing, coupling, frequency determination, R-C timing, and energy storage. Because of the varied requirements of these uses, fixed capacitors are made in many types and sizes, each especially engineered to fulfill a specific application or function. An important part of modern circuit design is therefore the choice of the proper capacitor for the circuit appplication at hand. In many cases, the success or failure of the design will actually depend upon this choice. The radio engineer, experimenter, and amateur must therefore have a firm background in capacitor design and application. This article will review this material and point out certain important "kinks" in the use of fixed capacitors.

Probably the most direct route to a mastery of the "safe and sane" use of capacitors is to establish a thorough understanding of the characteristics and limitations of each general type. The choice of the proper type for each circuit application then becomes merely a matter of following good engineering practice. For this reason, we will commence with a discussion of the basic types of fixed capacitors which are encountered in electronic circuitry.



CAPACITOR EQUIVALENT CIRCUIT
FIG.1

Since a capacitor is fundamentally two metallic conducting sheets isolated by a suitable dielectric material, the basic types are classified according to the type of dielectric used. They include:

- Air Dielectric Capacitors
- Mica Capacitors
- Ceramic Capacitors
- Paper Capacitors
- Electrolytic Capacitors

Just as all inductances have distributed capacity and resistance, and everyday resistors have some inductance and "end-to-end" capacitance, practical condensers are not perfect capacitances. All have a certain amount of residual inductance associated with the leads and plates, and also a finite value of resistance called the "insulation resistance". Thus, the equivalent circuit of any capacitor can be considered as in Fig. 1. The magnitudes of these unwanted characteristics vary through wide limits as a function of mechanical design and type of insulation or "impregnant" used, and must be considered along with such other characteristics as capacitance value, voltage and current ratings, temperature coefficient, stability, etc., in selecting a condenser for a particular job. The actual choice is usually a compromise between mechanical and electrical perfection on one hand, and the dictates of economy, space, and the practical requirements of the application on the other.

The Air Dielectric Capacitor

From the standpoint of low losses (high capacitor) and constancy of capacity value, the most nearly ideal capacitors are built with air (or vacuum) as the dielectric between the plates. Such capacitors are not perfect, however, for although air is a perfect dielectric having zero power factor, some losses arise due to dielectric hysteresis in the insulating material used to support the plates. Charging currents flowing in the leads and plates cause additional power losses and give rise to some residual reactance.

The air-dielectric condenser occupies much more volume for a given capacitance and is usually more expensive than any of the other general types. The reasons for this are apparent from an inspection of one of the simpler empirical formulas for the capacitance between parallel plates whose dimensions are large compared with the spacing between them, so that "fringing" may be neglected:

$$\text{CAPACITANCE } (\mu\mu\text{fds}) = .2244\ K\ A/d$$

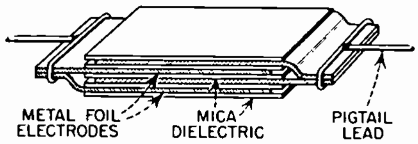
Where:
K is the dielectric constant of the material between plates.
A is the area of the smallest plate. (Sq. In.)
d is the distance between the plates (In.)

From this it is seen that the capacitance is *directly* proportional to the dielectric constant and the plate area, and *inversely* proportional to the spacing. Since the dielectric constant of air is only 1.0, but is greater than unity for all other insulating materials used in condenser construction, greater areas must be used in air capacitors to achieve a given capacitance. In addition, the dielectric strength of air is considerably lower than that of the other dielectrics, so that greater electrode spacings are necessary for a given working voltage. As a result, the volume occupied by an air-dielectric condenser will be at least 500 times greater than that of a comparable capacitor using a high grade mica dielectric (as is employed in all AEROVOX mica capacitors).

Because of these factors, air as a dielectric is used only to a very limited extent in fixed capacitors, such as in certain laboratory capacitance standards. Fixed capacitors using vacuum or an inert gas under pressure are used to a greater extent, since the breakdown voltage is increased about four to ten times thereby. Air dielectric *variable* capacitors are, of course, widely used for tuning r.f. circuits because of their mechanical simplicity.

Mica Capacitors.

Mica is widely used as the insulating material in capacitors manufactured primarily for r.f. applications. The mica capacitor is characterized by low power factor, high puncture voltage, good stability, high insulation resistance, and reasonable cost. As mentioned above, the size for a given capacity is considerably smaller than that of a comparable air-dielectric condenser. Due to the stacked construction usually employed, the inductance is quite low. A common construction is illustrated in Fig. 2. The plates consist of metal foil sandwiched between thin sheets of mica dielectric material. The ends of alternate foil strips extend beyond the



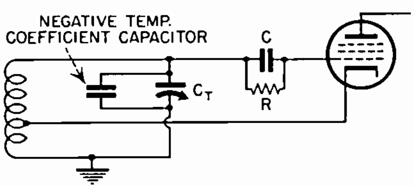
TYPICAL MICA CAPACITOR CONSTRUCTION
FIG. 2

mica sheets at opposite ends of the stack and each group is clamped together and connected to a lead. Thus, the charging currents which flow into each plate do so through a relatively short, broad path. Therefore, the inductance is low, being mainly that contributed by the wire leads.

Mica capacitors are used in a multitude of electronic applications where a high degree of capacitor excellence is required. Such uses include; r.f. fixed tuned circuits, r.f. by-passing, r.f. coupling, d.c. blocking, r.f. neutralizing, r.f. filtering, a.f. tone control, a.f. degenerative feedback, a.f. coupling where high insulation resistance is important (as in certain RC-coupled amplifiers), and many others.

In radio frequency applications, mica capacitors are rated according to r.f. current handling capability as well as maximum instantaneous voltage. The observance of both of these ratings are equally important in practice. Excessive r.f. current results in capacitor heating, which, in turn, causes increased dielectric losses, capacitance deviation, and lowered breakdown voltage. The effect is thus cumulative. The r.f. current through a capacitor in any given application can be determined by connecting a suitable r.f. thermoammeter in series with it.

In applications where stability of capacitance value is important, as in tuned circuits, r.f. filters, and other critical circuits, capacitors of the "silvered mica" variety are used. These units have extreme capacitance stability and low temperature coefficients. (The AEROVOX types 1464-1469-1479 have a positive temperature coefficient of only 30 parts per million per degree Centigrade.) These excellent characteristics are obtained by depositing a silver coating on the opposite surfaces of mica wafers and "sintering" this assembly at high temperature to form highly conducting metal "plates" in intimate contact with the mica. The variable factor of stacking pressure is thus drastically reduced, with correspondingly improved stability.



USE OF TEMPERATURE COMPENSATING CAPACITOR
FIG. 3

High quality mica units are manufactured with either positive, zero, or negative temperature coefficients of capacitance. Capacitors of this type (such as the AEROVOX "K" units) can be used for temperature compensation in tuned LC circuits in which low frequency drift with ambient temperature change is important. By such means, self-excited r.f. oscillators having frequency stability comparable to crystal controlled oscillators can be built. Stabilized oscillators of this type are used for receiver local oscillators, amateur v.f.o.'s, power oscillators where crystal control is impractical, etc. An example of the application of temperature compensating mica capacitors is given in Fig. 3. Here it is desired to maintain the LC product (and hence the frequency) of an R.F. oscillator "tank" circuit at a constant value over a wide temperature range. This may be accomplished by determining the approximate temperature coefficient of the uncompensated circuit in terms of capacitance deviation in parts per million per degree Centigrade. This coefficient will usually be positive with common circuit elements, i.e., the frequency decreases with increasing temperature. Temperature compensation then consists of the selection of a capacitor having a *negative* temperature coefficient approximately equal to the *positive* characteristic of the other circuit elements. Thus, with all circuit elements subjected to the same ambient temperature changes, frequency "drift" is compensated. A trick frequently resorted to by circuit designers consists of placing the compensating capacitor at a location in the equivalent where a temperature gradient exists, such as near a vacuum tube. A "vernier control" of temperature compensation is then obtained by adjusting the position of the capacitor within this gradient by trial and error until a point of best frequency stability is located.

The Ceramic Capacitor

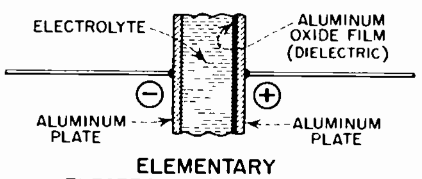
Another type of condenser which in some cases is comparable to the mica capacitor in electrical characteristics uses a ceramic as the dielectric material. A typical design is shown in Fig. 4. The capacitor plates are deposited on the inner and outer surfaces of a ceramic tube with connecting leads at either end. This unit is then sealed in a second ceramic tube and the whole assembly is wax impregnated for moisture proofing.

Ceramic capacitors are manufactured in a wide variety of characteristics, depending upon the type of ceramic used for the tube upon which the electrodes are deposited. Since some of the ceramics have very high dielectric constants, the volume efficiency (micromicrofarads, cubic inch) is high. Titanium dioxide ceramics, for instance, are used extensively for their high dielectric constants (90-170), low losses, and low temperature coefficients. Since the temperature coefficient can be controlled by the ceramic mixture, units ranging from essentially zero to high negative values of temperature coefficient are available for temperature compensation. Due to the coaxial type of construction, tubular ceramic capacitors have low values of residual inductance.

One grade of ceramic capacitor is used interchangeably with mica capacitors in critical r.f. circuits, while a lower quality variety which has very high volume efficiencies but poor stability, is used for general purpose applications such as by-passing. Ceramic tubular capacitors are usually more expensive than equivalent mica units. However, disk type ceramic capacitors are less expensive than equivalent mica capacitors and are sold on a "guaranteed minimum value" basis. Disk ceramics are used in high frequency by-pass applications only.

Paper Capacitors

Capacitors using wax or oil impregnated paper dielectric are employed extensively in d.c., audio, and low frequency r.f. applications where high capacitance per unit volume and low cost is required. They are characterized by generally poorer electrical characteristics than mica or ceramic capacitors, including; higher power factor, larger temperature coefficients, lower operating voltages, higher inductance and shorter life. These factors depend to a large extent upon the type of impregnant used, the purity of the impregnant, the method of construction, and the casing employed.

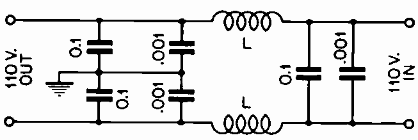


ELEMENTARY ELECTROLYTIC CAPACITOR
FIG. 6

Wax is used as the impregnant in a large variety of utility capacitors for the lower voltage ratings, where small size and economy are important. The tubular capacitors used in receiver audio, blocking, and by-pass work are examples. Moisture absorption shortens the life of cardboard-cased wax capacitors to some extent, as does high ambient temperature.

Castor oil (AEROVOX HYVOL), mineral oil, and chlorinated synthetic oils such as "askerels" are used in paper capacitors for higher operating voltages and greater dependability. Mineral oil filled units have the best temperature characteristics and lower power factors, but are about 35% larger in volume because of the lower dielectric constant. For this reason, castor oil filled condensers are used in most non-critical applications or where space is at a premium.

Typical paper condensers have temperature coefficients of capacitance approximately ten times larger than high grade mica capacitors, such as the silvered-mica types. Power factors are greater by at least one order of magnitude and inductances are larger, especially in the types using

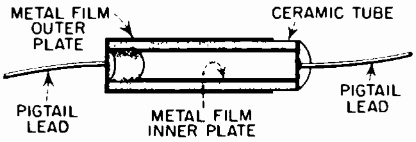


ILLUSTRATING USE OF DUAL BY-PASSING
FIG. 5

paper-foil rolled construction in which the contact tabs are at the ends of the rolled foil plates. In paper capacitors of advanced design (such as the AEROVOX Type P123ZG Metallized-Paper Subminiatures), residual inductance is minimized by the use of the extended electrode construction, in which electrical contact is made at the edges of the rolled electrodes, so that charging-current paths are short.

In applications where a wide range of frequencies must be effectively bypassed, as in the TV line filter shown in Fig. 5, a high capacitance paper capacitor may be used in parallel with a small mica unit. Otherwise, the residual inductance of the paper condenser may make it ineffective as a by-pass for the high r.f. frequencies.

Another by-passing device used in video i.f. amplifier design consists of using capacitors which are *self-resonant* at the frequency to be by-passed.



CERAMIC CAPACITOR CONSTRUCTION
FIG. 4

A value of capacitance is chosen which is series resonant with the inherent inductance of the capacitor and it's leads. This type of single-frequency by-passing is very effective.

The Electrolytic Condenser

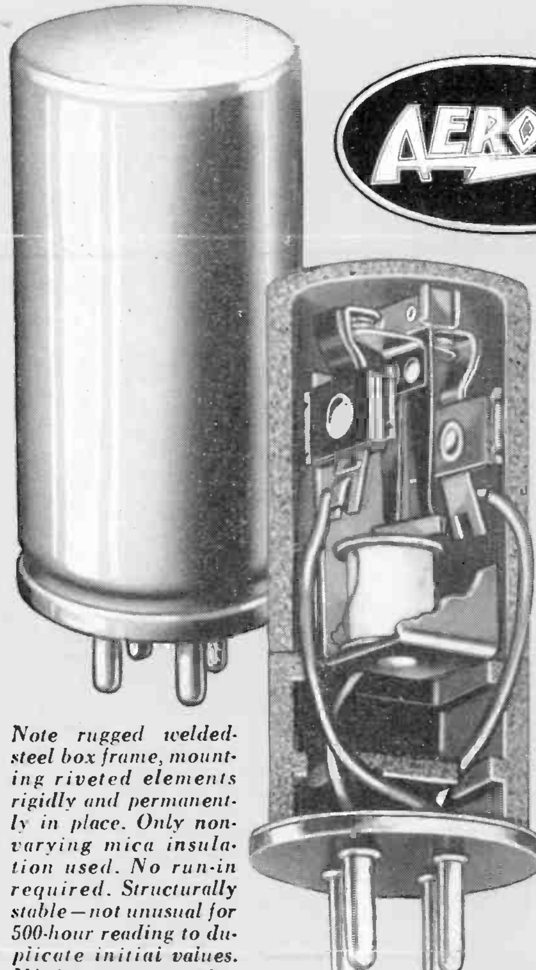
The familiar electrolytic capacitor is the "work horse" of the receiver power supply filter field. These units have extremely high volume efficiencies, occupying only about 15% of the space required for equivalent paper capacitors. The cost per microfarad is also very low. For these reasons, although inferior in most other respects to the other types, the electrolytic capacitor is extensively used for filter and by-pass applications.

An electrolytic capacitor may be made either by immersing two aluminum electrodes in an electrolytic solution such as ammonium borate or sodium phosphate (a "wet" electrolytic) or by filling the space between rolled foil electrodes with a thick paste of similar material (the "dry" electrolytic). A "forming voltage" applied between the plates deposits a film of aluminum oxide on the positive plate. See Fig. 6. This film is the dielectric material of the capacitor. Because it is extremely thin-being only .000025 inch thick in some cases — the capacitance per unit area is very high. For the same reason, the operating voltage of the unit is limited to about 450 volts. Electrolytics may, however, be used in series for higher voltages with the use of the usual voltage equalizing resistors shunting each unit, as must be used with mica and paper capacitors which have higher insulation resistances.

The electrolytic condenser is essentially for d.c. applications, since to maintain the oxide film, the plate bearing it must never become negative. If a.c. components are present, they must be smaller in voltage than the steady d.c. voltage impressed.

The high leakage current of the electrolytic becomes much greater after prolonged inactivity, but soon drops to a normal value of about 200 microamperes per microfarad. The wet electrolytic has been used in voltage limiting applications because of its particularly steep leakage-current versus applied voltage characteristic.

Quiet as a mouse



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