UNDERSTANDING

CAPACITORS

and

their

uses

by **William F. Mullin**

Capacitor theory, design,

application, relacement,

and testing...

for anyone who works

with electronic circuits.

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PREFACE

Did you know that capacitors have been in existence for over 200 years? Discovered by accident and for many years regarded as little more than a scientific curiosity, they are still surrounded by much mystery and misinformation. Even the name of this component is confusing. It was originally called "condenser" and many persons still use that terminology. The word "condenser" came into use because the unit apparently *condensed* electricity. More investigation, however, disclosed that this was not the case. As a matter of fact, capacitors have the ability to store electrons and thus the capacity for retaining a given charge. Therefore, the more accurate name of *capacitor* is used throughout this book.

This is a practical treatise and not a lengthy scientific dissertation. It has been written to answer practical questions that might arise in the everyday servicing of electronics equipment. While a certain amount of theory has been included, the principal purpose of this book is to eliminate the mystery surrounding capacitors, and explain how they operate, how they are made, how they are used, and why they fail in service. In addition, there is practical information on testing and replacement.

When you have digested the contents, you should have a much better understanding of the working principles of capacitors.

The author wishes to express his sincere gratitude for the assistance rendered by many engineers, technicians, and editors who made this book possible.

<div align="right">WILLIAM F. MULLIN</div>

May, 1961

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CHAPTER 6

Chapter 1

WHAT IS A CAPACITOR?

To those who know anything about electronics, the question "What is a capacitor?" may sound rather pointless. They may know what capacitors look like, having used them in the repair of equipment, in experimenting, or in the construction of some equipment. But do they really know the basic principles of capacitors—their characteristics, performance, and construction?

There are literally dozens of different kinds of capacitors, varying in size, shape, and value. Fig. 1-1 shows a few of

Fig. 1-1. Common types of capacitors.

the more common types. Each has something in common with the others, and yet each is designed for specific applications where it excels the others in performance.

DEFINITION

In order to properly explain why there are so many kinds of capacitors, and why one type will do a certain job better than another, we have to start by learning more about what a capacitor really is. Let's begin with the simplest definition possible: *a capacitor is an electronic device capable of temporarily storing electrical energy*. It would be quite possible to confuse this definition with the one for a battery. There is, however, an essential difference between the two. A battery stores electrical energy, releasing it by chemical action, whereas a capacitor stores the actual electrons themselves. In other words, a battery is essentially a chemical device, and a capacitor is an electronic device.

Although a capacitor is not a battery, it can exhibit some of the characteristics of a battery. In addition, capacitors are capable of acting like resistors, rectifiers, or inductors. To add to the confusion, they can exhibit these characteristics all at the same time and still perform the functions of a capacitor.

HISTORY

For the moment, however, let's not be concerned about these other characteristics. Instead, let's concentrate on a simple explanation for this device, and the best place to start is at the beginning—back when capacitors were first discovered. It all happened in the year 1746. The place was Leyden, Holland, where a physicist by the name of Pieter van Musschenbrock was performing some experiments in an attempt to "electrify" water. He had a number of bulky batteries, a few glass jars, and some thin copper foil. You must bear in mind that this all took place at the very dawn of the electrical age, when the scientists of the day were

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willing to try anything—no matter how ridiculous it may seem to us today. At any rate, van Musschenbrock's experiment consisted of lining a thin glass jar inside and out with copper foil, filling the jar with water, and then dropping it into a larger jar which was also filled with water. When he attached the leads from the batteries, nothing happened. Naturally, he assumed his attempt to "electrify" water was unsuccessful, so he emptied the jars and disconnected the batteries. In so doing, he accidentally touched the leads from the two copper foils, and received a distinct and unpleasant shock. This came as a surprise to him, since the batteries were no longer in the circuit. Well, you and I know that van Musschenbrock had accidentally produced a capacitor. It is interesting to note that his original construction is almost identical to the present-day laboratory standard. His discovery is called the Leyden jar, in honor of its place of discovery. (It's unfortunate Herr van Musschenbrock's name wasn't a little shorter and easier to spell, because he gets very little glory for what he did.)

BASIC CONSTRUCTION

Fig. 1-2 shows the basic configuration of the Leyden jar. Notice that one copper foil is connected to the positive terminal of the battery, and the other to the negative terminal.
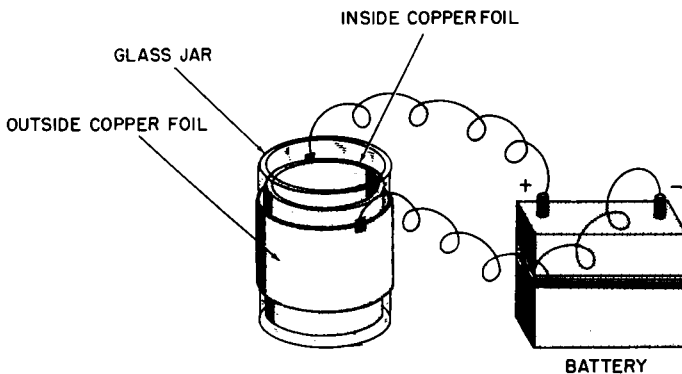
Fig. 1-2. Basic Leyden jar capacitor.

The two foils are unable to touch each other because they are separated by the glass jar. Here we have the three essential parts of any capacitor: two conductors (the copper foils) and an insulator (the glass jar). Each of these three parts has a name: the positive conductor is called the *anode* plate, the negative conductor is the *cathode* plate, and the insulator is called the *dielectric*. It makes no difference whether the parts are cylindrical (as in the Leyden jar) or flat; the names remain the same—anode, cathode, and dielectric.

Suppose we take the cylindrical Leyden jar and flatten it. The essential ingredients of the capacitor remain—two conductors separated by an insulator (Fig. 1-3). Now this insulator (dielectric) can be glass, or any of a dozen other insulating materials such as mica, plastic, paper, ceramic—
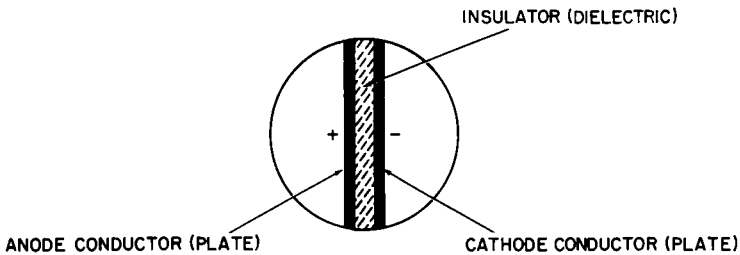
Fig. 1-3. Basic parts of a capacitor.

even air or a vacuum. The essential thing to bear in mind is that the conductors (plates) must be electrically insulated from each other. If they are allowed to touch, the ability of the device to store electrons will be destroyed.

BASIC THEORY

Since there is no direct connection between the two plates, no current should flow—even though each is connected to a battery terminal. There is, however, a *tendency* for the electrons to want to pass from the negative to the positive plate through the dielectric. In other words, a potential exists across the two conductors, and electrons tend to accumulate on the surface of the negative plate (see Fig. 1-4A). Even

after we disconnect the battery, they will stay there (Fig. 1-4B). However, if the two leads are permitted to touch, the accumulated electrons on the negative plate will have a way to reach the positive plate, which is lacking in electrons. Since the electron movement is instantaneous, a spark will be produced (Fig. 1-4C).
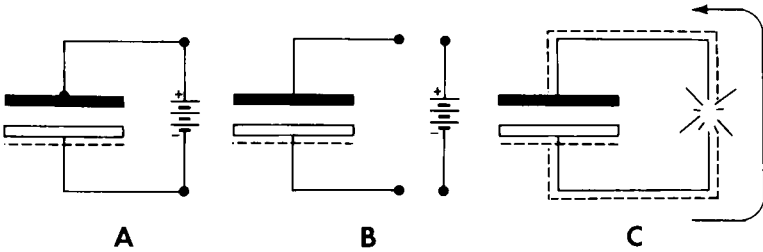
Fig. 1-4. Electron storage on the surface of the negative plate.

The number of electrons stored on the surface of the negative plate depends on its area and on the total force applied to put them there. Suffice it to say that the electrons are there, and that obviously our capacitor is capable of storing them for a short period (witness the spark). It therefore follows that a capacitor has the ability to store a given amount of electrons. The term *capacitance* is used in referring to the amount of electrical energy a capacitor can store.

MEASUREMENT UNITS

This brings up the question "How does one evaluate or measure capacitance?" Michael Faraday developed the method we use today. In fact, the basic unit of capacitance —the *farad*—is named after him. A capacitor which requires one ampere of current to raise the potential across the plates by one volt in one second is said to have a capacitance of *one farad*.

Now, one ampere of current is a rather large amount and, as one might suspect, a one-farad capacitor would be enormous indeed. As a matter of fact, such a large capacitor is impractical for use in everyday circuitry (although some

equipment requires the use of even larger units). Much smaller units, with values expressed in *microfarads* and *micromicrofarads*, are most commonly used. A *microfarad* is equal to one millionth of a *farad*, and a *micromicrofarad*, to one-millionth of a *microfarad*. Or:

$$1 \text{ microfarad (mfd, mf, } \mu\text{f)} = \frac{1}{1,000,000} \text{ farad}$$

VARIATIONS IN CONSTRUCTION

Let us now examine two capacitors, one a 50-mfd unit rated at 5 volts, and the other a 50-mfd value with a rating of 450 volts. What's the difference between them, and why?

In order to understand the difference, we have only to consider the basic capacitance formula. The number of electrons a capacitor can store is a function of the plate area. In addition, we have two other factors to consider— the kind of dielectric used, and the distance between the two plates (thickness of the dielectric).

The formula we will use is:

$$C = 0.2235 \frac{KA}{d} (N\text{-}1)$$

where,
    C is the capacitance in micromicrofarads (mmf),
    K is the dielectric constant of the insulator,
    A is the area of one plate in square inches,
    d is the distance between the plates in inches,
    N is the number of plates.

Dielectric constants for the more common materials are listed in Table 1-1.

Using the capacitance formula, we find that two one square-inch plates, separated by Kraft paper (K = 4.0) .001 inch thick, will have a capacitance of approximately 90 mmf. It should be noted that the thinner the dielectric, the smaller the capacitor can be physically and still retain its rated capacity. In other words, capacitance increases as the distance between the plates decreases; thus, the same

amount of capacitance can be achieved with smaller plates. There is, however, another factor to be considered, and that is the applied voltage. If it becomes too great, a flashover or breakdown will occur.

Table 1-1

Approximate dielectric constants of common capacitor materials.

Material	Dielectric Constant
Air	1.0
Aluminum oxide	10.0
Beeswax	3.0
Cambric (varnished)	4.0
Celluloid	4.0
Glass (*Pyrex*)	4.2
Glass (window)	7.6
Mica (clear India)	7.5
Mylar	3.0
Paper (Kraft)	4.0
Porcelain	6.2
Quartz	5.0
Tantalum oxide	11.0
Vacuum	1.0

A potential of 5 volts is less likely to produce enough stress to cause a breakdown, compared with a potential of 450 volts. This, then, is the principal difference between capacitors with the same value but different voltage ratings.

As you can see from the previous paragraphs, a capacitor is subject to several compromises in design. In order to raise capacitance, we can do any of three things—move the plates closer together, increase the plate area, or use a better dielectric (one with a higher K). On the other hand, to avoid voltage breakdown we may have to space the plates farther apart (which makes the capacitor larger), or use a different and perhaps more expensive dielectric.

CAPACITOR SAFETY

Before we close this chapter, let's take a moment to dwell on the potential danger involved in handling capacitors. One can receive a nasty shock, or even a fatal one, by failing to observe certain elementary safety precautions.

Capacitors can be lethal weapons—don't ever forget that. A current as small as 5 milliamperes can be lethal under certain conditions. Before handling a capacitor be certain it has been properly discharged. This does not mean using a screwdriver or touching the leads together. Capacitors should be discharged only through an appropriate resistor. A very rapid discharge through a short conductor can ruin an otherwise valuable component. Also make certain the discharging resistor is of adequate size, to prevent being damaged. *Remember!* A capacitor of only 1 mfd, charged to 1,000 volts, is capable of delivering up to 50 watts of power. So handle capacitors with respect.

Chapter 2

CAPACITOR THEORY

To more fully understand the theory of capacitors, especially how they perform in actual operation, it is necessary to analyze the effects of the different conditions to which they will be subjected.

Fig. 2-1A shows a theoretically perfect capacitor. The equivalent circuit of an actual capacitor, as shown in Fig. 2-1B, indicates there are other characteristics besides capacitance to be considered. There is the inductance L of the

A   B
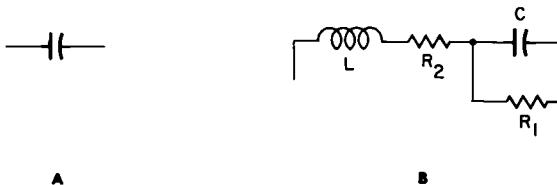
Fig. 2-1. Theoretical and equivalent circuit of a typical capacitor.

leads and plates, resistance R1 of the dielectric (leakage resistance), resistance R2 of the leads and plate material (effective series resistance), and measured capacitance C.

ENERGY ABSORPTION

Whenever a capacitor is charged or discharged, work is performed; in other words, energy must be expended. It takes a certain amount of voltage to produce enough current to charge a capacitor, and the product of amperes and volts

is watts, which is the unit of power. This power must be expended in some way. Most of it will be held in reserve until the capacitor is discharged. This will represent the major portion in a good-quality capacitor. The remainder of the power, however, will be dissipated in the form of heat. This is caused by the I^2R loss in the resistance R2 (Fig. 2-1B) of the leads and plates of the unit. I^2R losses take place during both the charge and discharge cycles. Obviously, this heat loss must be held to some reasonable level. Therefore, it is often necessary to make a capacitor larger than mere electrical requirements would seem to dictate.

The heat produced during the charge and discharge cycles results from the fact that there is no such thing as a perfect capacitor. If there were, all the energy it receives would be stored there for future use. The more rapidly a capacitor is charged and discharged, the more critical these internal losses become. In fact, heat can build up to the point where the capacitor can be damaged.

POWER FACTOR

Power factor is the term used to describe the ratio of power lost to the total power used to charge a capacitor. It is a rather complex function involving all the losses encountered, and depends on frequency, temperature, dielectric material, voltage stress, and the resistance of the leads and plate material. Let's take a look at these factors to see how they affect power factor.

Everything in nature has a tendency to vibrate, and the vibrations will occur more freely at one frequency than at any other. Witness the window glass rattling as an airplane passes overhead, or the singer cracking a crystal goblet with a high C note. These are examples of mechanical vibrations to which some capacitors may be subjected under certain circumstances. Such vibrations can result in a change of capacity as the distance between the plates varies at its natural (resonant-frequency) rate.

The greater effect in capacitors, however, is electrical in nature. When an inductor and capacitor are placed in series, they form a resonant circuit which has the property of offering a very low opposition to the flow of a changing (alternating) current at some particular frequency, but maximum opposition at all others. The frequency at the point where this opposition is lowest is known as the resonant frequency of the circuit.

So how does all this affect capacitors? As the resonant frequency is approached, apparent capacitance drops off very sharply and power factor increases rapidly. Here's an example of what we're talking about. Suppose we are replacing a capacitor in a circuit which handles a frequency of 2,000 kc. The original unit was rated at 0.1 mfd, 600 VDC. Can we replace it with one, which just happens to be there on the bench, rated at 0.1 mfd, 3,000 VDC? Not necessarily, because the resonant frequency of the original was selected to be well above 2,000 kc, whereas the resonant frequency of the second could very well be at or near 2,000 kc. Use of this second unit would be wasted effort, because it could quickly overheat and fail.

A second important frequency consideration is lead length. The shorter and thinner the leads, the higher the resonant frequency becomes. Let's take another example, involving 5,500 megacycles. The original unit was rated at 0.01 mfd and its leads were one-half inch long. It is in a particularly awkward spot, so we'd like to install a replacement unit with 2-inch leads for convenience. Can we do it? Again, not necessarily. The half-inch leads have a resonant frequency well above the signal frequency in our circuit, but the 2-inch leads may resonate near 5,500 mc. This could result in rapid capacitor deterioration, meaning we'd just have to do the job over.

The conscientious technician will always remember to replace capacitors with the same type, and to install them as nearly as possible like the original unit. This is especially true in highly critical circuits and/or where frequencies are relatively high.

TEMPERATURE

Capacitors are affected more by temperature than by any other environmental condition (except humidity). Capacitors are rated at a particular temperature, most generally 25°C. Any deviation from this temperature will change their capacitance and voltage rating.

As the temperature increases beyond 25°C, the capacity also increases, but the voltage-breakdown resistance decreases. On the other hand, a decreasing temperature does just the opposite—it decreases the capacitance and increases the voltage-breakdown resistance. In both instances the power factor will increase. In short, most capacitors perform best at approximately 25°C; any deviation will adversely affect their performance.

The preceding paragraph is to be considered only a general rule; there are exceptions, of course. Many capacitors, particularly ceramic types, are specifically designed to decrease in value with an increase in temperature. A description of this type will be found in Chapter 3.

The principal reason a rising temperature has such an effect on capacitor operation is that electron activity increases also. Thus, at 25°C a dielectric gap could be sufficient to prevent a breakdown at 450 VDC, but at 100°C the capacitor might rupture.

DIELECTRIC MATERIAL

Dielectric material characteristic is also affected by a change in temperature. The relative merits of various materials were discussed in Chapter 1, but only from a dielectric or insulating standpoint. Now let's examine these materials from a power-factor standpoint. It must be emphasized that the values in Table 2-1 are only approximate; they may vary in specific cases.

It is interesting to note that although *Mylar* has only a slightly lower dielectric constant than paper, its power factor is substantially lower. As a result, though its dielec-

Table 2-1
Dielectric constants and power factors of common dielectric materials.

Dielectric Material	Dielectric Constant K	Power Factor %
Vacuum	1.0	0
Air	1.0001	0+
Paper (Kraft)	4.0	3.0
Mylar	3.0	0.5
Glass	6.7	0.06
Mica	6.85	0.02
Aluminum Oxide	10.0	10.0
Tantalum Oxide	11.0	10.0

tric might have to be slightly thicker, a *Mylar* capacitor should have lower internal losses than its equivalent paper unit.

The more common dielectrics tend to become less effective as their temperature increases. The lower efficiency adds to the already increased electron activity and in this way hastens voltage breakdown.

You will note that Table 2-1 does not include ceramics. There is no standard ceramic dielectric; each one is specially formulated to suit a particular application.

DIELECTRIC STRESS

Too high a voltage will weaken the dielectric strength of an insulator. Thus, a dielectric rated at 600 VDC will probably break down at 1,600 VDC. Even though a breakdown doesn't occur at the higher potential it will leave the dielectric susceptible to future failure at even its rated voltage.

As would be expected, an important factor involved in dielectric stress is the quality of the dielectric itself. Impurities, especially if they are metallic, can produce areas

of poor resistance and result in breakdown. During the manufacture of paper capacitors, minute amounts of impurities will creep into the fibers of the paper pulp, even with the most careful quality control. To minimize the alignment of these conductive particles, paper capacitors are commonly constructed of layers upon layers of paper.

Dielectric stress is expressed in terms of volts per mil (.001 inch) thickness—the better the dielectric, the higher the volts per mil. However, this figure will decrease as the temperature, frequency, and/or thickness of the material increases.

PLATE LOSSES

The over-all performance of a capacitor depends on a wide variety of factors. Of these, dielectric efficiency is of primary importance, but the efficiency of the plates (conductors) cannot be overlooked. The choice of plate material must of necessity be a compromise. Copper would be the obvious choice electrically, but it corrodes easily and is relatively less stable than aluminum. Aluminum, therefore, has become the most common plate material in spite of slightly less conducting ability. Silver and tantalum are used where their advantages outweigh their added costs.

The efficiency of plate materials decreases as temperature increases because of added conductive resistance. In addition, the efficiency of the dielectric decreases. Many other factors are involved, but generally, over-all losses increase as temperature increases and vice versa. In spite of this, many capacitors exhibit increased capacitance as temperature increases. But, the over-all *losses* are *higher* and over-all *efficiency* is *lower*.

EQUIVALENT CAPACITOR CIRCUIT

Let's return to the equivalent circuit of a capacitor. While the perfect capacitor would have no losses of any sort, and would merely represent an energy potential inserted in any given circuit, an actual unit unfortunately has several imperfect characteristics.

Every conductor possesses a certain amount of inductance. A conducting wire or the flat plates of a capacitor will exhibit minimum inductance. By rolling the plates into a cylinder, the inductive value will increase. A further increase will result by rolling the plates into a coil—more turns produce a higher inductance.

A perfect capacitor would have an infinite resistance. In actual practice, however, all capacitors have a certain amount of leakage, which an ohmmeter will show as a resistance. The amount of this leakage resistance (R1) will vary from one type and value of capacitor to another. It may range from 1,000 megohms in one unit, down to 50K in another. Yet both units may be performing satisfactorily. This matter of capacitor leakage is covered more fully in Chapter 6.

The effective series resistance (R2) of a capacitor is actually a combination of the lead and plate losses and is generally much lower than the leakage resistance. It is useful only in calculating the over-all efficiency of a capacitor.

CAPACITANCE MEASUREMENT

By definition, a capacitor is a device capable of temporarily storing electrical energy. That is, the device is said to have capacitance.

How does one measure capacitance? One way is to compare the capacitor against a known standard by means of a bridge circuit. Another is to use a wattmeter, which measures the actual amount of energy. The latter is probably the only true means of fulfilling the requirements of the following formula for capacitance:

$$C = \frac{Q}{V}$$

where,

C is the capacitance in farads,

Q is the quantity of charge in coulombs (one coulomb is equal to a current of one ampere flowing for one second),

V is the voltage across the capacitor plates.

As an example, assume we charge a capacitor to 500 volts and then discharge it through a sensitive watt/second meter, getting a reading equivalent to one ampere/second of current flow. Solving the equation, we find that C = 1/500, or .002 farad (2,000 mfd).

The time-constant method is another way of measuring capacitance with substantially the same accuracy. A circuit diagram of this method is shown in Fig. 2-2.
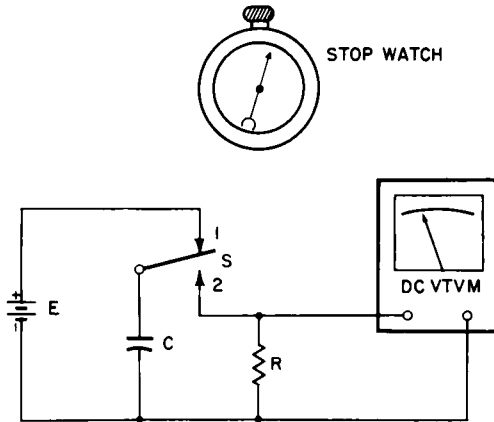
Fig. 2-2. Circuit for use in the time-constant method of capacity measurement.

This admittedly is a rather crude test, since a stopwatch is used, but it serves to depict the principle involved. E is the energy source, S is a single-pole–double-throw switch, R is a 1,000-ohm resistor, and C is the capacitor under test. A sensitive vacuum-tube voltmeter, with an input resistance of a least 1,000 times the value of R, is used for the voltage readings.

While the switch is in position 1, the capacitor remains charged. To start the test, we simultaneously depress the switch to position 2 and start the stopwatch. When the VTVM reads approximately 37% of the maximum voltage reading, we stop the watch. Capacitance can now be calculated from the following equation:

$$C = \frac{t}{R}$$

where,

C is the capacitance in farads,
t is the time in seconds,
R is the resistance in ohms.

For purposes of illustration, assume two seconds has elapsed. The equation is solved to give $C = 2/1000$, or .002 farad (2,000 mfd). If the time had been one second, the answer would have been 1,000 mfd, and so on.

This test is only as accurate as the timing method used. The one described would be useless for small capacitors. However, by substituting an oscilloscope equipped with a millisecond timing pulse, we could achieve a high degree of accuracy.

CAPACITOR OPERATION

A capacitor does not charge or discharge at a steady rate. At the first instant that voltage is applied, the capacitor will have the least amount of opposition to electron flow. Therefore maximum current will start flowing. As electrons ac-
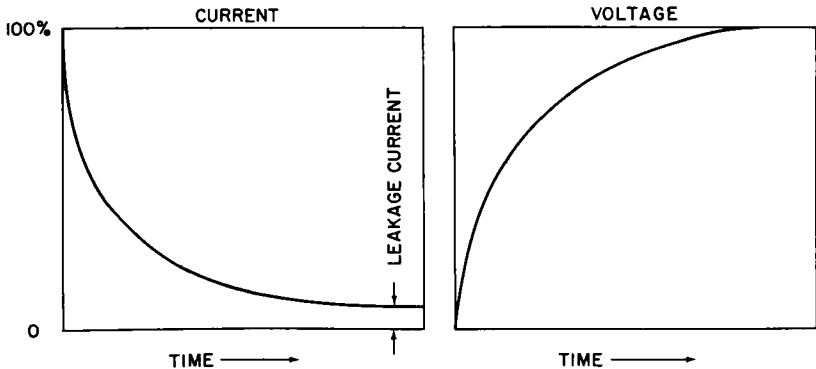
Fig. 2-3. Capacitor charging characteristics.

cumulate on one plate of the capacitor, it becomes more and more difficult to add others. Finally, the point is reached where the available force (voltage) will no longer be able to increase the charge, and the capacitor will be fully

charged. To put it in another way, let's go back to the
first instant, just as current starts to flow. No voltage dif-
ference exists across the capacitor (no excess electrons),
but as electrons rush to one plate and withdraw from the
other, they produce a potential which opposes the applied
voltage. There is less voltage difference existing now, so a
reduction in current flow takes place. In other words, the
more the capacitor charges, the greater the opposing voltage
becomes—until finally it reaches the same value as the ap-
plied voltage and current flow ceases. The action occurs at
an exponential (nonlinear) rate. Fig. 2-3 illustrates the
typical response of a capacitor to a charge cycle.

Notice that the current flow reaches maximum almost
instantly, but diminishes gradually to minimum. It never
reaches absolute zero, which is an indication of the leakage
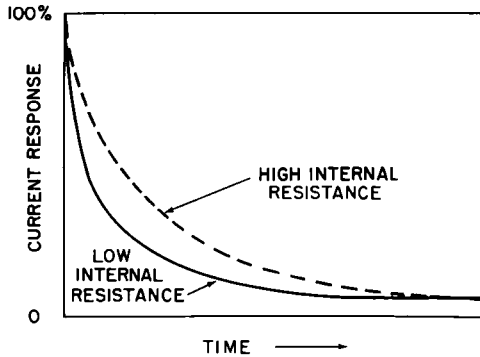current; if the capacitor were perfect, the current *would*

Fig. 2-4. Comparison of charging current
response.

drop to zero. The voltage rises in a manner similar to the
current decrease, except it finally reaches a maximum value
and remains there as long as voltage is applied to the ca-
pacitor.

The speed with which a capacitor charges is a function of
its size (or capacity) and the external and internal resist-
ances. If we have two capacitors of equal value, but one has
a low and the other a high internal resistance, the com-
parison would be similar to Fig. 2-4.

You will note that the current finally decreases to the same level in the higher-resistance capacitor, but takes longer to do so. The actual lag between the two may be only a small fraction of a second, but even this difference can be critical in a high-frequency application. The reason is that the capacitor must be able to respond to the frequency of the applied voltage at a given rate. If the time response of the capacitor changes, the entire circuit operation could be upset.

When a capacitor is discharged, the response curve is as shown in Fig. 2-5. Now the current and voltage responses
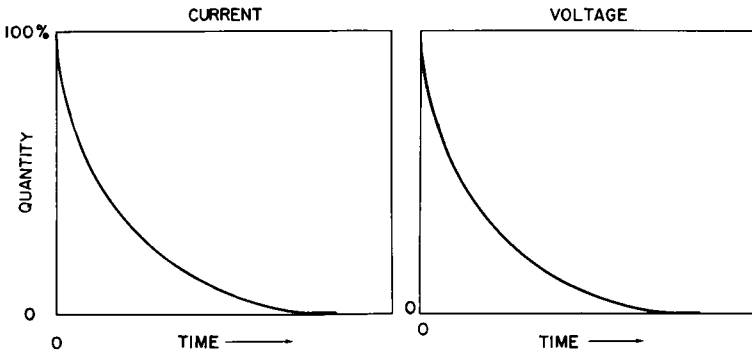
Fig. 2-5. Capacitor discharge response.

are the same. The discharge of a capacitor is very rapid at first, and then tapers off until the device is apparently completely void of charge.

Perhaps you have experienced this situation—a capacitor, which you are certain has been completely discharged, suddenly shows a charge again—and have wondered why. Let's take another look at the discharge characteristic of a capacitor, but this time we'll expand the time scale as shown in Fig. 2-6.

Here we have discharged the capacitor briefly, until it apparently has no charge left. Then we place it to one side. Gradually the charge seems to rebuild until it reaches a definite level. If we now check, we will verify that a small charge has been retained by the capacitor. The reason is

that not all of the electrons were evenly redistributed during the discharge operation. This phenomenon is referred to by engineers as *dielectric absorption*. All materials have atomic structures, and all atoms have electrons in orbit around a
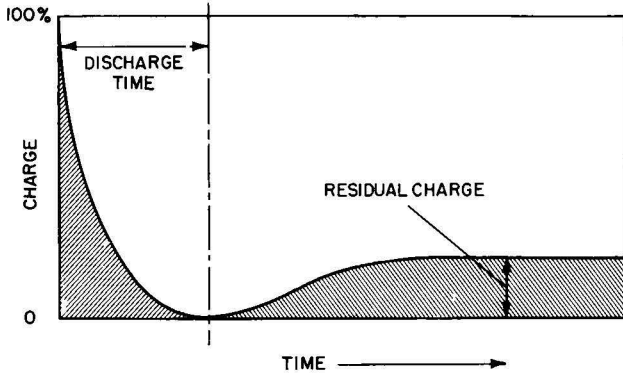

Fig. 2-6. Discharge curve with residual charge shown.

nucleus. The freedom with which one or more of these electrons enter or leave their orbits determines the relative merit of a material as a conductor.

Application of voltage across the dielectric causes the electrons to be redistributed so that more of them accumulate near the positive plate and less near the negative plate. This stressing of the dielectric occurs upon initial appli-
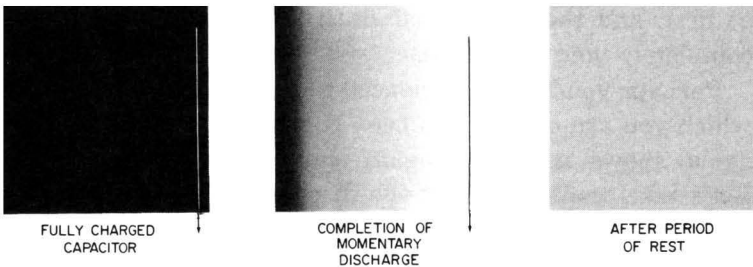

Fig. 2-7. Illustration of capacitor residual charge.

cation of voltage and, in effect, "forms" the dielectric. Never again will the material be the same as it was before the potential was applied. When the capacitor is allowed to discharge, most of the electrons will try to redistribute

themselves evenly. But those in the dielectric are "held" fairly tightly, a condition that predominates in insulators. Fig. 2-7 shows the principle involved. A fully charged capacitor is shown as having a dense accumulation. At the time of discharge most of them move from the capacitor as shown by the arrow. Some, however, are firmly entrenched, and will not leave their orbits of their own volition. Thus, it is impossible to ever completely discharge a capacitor once it has been subjected to a DC charge.

TIME CONSTANT

Mention has been made, throughout this chapter, of the charge and discharge cycles of a capacitor. In each instance time has been a factor. This was taken into consideration in the problem of capacitance measurement, but further examination will be helpful.
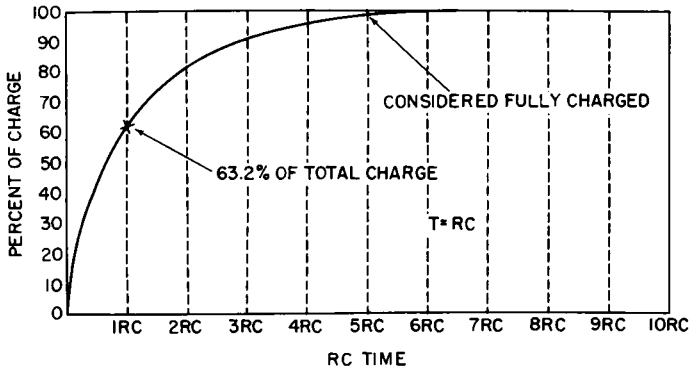

Fig. 2-8. Charge on capacitor at various RC times.

The formula $C = t \div R$, used in solving for the capacitance value, is also the one we will use to explain RC time constants. Expressed in terms of time, the formula becomes $t = RC$; t being time in seconds, R resistance in ohms, and C capacity in farads. The definition of the term *time constant* (1 RC time) is the length of time required to charge a capacitor to 63.2% of the applied voltage. It is further recognized that at the end of 5 RC times, the capacitor will

be considered fully charged. Fig. 2-8 shows this graphically.

Since resistance is always present—whether deliberately introduced or contained in the internal structure of the capacitor—the RC time constant must always be considered. The discharge is governed by the same rules as the charging rate. Often the circuit is designed to have a different resistance on the charge than on the discharge cycle. This means the time constants will be different. An example of this is illustrated in Fig. 2-9. The capacitor is charged
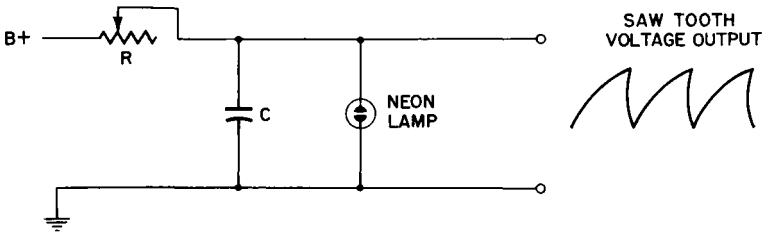
Fig. 2-9. Circuit of neon sawtooth generator.

through a relatively long time-constant and discharged through a very short one. When the voltage is first applied to this circuit, the potential across the capacitor starts rising from zero, at a rate determined by the values of R and C. If allowed to continue, it would reach the applied voltage in approximately 5 RC times. Before it reaches this point, however, the firing or ionizing potential of the neon lamp is reached and the capacitor now starts discharging through the very low resistance of the ionized neon, meaning the rate will be much more rapid. At some point, determined by the characteristic of the lamp, the voltage will have decreased to the deionizing potential of the neon, the lamp becomes an open circuit, and the capacitor again starts charging through resistance R, toward the applied voltage. This action is repeated as long as the voltage is present, producing the series of sawtooth waveforms shown in Fig. 2-10.

The repetition rate, or frequency, of this sawtooth is governed by the values of R and C and by the characteristics

of the neon lamp. In the circuit shown in Fig. 2-9 the value of resistance R is varied to change the frequency.

CAPACITIVE REACTANCE

In the charging of a capacitor, opposition to the flow of electrons is present in the form of resistance and the natural reluctance of the dielectric to accept them. As long as only DC voltages are involved in the charging process, the latter factor is a constant for a given unit. In applying alternating voltages, however, this second factor becomes variable, its
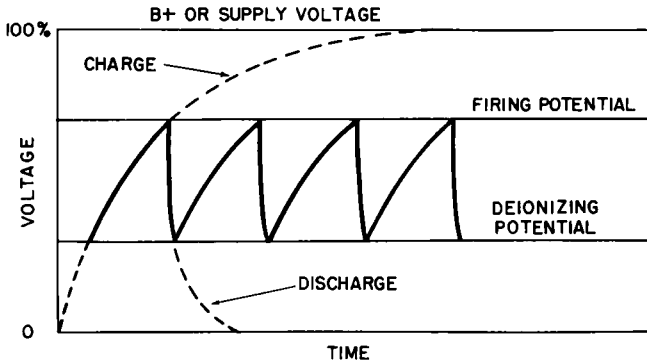
Fig. 2-10. Voltage variation on capacitor in neon sawtooth generator.

value determined by the frequency of the alternations. It is known as capacitive reactance, and opposes the flow of electrons in the charge-discharge process. Like resistance, it is measured in ohms. In applying an AC voltage, a capacitor is first subjected to an attempt at being charged in one direction and then, a short time later, in the opposite direction. This means the capacitor is charged toward a positive potential, discharged back to zero, charged toward an equal negative potential, and again discharged back to zero —this action repeating itself as long as voltage is applied. The length of time the capacitor has to attempt the charge or discharge is determined by the frequency of the applied voltage.

Capacitive reactance is expressed by the formula:

$$X_c = \frac{1}{2\pi f C}$$

where,

X_c is the capacitive reactance in ohms,

f is the frequency in cycles per second,

C is the capacity in farads.

From this formula it can be seen that the higher the frequency and/or capacity, the lower the reactance becomes. As the frequency is decreased the reactance increases, until the condition corresponding to zero variation in the applied voltage—in other words, DC—is reached. Here the reactance has reached infinity, as evidenced by the fact that no electrons are flowing because the capacitor has had time to become fully charged.

When frequencies are high with respect to the time constant of a particular R-C circuit, a condition will exist where the capacitor will neither charge nor discharge appreciably. In other words, the time for the voltage to change from zero to maximum permits the capacitor to accept only very few electrons. Therefore, very little of the alternating voltage potential will ever exist across the capacitor. Instead it will appear across the associated resistance. This would be an example of a good coupling circuit, such as shown in Fig. 4-5, where nearly all the alternating (signal) voltage will appear across R_g, to be amplified by V2.

IMPEDANCE

In circuits consisting of resistance and capacitance, another term is used to denote the total opposition to electron flow when an AC voltage is present. This is called impedance, represented by the symbol Z, and is a combination of resistance R (which remains constant regardless of frequency) and the capacitive reactance (which does not). When the resistance and capacity are in series, impedance is computed from the formula $Z = \sqrt{R^2 + X_c^2}$, where Z, R, and X_c are in ohms.

An example utilizing both the impedance and capacitive-reactance formulas will point out the variation existing at two different frequencies. Let us find the impedance of a 100-ohm resistor in series with a 0.1-mfd capacitor at 1,000 cps, and then at 10,000 cps. First we must find the capacitive reactance:

$$X_c = \frac{1}{2\pi fC}$$

At 1,000 cps:

$$X_c = \frac{1}{2 \times 3.14 \times 1,000 \times .0000001}$$
$$= 1,590 \text{ ohms}$$

At 10,000 cps:

$$X_c = \frac{1}{2 \times 3.14 \times 10,000 \times .0000001}$$
$$= 159 \text{ ohms}$$

Notice that X_c is 10 times greater at 1,000 than at 10,000 cps, illustrating that capacitive reactance is inversely proportional to frequency. Now using our impedance formula:
At 1,000 cps:

$$Z = \sqrt{100^2 + 1590^2}$$
$$= \sqrt{2,540,000}$$
$$= 1,593 \text{ ohms}$$

At 10,000 cps:

$$Z = \sqrt{100^2 + 159^2}$$
$$= 35,300$$
$$= 188 \text{ ohms}$$

Notice here that the impedance change is not proportional. This condition can be directly attributed to the addition of the resistive element.

These results show that a different opposition to electron flow exists for each frequency involved.

RESONANCE

Capacitors in combination with inductors form circuits capable of discriminating between different frequencies. These are generally known as tuned, or resonant circuits because they respond only to frequencies in the resonant range. Where a range of selection or rejection is desired, variable capacitors or inductors are employed.

Chapter 3

CAPACITOR CONSTRUCTION

A bewildering array of capacitor types have evolved from the simple Leyden jar (Fig. 3-1). Some are flat, some are round, some square—in fact they are to be found in just about every shape imaginable. Why this deviation from the
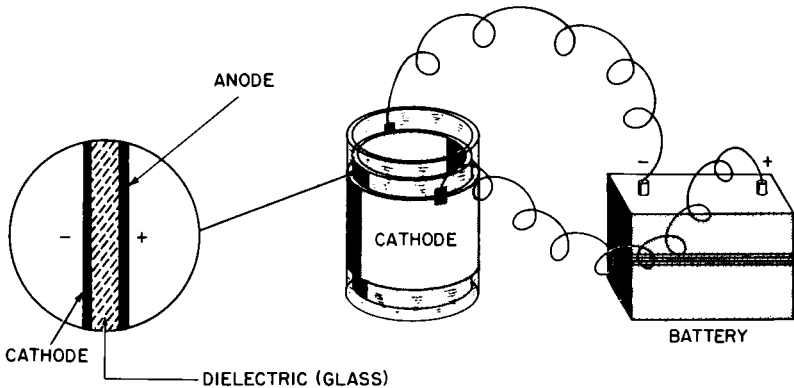
Fig. 3-1. Leyden jar capacitor.

original has taken place will become apparent as we investigate their development and construction.

BASIC DEVELOPMENT

Leyden jars were the basic capacitors used in early experiments with electrical energy. Even today they offer several definite advantages. In the first place, they are very dependable. Second, it is relatively easy to change the value by adding or removing metal foil. Third, they introduce very few undesirable properties, such as inductance, etc.,

into an experiment. However, they are bulky; furthermore, there is a definite limit to the amount of capacity attainable. After all, a glass jar can be made just so thin before it becomes too fragile to be handled.

The next logical development in capacitor design was the flat plate type. It is considerably smaller than the equivalent Leyden jar because there is no wasted space in the center. However, it is still extremely bulky and awkward to handle, especially when larger capacitances are involved.

Of course, flat-plate capacitors can be ganged into parallel circuits, as shown in Fig. 3-2, to provide a very definite saving in space.
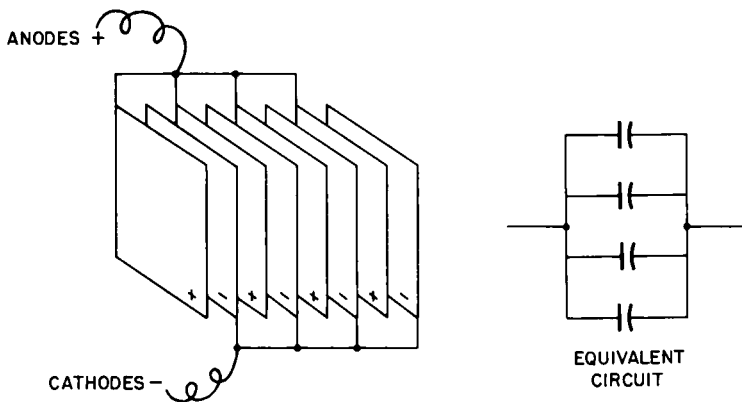
Fig. 3-2. Flat paralleled plate capacitor.

Like the original Leyden jar, the first flat-plate capacitors also used a glass dielectric. These units were superior to the jar, being much more compact; but because of their glass dielectric, they still were quite fragile. It was soon discovered that the glass could be eliminated if the plates were moved farther apart. We now know why—because air can be used as a dielectric, but being less effective than glass, the distance between plates must be greater in order to provide the same resistance against voltage breakdown.

This is where matters stood until the dawn of radio. Development then followed in rapid succession—first the mica

capacitor, then paper, electrolytics, ceramics, and now plastics.

AIR CAPACITORS

Although air is a poor insulator, it is still highly useful as the dielectric in a capacitor because its power factor is almost nil and its stability is excellent. Furthermore, it's free.

The capacity ratings of air-dielectric capacitors range from about 3 mmf, to above 330 mmf. Voltage ratings reach a practical limit at about 30,000 volts DC. Air capacitors may be either fixed or variable, but their primary advantage is that they are easy to construct.

Fig. 3-3 shows the basic arrangement of a simple single-plate air capacitor. The plates of the fixed unit (Fig. 3-3A)

INSULATORS

A   B
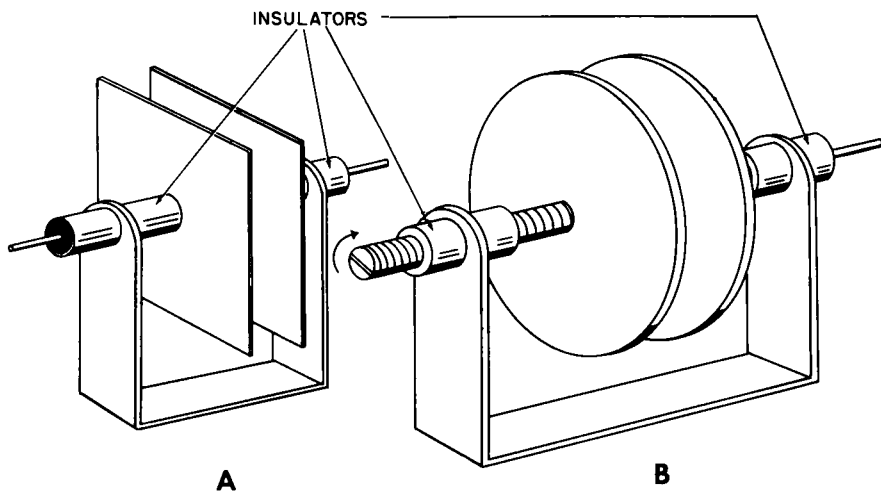
Fig. 3-3. Fixed and variable air dielectric capacitors.

are insulated from the supporting frame by an appropriate material. Fig. 3-3B shows a simple variable air capacitor. A screw thread varies the distance between the two plates and thus increases or decreases the capacitance. This arrangement has a disadvantage, however—the resistance to

voltage breakdown increases or decreases inversely with capacitance. Therefore, its application is somewhat limited.

The much more common variable air capacitor is shown in Fig. 3-4. This is the constant-gap type, in which the
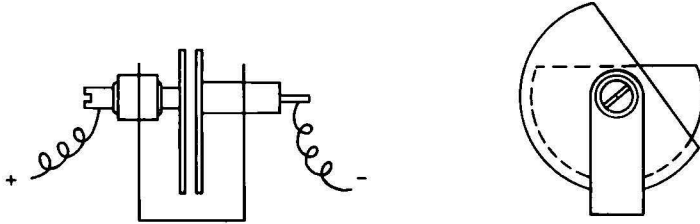
Fig. 3-4. Basic constant-gap variable air capacitor.

capacitance is varied by exposing more or less of the plate surfaces to change the area ratio between plates. Since the plates remain the same distance apart at all times, the resistance to voltage breakdown never changes. From this very simple type, the design can be varied in ways limited only
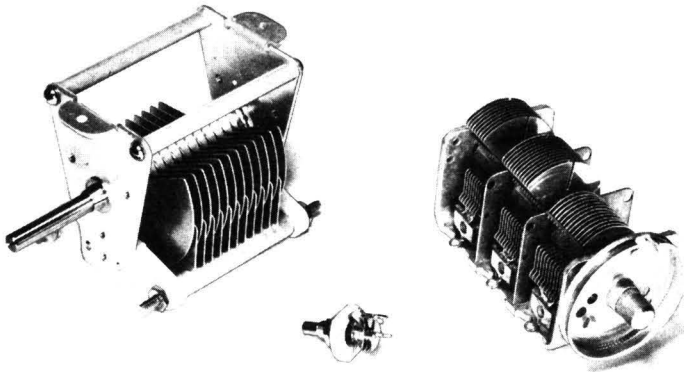
Fig. 3-5. Variable capacitors.

by imagination. Multiple plates may be added to increase the capacitance, and their shape designed to provide the precise variation required—semicircular plates will provide linear capacitance variation proportional to the amount of rotation. Other shapes can provide linear frequency variation proportional to amount of rotation. Representative

types, used principally in tuning and trimming applications, are shown in Fig. 3-5.

The rotor plates can be made of virtually any conducting material, but aluminum is the most common. Other metals such as brass or copper are sometimes used, but are subject to corrosion unless properly protected by plating. Silver plating is often used to provide a lower surface resistance, and nickel plating is used if extreme corrosion is likely to be encountered.

Although air-dielectric capacitors are among the poorest, when judged on the basis of size *versus* capacitance, they still offer definite advantages over other types. They are extremely stable, are only slightly affected by temperature changes, have a very low power factor, and their life is limited only by physical damage or by failure of the supporting insulators. Other than size, their principal disadvantages are that they are very susceptible to changes in humidity, which can cause the voltage to arc across the plates. Also, the plates may vibrate at high frequencies and cause the capacitance to fluctuate.

In an effort to ward off atmospheric effects, some capacitors are placed in sealed cases which have been evacuated or filled with an inert gas. In some transistor radios they are encased in plastic, primarily to prevent dust particles from forming stray conductive paths and thus affecting circuit performance.

PAPER AND FILM CAPACITORS

As more and more uses for capacitors unfolded, the need for units with larger capacitance values became more pressing. There is a practical limit to the physical size of a Leyden jar or flat-plate type. Thus, the search for more compact units resulted in further work on the development of dielectrics. It was discovered that high-quality Kraft paper, when impregnated with oil or wax, was an excellent dielectric. Furthermore, the paper, being flexible, could be rolled up tightly to form a most compact unit.

The actual construction of paper capacitors varies from one class to another, but the basic method consists of two metal foils separated by tightly rolled layers of paper. During manufacture the entire assembly is vacuum-dried to eliminate any moisture, and is then impregnated with oil, wax, or some synthetic material to increase the voltage rating. The unit may be housed in a cardboard tube or in a metal sleeve, or it may be molded into a plastic case for greater protection against moisture infiltration.

The paper dielectric is usually made up of many layers of thin paper, rather than a few layers of thicker paper. The former has a lower voltage stress—in other words, the capacitor can withstand a higher voltage.

Even the highest-quality papers will contain minute voids (microscopic openings) or foreign particles of conductive material. (Thicker stock would have fewer voids but just as many or more conducting particles.) The multiple layers of thinner paper greatly lessen the chance that these voids will line up, or that foreign particles will form a straight-through conductive path. Thinner stock also insures faster and more thorough drying, and a more even wax or oil impregnation.

Wax, mineral oil, and various synthetic compounds are the three basic impregnants. This is generally the order of final capacitor quality, too. Of the three, wax-impregnated types have the most restricted temperature range and lowest voltage rating (because it is difficult to completely impregnate the paper), and mineral oil provides the greatest temperature-capacitance stability. On the other hand, synthetics have higher dielectric strengths than mineral oil (making possible smaller capacitors), but their temperature characteristics are not as good.

Fig. 3-6 illustrates the basic construction of a paper capacitor. Notice that tabs (one for each plate) provide connecting points for the pigtail leads. This is the simplest method of doing the job—but the least satisfactory from a performance standpoint. The use of multiple instead of single tabs, or the extended-foil method, is superior.
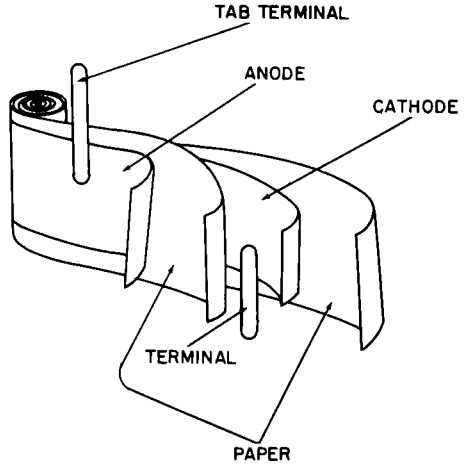
Fig. 3-6. Basic paper capacitor construction.

Fig. 3-7 shows the basic construction of an extended-foil capacitor. It is essentially noninductive, since all layers for one plate are mutually joined at one end. Another advantage of this construction is its lower internal resistance. How-
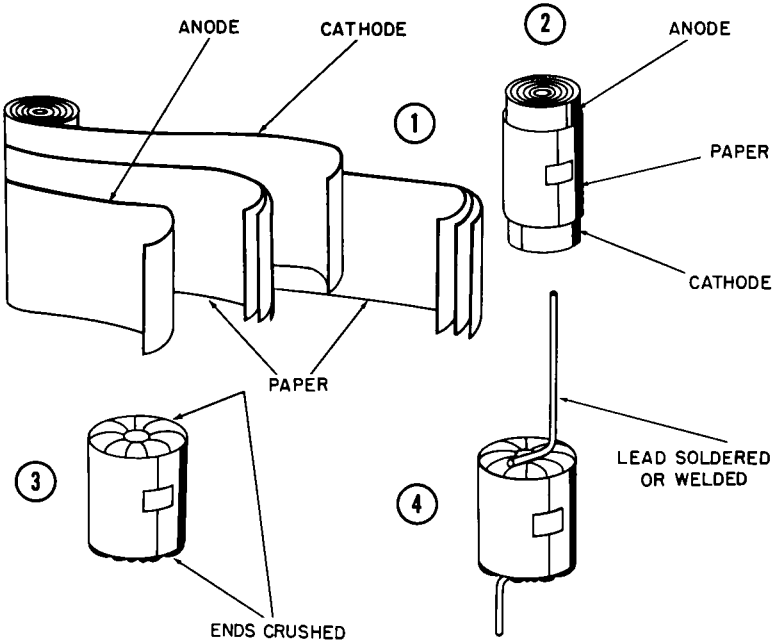

Fig. 3-7. Extended foil paper capacitor construction.

ever, it is more expensive and great care must be exercised during manufacture to avoid shorting the plates when the ends are crushed.

Paper capacitors as a class should not be operated at high temperatures, due primarily to the nature of the paper itself. The minute impurities found in paper pulp tend to become more chemically active as temperatures rise and, in combination with the inevitable impurities in the plates and impregnants, lead to premature failure.

In their ability to withstand high voltages, paper capacitors are exceeded only by mica types. Mineral-oil units, in particular, exhibit excellent capabilities in this direction. Their corona-starting potentials are on the order of twice the rated voltage. Thus, these units are often used in buffer applications, where high transient-voltage surges would quickly result in the failure of other types.

Plastic films such as polystyrene or *Mylar* are rapidly replacing paper as a dielectric, especially for general-purpose use. Plastic is much denser than paper, and contaminating foreign particles are practically nonexistent. Therefore, plastic units can generally be made smaller than paper units of equivalent value. Plastics can withstand higher temperatures and are considerably more stable than paper. Because of their lower corona-starting voltage, however, plastic units should never be used in high-voltage buffer applications.

Polystyrene types have better temperature characteristics than *Mylar*, but are limited to +85°C, whereas the latter can be operated up to +130°C. Where unusually high-voltage performance is required, oil-filled plastic capacitors may be used. Unlike paper, plastic is relatively nonporous and must be kept immersed in oil. (Some paper types are oil-immersed also, primarily to improve their heat-dissipation characteristics.)

A third type of capacitor, actually a combination paper and plastic, is the metallized paper type. A thin metal film (usually vacuum-plated aluminum) is deposited on the paper, which is then rolled alternately between layers of

Mylar. The metal film provides a "self-healing" property —it burns away when a flashover occurs and thereby opens the path for potential short circuits. This can be a disadvantage in low-noise circuits, however; the arcing will produce spurious signals, especially if the voltage is too low to burn completely through the film. Nevertheless, the paper and plastic combination make possible very small capacitors having excellent over-all performance characteristics.

Plastic film capacitors are customarily housed in cardboard tubes or metal containers, or are molded in plastic. Because of their relatively poor moisture resistance, cardboard containers are gradually becoming extinct for capacitors used in high-performance equipment. Today, the molded plastic case is the most common housing for both paper and film types. It may be either a one-piece arrangement or a tube sealed at both ends. For a true hermetic seal, it is necessary to house the capacitor in a metal case with a glass-to-metal seal. Use of this latter type is generally confined to computers and other high-reliability equipment.

In addition to a nominal voltage rating, paper capacitors have a surge voltage rating beyond which they should never be exposed—not even during tests. This rating is an insurance factor—it should never be reached. Remember that if you pretest a paper capacitor at—or even near—its surge voltage, you are practically asking for a failure. Always test paper capacitors at their rated nominal (working) voltage, never above it.

MICA CAPACITORS

Mica capacitors have been present in the electronics field for many years, but are gradually being replaced by the ceramic or glass types. Micas share the same generally poor size-to-capacitance ratio as all other flat capacitors. They are considerably smaller than the air type, however—primarily because, as a dielectric, mica is nearly seven times better than air. The fact that mica can be sliced quite thinly adds appreciably to the amount of capacitance attainable
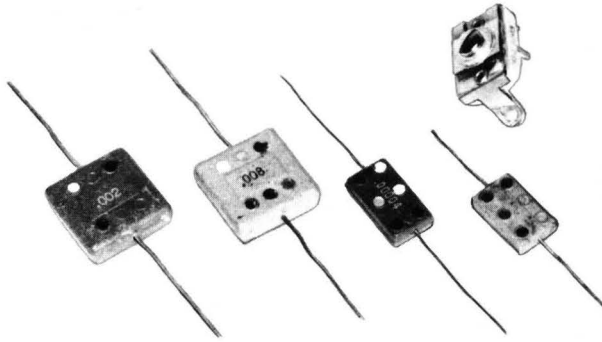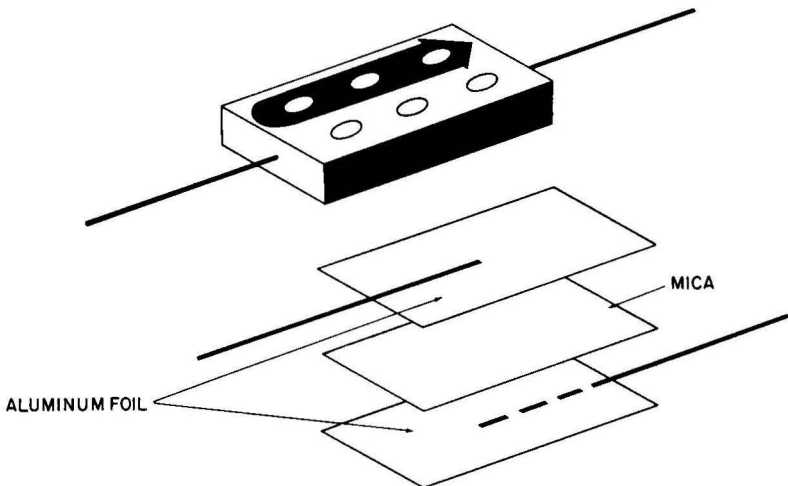
Fig. 3-8. Mica capacitors.

from a given plate area. Furthermore, mica, being relatively impervious to humidity and moisture, makes possible a very stable capacitor.

Mica capacitors are available with values ranging from 1 mmf to 1 mfd, and with voltage ratings as high as 35,000 VDC. Both fixed and variable types are made in two broad styles—foil and deposited silver. (See Fig. 3-8.)

A foil mica capacitor, shown in Fig. 3-9, consists of a thin slice of mica sandwiched between two thin aluminum

Fig. 3-9. Basic mica capacitor construction.

plates, plus a molded *Bakelite* case for protection. The foils and mica dielectric are built up in alternate layers (the more layers, the higher the capacitance) to produce a set of essentially paralleled capacitors.

A silver mica is similar to the foil type, except the silver is deposited directly onto the mica sheet. The more intimate contact between plate and dielectric results in increased
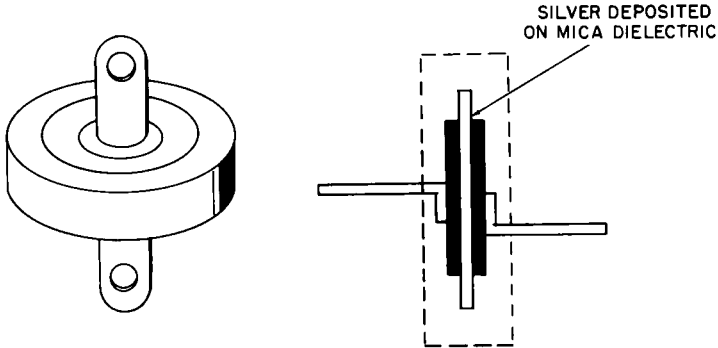
Fig. 3-10. Button silver-mica capacitor construction.

capacitance and improved stability. There is, however, some danger that particles of silver will migrate through the mica under a high-voltage stress situation, especially if the slightest amount of moisture is present. Under these conditions, silver mica capacitors have been known to fail in minutes. Button micas resemble the molded rectangular type, but are more fragile. (See Fig. 3-10.) Their principal advantages are a lower inductance and a very high leakage resistance.

Variable mica capacitors (Fig. 3-11) are common in trimmer applications. The capacitance is raised by tightening
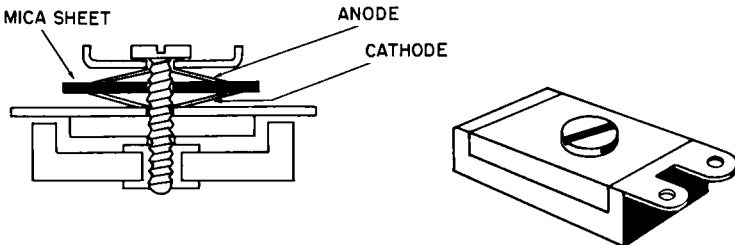

Fig. 3-11. Variable mica capacitor construction.

the screw to bring the plates closer together, and vice versa. Because trimmers are exposed, mica is especially effective as a dielectric since it is relatively impervious to moisture.

CERAMIC CAPACITORS

Ceramic capacitors are among the most versatile of all, primarily because the dielectric can be made to give such a wide variety of results. The most common ceramic capacitor is the disc, although tubular and rolled types are also available. Fig. 3-12 illustrates several common ceramics.
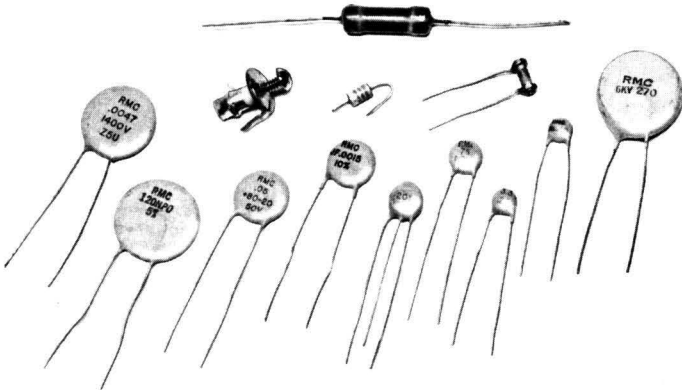
Fig. 3-12. Ceramic capacitors.

The capacitance ratings of ceramics range from 0.5 mmf to over 0.1 mfd. Voltages range as high as 30,000 VDC, with surge voltages up to 40,000 VDC. The disc and rolled styles are available as fixed capacitances only, but the tubular comes in both fixed and variable units. (There is one which, although essentially a disc, is available as a variable trimmer.) Ceramics offer a good size-to-capacitance ratio, in addition to some other valuable characteristics we will learn about.

Disc ceramics have similar capacitance values, but lower inductances, than mica types of corresponding values. The four types are general-purpose, temperature-compensating, temperature-stable, and frequency-stable. Each of these four

broad types has characteristics which suit them to particular applications.

General-purpose types can be used in place of most general-purpose mica, tubular ceramic, or molded paper types in filter, bypass, or coupling circuits. The construction in Fig. 3-13 is common to all disc ceramics.

Their temperature *versus* capacity curve is similar to the one in Fig. 3-14. Note that it is merely representative of
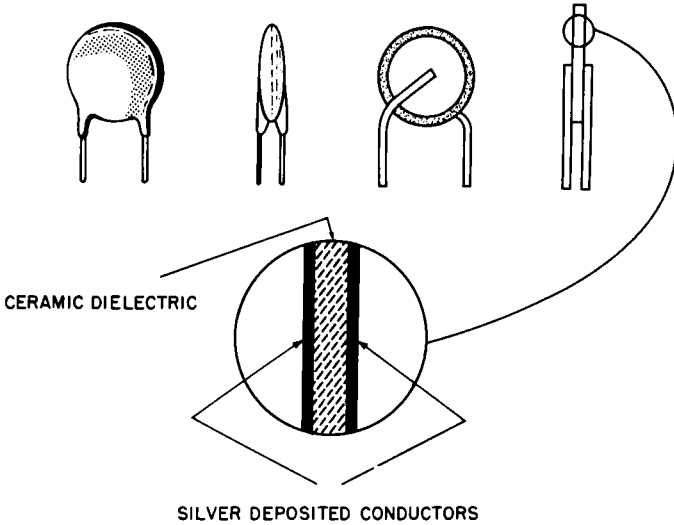
CERAMIC DIELECTRIC

SILVER DEPOSITED CONDUCTORS

Fig. 3-13. Disc ceramic capacitor construction.

actual curves; the exact curve for the capacitor in question must be obtained from the manufacturer.

Temperature-compensating disc ceramics can survive temperatures ranging from −40°C to +85°C with virtually no change in capacitance, whereas the value of other units will change from +15% to −10% over the same temperature range.

The exact variation in capacitance to be expected from a temperature-compensating capacitor is stated as so many parts per million for each degree centigrade of temperature change between +25°C and +85°C.

Temperature-compensating disc ceramics are designated by a number with a letter prefix. The system is actually

fairly simple, once you become familiar with it. The prefix *P* means that above +25°C the capacitance will rise with the temperature (or a positive coefficient); *N* means the capacitance will drop (negative coefficient); and *NPO* signifies no change. The larger the number following the prefix, the greater the change. *NPO* types will of course have no number.

Thus, a designation of P100 means that for every degree centigrade that the temperature increases (between +25°C
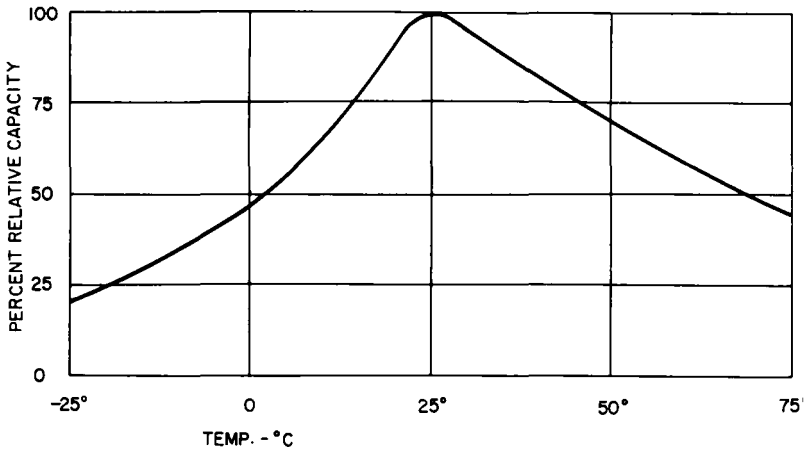

Fig. 3-14. Characteristic curves of general-purpose disc ceramic capacitors—temperature versus capacity.

and +85°C), the capacitance will rise 100 parts per million. An N750 rating produces a decrease of 750 parts per million per degree increase, whereas an N1400 produces almost twice that amount.

These capacitors are particularly useful in compensating for value changes which occur in other components when equipment temperature rises. Fig. 3-15 shows typical curves of performance.

Temperature-stable disc ceramics are merely a refinement of the temperature-compensating type. They have an extended temperature range and are rated from −60°C to +110°C, with a capacitance change of about ±7.5% from

the stated value at +25°C. Both types are rated at 1,000 VDC.

Frequency-stable disc ceramics maintain a relatively fixed resonant frequency over a wide temperature range, unlike other types where temperature has a very marked effect on
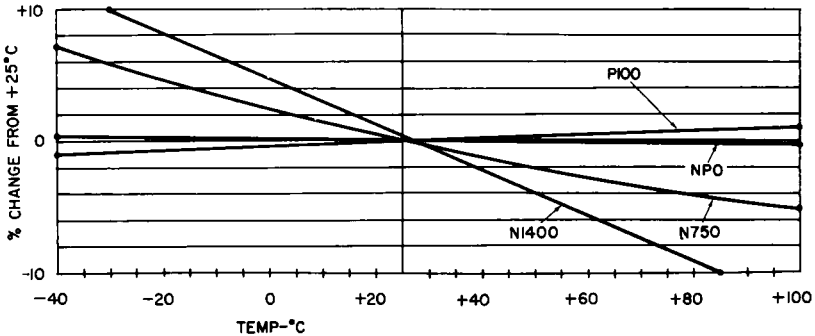

Fig. 3-15. Characteristic curves of temperature compensating disc ceramic capacitors.

resonant frequency. Because they utilize materials with higher power factors in order to achieve the desired stability, frequency-stable discs are more susceptible to charge-discharge cycle problems.
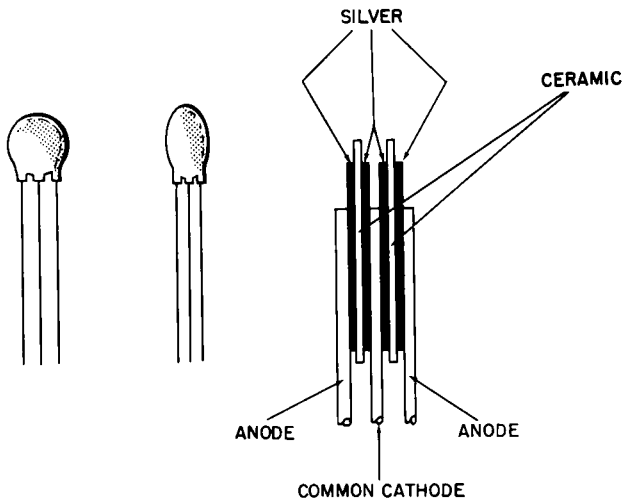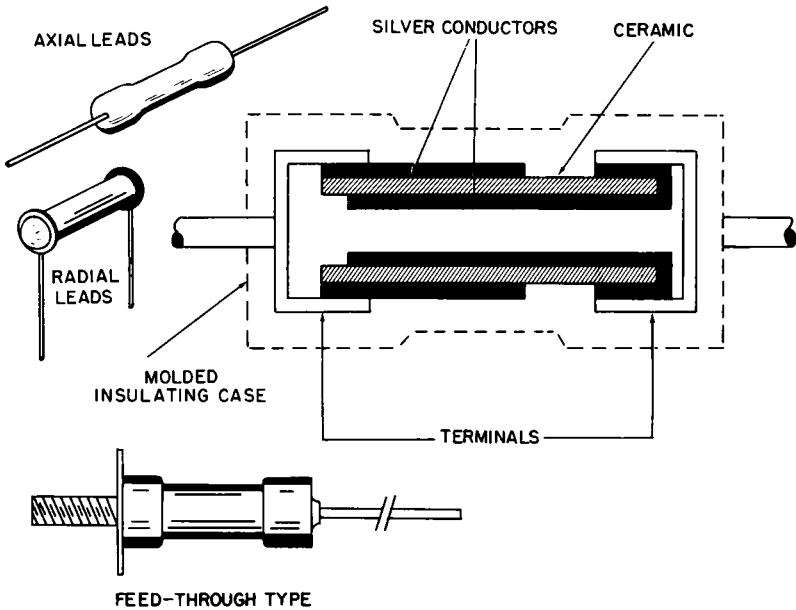

Fig. 3-16. Dual-disc ceramic capacitor construction.

Disc ceramics are normally used individually. However, a number of dual-section types are available. They are particularly useful where mutual coupling between capacitors would alter the circuit characteristics. Dual ceramics consist essentially of single units encapsulated back-to-back as in Fig. 3-16.

Tubular ceramic capacitors correspond in basic principle to the Leyden jar. They consist of a ceramic dielectric tube with silver plating deposited on both the inside and outside. The basic construction of this type is shown in Fig. 3-17. Leads may be either axial or radial, or a special arrangement as in a feedthrough unit.

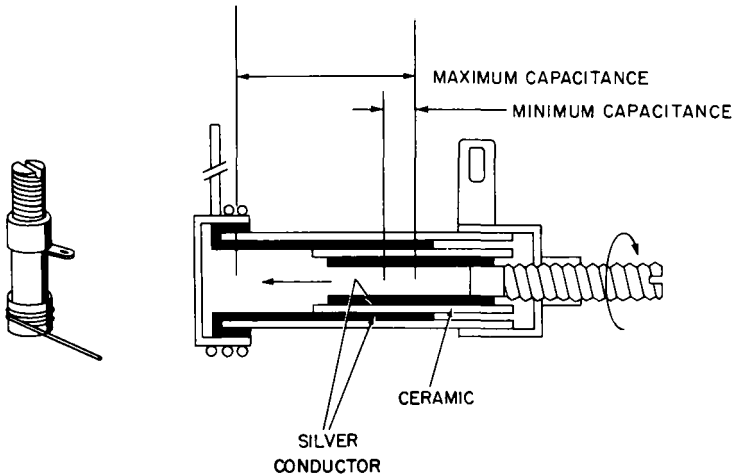*Fig. 3-17. Tubular ceramic capacitor construction.*

Tubular ceramics have a poorer size-to-capacitance ratio and slightly more inductance per mfd than disc types. Because of this, their use has become rather restricted, except the feedthrough types. Furthermore, tubular types are more fragile than discs.

Because of their superior dielectric properties, ceramic capacitors are becoming more popular than the older mica

types in trimmer applications. There are two common basic configurations. One configuration is essentially a concentric tubular unit, and the other is similar in principle to the variable air type.

The variable tubular (Fig. 3-18) consists of a silvered supporting tube with one plate on the inside. A movable ceramic tube, fired with silver on its inside, fits precisely within the first tube. As the inner tube is moved the effective area of the plates changes and varies the capacitance. A typical adjustment range is from 1 to 8 mmf.

MAXIMUM CAPACITANCE
MINIMUM CAPACITANCE

CERAMIC

SILVER
CONDUCTOR

Fig. 3-18. Variable tubular ceramic capacitor construction.

The tubular variable ceramic is a precision type which produces very small changes in capacitance as the screw is rotated. However, the total capacitance is relatively small.

Another variable ceramic, quite popular as a trimmer, consists of two partially silvered, ground ceramic discs. As the one disc is rotated, it presents more or less effective plate area to the fixed disc. This is very similar to the action of a variable air capacitor, as shown in Fig. 3-19. Its principal advantages are that a 180° rotation produces maximum capacitance change, and that it is available in larger values than the tubular type. Furthermore, temperature-compensating types ranging from NPO through N750 are

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possible, with ratings of 1.5-7 mmf and 8-50 mmf. Side-by-side dual-variable types are also available.

Ceramic capacitors of the so-called "door-knob" type are common in TV high-voltage applications. They are supplied in large molded cases with rings arranged to minimize high-voltage flashover.

Another type of ceramic capacitor, intended primarily for universal replacement use, is actually a set of laminated units. Its leads are brought out in such a way that by soldering certain ones together, and cutting others off, a wide range of values can be obtained. The biggest advantage to the service technician is in not having to stock as many different ceramic types. There is some size and performance disadvantage, however.
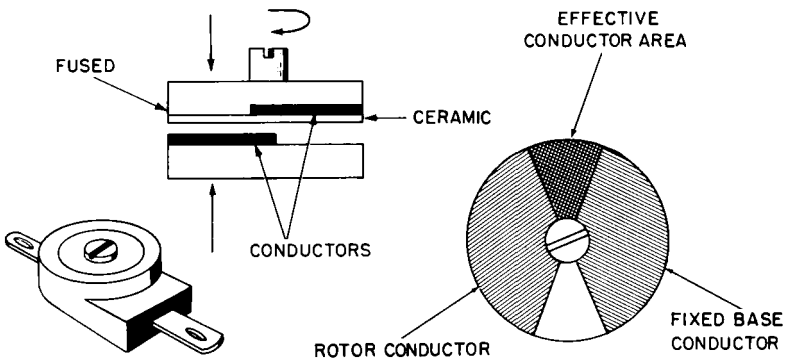
Fig. 3-19. Variable disc ceramic capacitor construction.

Ceramic capacitors, especially the disc type, are becoming ever more popular with equipment designers. But there are some important facts you should be aware of in working with these components. First, moisture can radically affect their performance. Even though manufacturers go to great lengths to insure moisture-resistant enclosures, there is still some possibility of infiltration.

All ceramics tend to be rather fragile. Avoid exerting more than a very slight pressure on leads during installation, because you may crack the base material or even damage the capacitor internally. Also, be extremely careful while soldering, because excessive heat will ruin a capacitor.

ELECTROLYTIC CAPACITORS

Electrolytic capacitors provide more capacitance, for their size, than any other type. From the service technician's viewpoint, they are also the most confusing. They seem to defy all the rules applicable to capacitors—yet electrolytics are able to perform jobs no other type can. Fig. 3-20 shows only a few of the wide range of values and sizes that are available.

Fig. 3-20. Typical electrolytic capacitors.

Electrolytics all have one thing in common, however—they are made differently from other capacitors. (See Fig. 3-21.) Instead of the usual plates separated by a dielectric, the electrolytic has an aluminum anode coated with a film of aluminum oxide. This outer covering is the dielectric, and a liquid electrolyte acts as the cathode. A second metallic conductor, usually of aluminum also, serves primarily as the connection to the liquid cathode, providing an external termination.

In actual practice, porous paper is wrapped around the anode and saturated with the electrolyte to eliminate the spillage problem.

The aluminum oxide film has a very high resistance to current in one direction and a very low resistance in the opposite direction. In other words, the film acts as a dielectric in the first instance and as a plate in the second. Because
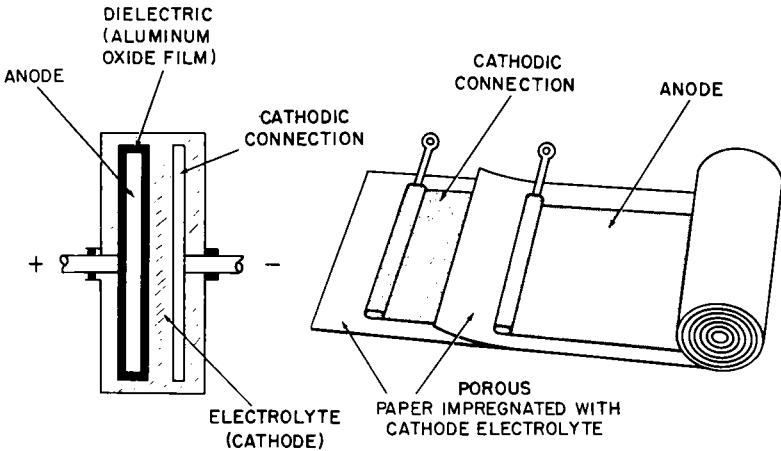
Fig. 3-21. Basic electrolytic capacitor construction.

of this, electrolytics are polarized. If the designated polarity is not observed, the oxide film on the anode will break down and migrate to the cathodic connection, resulting in prompt failure of the capacitor.

Electrolytics are made in three basic styles. The polarized type is the one just described. Its aluminum oxide film is relatively thick, and its physical size is very small per unit of capacitance.

The semipolarized type has a thin oxide film on the cathodic connection also, much thinner than on the anode. During polarity reversals of relatively low currents, this connection will act as an anode and offer minimum resistance to this small current flow.

The nonpolarized type is actually double-polarized—both plates being coated equally with oxide and therefore insen-

sitive to polarity reversals. This type is commonly used in AC circuits such as for motor starting. The nonpolar types are substantially larger per unit of capacitance than the polarized type. Fig. 3-22 shows the relative sizes and basic construction of the three types.
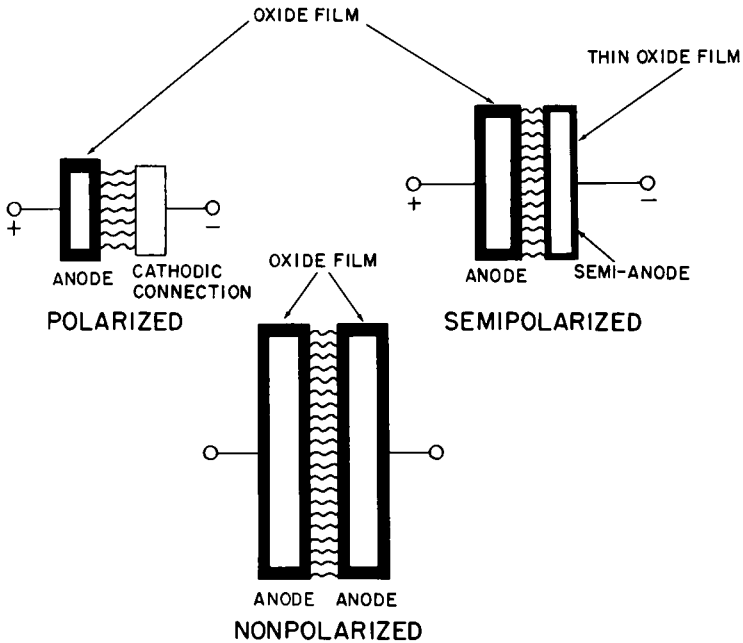
Fig. 3-22. Three types of electrolytic capacitors showing relative size for same capacitance value.

The anodes in an electrolytic capacitor are more than simple flat aluminum foil. Prior to the formation of aluminum-oxide film, the anodes are deep-etched in an acid bath. This etching process produces a roughened surface which vastly increases the effective area. Since capacitance is directly proportional to the effective anode area, etching results in a capacitor having more than ten times the capacity of a unit with a plain anode of the same physical size.

The "cathode" is also often treated similarly. Etching increases the contact area between the actual (liquid) cath-

ode and the cathodic connection ("cathode"). Thus, current carrying capabilities are increased. An added advantage is that hum-producing oxide film is less likely to form where AC ripple currents are encountered in power-supply applications.

Electrolytics are supplied in aluminum or plastic cans. All present types are of the "dry" arrangement—that is, most of the electrolyte is in the porous paper. On the other hand, the older "wet" type was filled with an electrolyte and the metal container served as the cathodic connection. A vent in present-day capacitors keeps out external contaminants, but still allows pressure equalization at high temperatures.

The electrolyte is varied, depending on the voltage rating of the capacitor. Basically it consists of a solution of ammonium borate and boric acid, plus glycol to prevent freezing. It is wise to remember that the electrolyte is compounded for a specific operating voltage. This means that the electrolyte for 150 VDC is slightly different from one for 450 VDC. Therefore, it is unwise to consistently operate a 450-VDC unit at far below the rated voltage. Eventually the oxide film will become deformed and the total capacitance will deteriorate as a result.

Electrolytic capacitors have a characteristically higher leakage current than other types. This is due partially to their design and partially to impurities in the foil and electrolyte. Leakage current increases as the temperature rises; simultaneously, the voltage-breakdown resistance decreases. This is a sort of self-feeding situation where the more the leakage, the hotter the capacitor becomes, further increasing the leakage, and so on. Therefore, the operating temperatures of electrolytics must never be allowed to exceed their maximum limit.

The DC leakage of electrolytics should conform roughly to the values given in Table 3-1. These figures will serve as a guide to the maximum allowable leakage current after continuous application of the rated voltage for a minimum of 500 hours. Thus, a 100-mfd 150-WVDC capacitor should

Table 3-1

Maximum allowable leakage current for electrolytic capacitors.

Rated WVDC	Maximum leakage (ma)
25	.002C + 0.1
50	.004C + 0.1
150	.010C + 0.2
450	.02C + 0.3

C = capacitance in mfd

have a leakage current of not more than 1.2 ma after 500 hours of continuous operation.

The power factor losses of electrolytics tend to be higher than other types. But since the power factor of these units can be misleading, it is more common to describe the losses in terms of equivalent series resistance (esr). Manufacturers' data show the esr on each value produced. For example, the esr for an etched plate, 100-mfd 150-WVDC unit, is 2.5 ohms. This rating is given for a frequency of 120 cycles at 25°C.

Electrolytic capacitors are rated at 25°C, and the value is stated as a mean capacitance with a tolerance. The latter is determined by the individual manufacturer and will vary depending on voltage rating. A typical tolerance would be −10% to +50% for a capacitor of over 351 volts. Tolerance can be very important to the service technician. Here it means that a 100-mfd capacitor actually can range from 90 to 150 mfd. In other words, if you are faced with the necessity of replacing a 125-mfd unit, it would be quite satisfactory to use a 100 mfd capacitor as long as operating temperatures are held well below maximum. The temperatures encountered in normal home entertainment equipment will usually not exceed this maximum.

Temperature has a very marked effect on the capacitance of electrolytics. At −55°C, an electrolytic has practically no capacitance, and its power factor will be as high as 50%.

When equipment has been exposed to extremely low temperatures, all electrolytics will lose a significant percentage of their normal capacitance. The increased power factor may be sufficient to cause internal heating when power is applied. This, in turn, may or may not result in capacity recovery.

Electrolytic capacitors seem to have all sorts of idiosyncrasies. They will gradually deform (decrease in capacity) if allowed to remain idle. Extended periods of idleness can be harmful to electrolytics. A sudden surge of full rated voltage may then break down the deformed oxide film and permanently ruin the unit. In order to reform an electrolytic, you can use a capacitor checker, starting with a low (10% of rated) voltage setting and increasing it up to the rated maximum over a period of about one minute. Or you can do the same thing with a 5-watt resistor of approximately 1000 ohms connected in series with a voltage source not exceeding and preferably below the capacitor rating. When one considers that the list price of an average unit is about $2.50, it seems wasteful not to take proper precautions when installing a new one. This is especially true if the capacitor has been idle for a year or more.

If this procedure seems a waste of time, consider the extra expense of a customer callback. You will always hear of technicians who ignore this operation. They may have been lucky, just like those who say they don't believe in changing the oil in their car.

For a final note on electrolytics, a word of caution: Some electrolytics have a very high capacitance and are of such excellent quality they can hold a LETHAL charge. Always be careful when working in circuits containing high capacity.
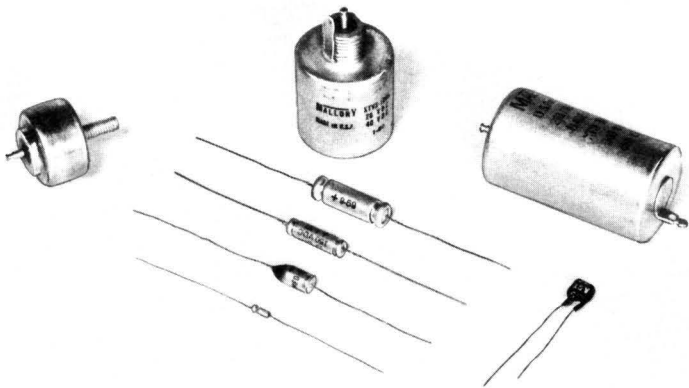

TANTALUM CAPACITORS

Although unfamiliar to most electronic technicians, tantalum capacitors are finding more widespread usage. At present their use is pretty much confined to military equipment and very high-quality devices such as computers.

Tantalum electrolytics have the highest capacitance per size than any other present-day capacitor. This makes them especially attractive for miniature electronic equipment in spite of their higher cost. This high cost is due partially to the fact that tantalum is a relatively rare metal. In fact, its name is derived from "tantalize" because it is so difficult to isolate and process. On the credit side, it is highly resistant to corrosion and has a high melting temperature.

The same principles that apply to aluminum electrolytics apply to tantalums. They are available in both polarized and nonpolarized foil form, as well as a unique configuration which utilizes a sintered anode.

Fig. 3-23 shows some representative tantalum capacitors. They range in size from a grain of rice, up to a normal metal-can electrolytic.

Fig. 3-23. Tantalum capacitors.

In addition to their small size per unit of capacity, tantalums can be operated at temperatures from −80°C. to +200°C. Furthermore, their capacity is significantly less affected by temperature than aluminum types. Their stability is excellent, and they can be stored almost indefinitely. This fact alone has led to their adoption by public utilities because of the freedom from reforming them periodically

while in storage. Operating life is equally long if normal precautions are observed.

Tantalum capacitors range in value from 0.25 to 2,200 mfd. Voltages range from 3 WVDC up to 640 WVDC. The foil types are normally furnished in axial lead styles, and may be either polarized or nonpolarized. The sintered anode types are furnished in a wide range of styles. The electrolyte may be either "wet" or "solid."

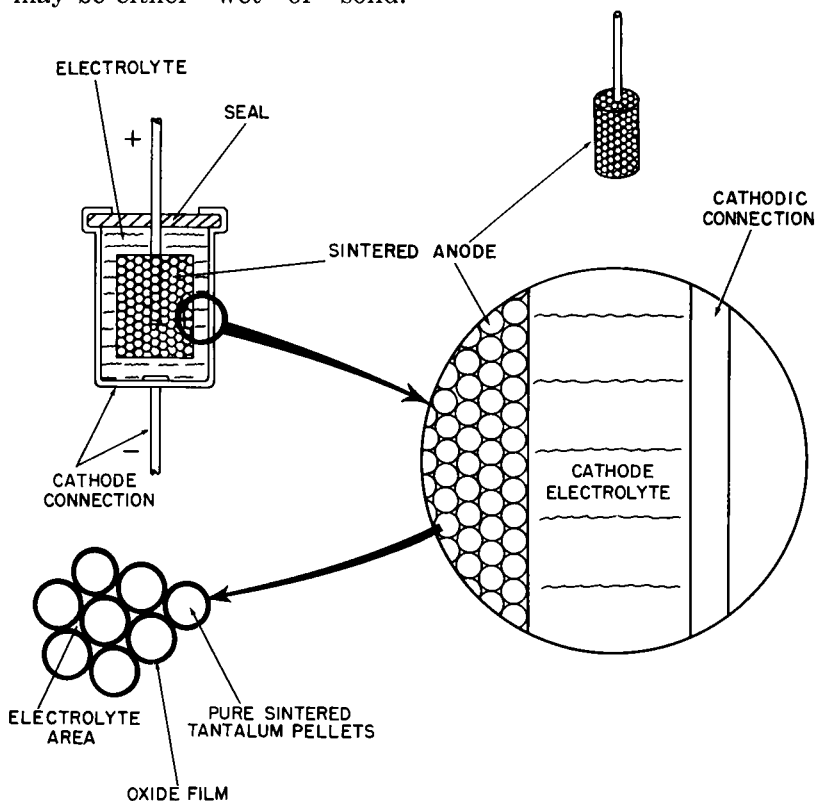*Fig. 3-24. Basic sintered-anode tantalum capacitor construction.*

Tantalum foil capacitors are constructed in almost the same manner as the aluminum electrolytic type. The tantalum electrolyte may be sulphuric acid or lithium chloride, depending on the characteristics desired.

Fig. 3-24 illustrates the basic construction of the sintered anode type of tantalum capacitor. Pure tantalum is pro-

duced in minute pellet form. It is then pressed, under very high pressure, into a cylindrical shape onto a supporting and conducting tantalum wire lead. This cylinder is then fired in a furnace to fuse the areas of contact. It is then electrochemically treated to form a tantalum oxide coating over the entire sponge-like surface. The acid electrolyte is then forced into the cylinder under high vacuum and the cylinder is assembled into the case, which can also serve as the cathodic connection. More electrolyte is introduced and the assembly is sealed.

This type of construction has several advantages. The actual surface area of the sponge-like cylinder is very large in proportion to its volume. The electrolyte intimately contacts every part of the oxide film, which in turn contacts every surface of the tiny tantalum pellets. Resistance to physical shock is excellent because the anode is a single homogeneous unit.

Actual manufacturing practices are much more refined than the drawing in Fig. 3-24 would seem to indicate. Double cases and true glass-to-metal hermetic seals are often employed.

The construction just explained is called the "wet-slug" process. The electrolyte is a liquid, and the sealing problems are concerned primarily with preventing the escape of this highly corrosive electrolyte. Operating temperatures range from −55°C to +200°C.

Another type of construction utilizes a solid electrolyte. Its principal advantage is improved performance at very low temperatures. Depending on case structure, these capacitors may be operated at temperatures ranging from −80°C to +125°C.

The cylindrical anode is prepared in exactly the same manner as the wet type, up until the introduction of the electrolyte. At this point, a solid electrolytic material is vacuum-impregnated into the anode and baked to assure complete dryness and adhesion. Appearance externally is similar, but the performance is different. Another form of this capacitor uses a flat anode with an epoxy encapsulation

and parallel leads similar in appearance to disc ceramic types. It is useful in printed-circuit applications. The sealing problems of solid electrolyte types are more concerned with preventing the entrance of outside contaminants and are thus less severe than for the wet type.

Tantalum capacitors are relative newcomers to the capacitor field, and as such are in a constant state of improvement. As these types gain wider acceptance, increased production will probably reduce their price and they will appear in more consumer applications.

SPECIALIZED CAPACITORS

There are a number of specialized capacitors. Among them are the glass and the vitreous enamel types, used primarily as high-grade replacements for mica and ceramic units where operating conditions require a better type of capacitor.

Glass dielectric capacitors are made of alternate layers of glass ribbon and a conductive metal. The entire assembly is fused into a solid block under high temperature and pressure. This type offers the best protection from moisture infiltration because the outer case is the dielectric. Hence, there are no joints to fail.

Vitreous enamel types are constructed in a similar manner, except the glazing material is substituted for the glass. If the plates and dielectric have a different coefficient of expansion, extreme temperature changes may cause the two to separate or the dielectric to crack. Both types are able to withstand acceleration of several *G's*—yet may be easily damaged by a mild physical blow.

Performance roughly parallels that of mica types, but lacks the temperature-compensating characteristics of the ceramic types. They are used primarily where high humidity might cause failure of other types.

Chapter 4

CAPACITOR APPLICATION

Selecting the proper capacitor for a specific application is a problem which confronts the average electronics man at some time or other. In the case of equipment repair, replacement of the defective unit with an exact duplicate is a simple matter. As often happens, however, an exact replacement may not be available, so a suitable substitute must be made. Others may want to design their own equipment and therefore will need information about the correct units to employ.

OPERATING CHARACTERISTICS

The principal use of a capacitor, from a theoretical standpoint, is for simple energy storage. In any capacitive circuit some resistance will always be present, offering an opposition to the charge and discharge of the capacitor. Therefore, the RC time constant becomes important and must be considered in selecting a capacitor for a particular circuit.

Two capacitors of equal value but different internal resistance will have different charge-discharge time cycles— the unit with the higher resistance taking longer to charge or discharge. This can be expressed by the formula: $t = RC$, where t is the time in seconds, R the resistance in ohms and C the capacitance in farads. Since time is a factor in any AC voltage, the RC time constant is directly affected by the voltage frequency. Hence, a capacitor might be usable in a low-frequency circuit, but be unsuitable at higher-frequencies. Size, weight, and cost often govern the selection of a particular unit. Therefore, you might run into a situation

where a tantalum capacitor would have been the perfect answer, and yet find an ordinary aluminum electrolytic has been used. The reason here is cost. On the other hand, an oil-filled paper capacitor might be electrically indicated, but an electrolytic used instead. Bulk and weight considerations led the designer to the selection here.

Yet, despite all these rather confusing considerations, you will find that certain types of capacitors are nearly always used for particular applications. The reason is simple—most engineers are faced with the same problems, consult the same books, and arrive at similar answers. The chart in Fig. 4-1 shows the primary applications of the most common types of capacitors. Glancing over this chart, you will note

	ENERGY STORAGE	FILTERING	TUNING	COUPLING	BYPASS	BUFFER	MOTOR START	MOTOR RUN	TEMP. COMPENSATING
AIR			×	×					
MICA		×	×	×	×	×			
CERAMIC		×	×	×	×				×
PAPER	×	×		×	×	×		×	
PLASTIC		×		×	×				
ALUMINUM ELECTROLYTIC	×	×			×		×		
TANTALUM ELECTROLYTIC		×			×				

Fig. 4-1. Primary applications of capacitors.

that filtering can be done by almost any type—the over-all requirements of a particular circuit determine the final selection here.

The preceding paragraphs may have led to a certain amount of confusion in your mind. To partially dispel this, let us now examine particular applications and, in at least a general way, find out which capacitors are most suitable.

ENERGY STORAGE

The simplest capacitor applications is for energy storage. Here the only problem is storing the required quantity of electrons to meet a specific need. Examples of such applications are welding and electronic photoflash. Primary considerations center on the total energy required, space available, charge-discharge time, and cost.

We will start with the energy requirement. Assume we are concerned with an electronic-flash application calling for a power of 100 watt-seconds. Our power supply is 450 VDC. What value of capacity will be required? The following formula will enable us to make an approximate choice.

$$W = \frac{CV^2}{2}$$

$$100 = \frac{C \times 450^2}{2}$$

$$200 = C \times 202{,}500$$

$$C = \frac{200}{202{,}500}$$

$$C = .000987 \text{ farads or } 987 \text{ mfd.}$$

where,

W is the amount of work in watt-seconds,

C is the capacitance in farads,

V is the DC voltage.

The fact that the power supply is rated at 450 VDC and the capacity is large means we should consider using an electrolytic capacitor. We might select a single 1,000 mfd 450 VDC unit, or two 500-mfd capacitors in parallel. The latter would be the more practical solution, since 1,000 mfd units are scarce and relatively expensive.

Suppose, however, that our power supply was 2,500 VDC. Obviously, we cannot use an electrolytic capacitor with such a high potential. The only other type available is an oil-filled paper dielectric. Using the formula as before, we find a value of approximately 32 mfd is indicated. The unit is much

larger and heavier, but is comparable in cost to the electrolytic.

Another consideration in energy storage is the charge-discharge cycle. If either cycle is fairly long, almost any capacitor will do. The shorter either cycle becomes, however, the more important internal resistance becomes.

You will recall that we considered this cycle in Chapter 2. Typical curves are shown in Fig. 4-2. The length of time a capacitor takes to reach full charge is a function of the charging force, and the internal capacitor and external cir-
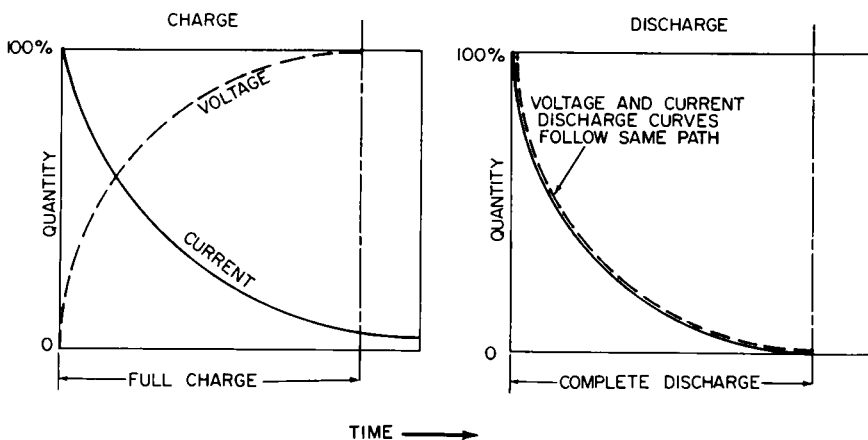

Fig. 4-2. Charge-discharge cycle of a capacitor.

cuit resistances. Therefore, a capacitor with a higher internal resistance will have longer charge and discharge cycles. If the circuit requires very short cycles, we must select suitable capacitors. One method is on the basis of work required. Here we might use much larger units than are needed, in effect shortening the time cycle. This would result in a further advantage—the internal heating of an otherwise unacceptable unit would be reduced to a safe level. Cost would be higher, however.

From the service technician's standpoint, capacitor replacement is much more important than original selection. Also, it is his responsibility to make certain the replacement matches the characteristics of the original equipment.
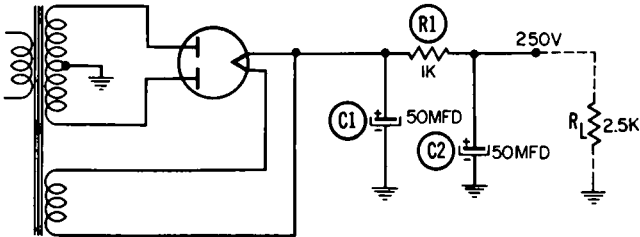
FILTERING

Capacitors in a rectifier circuit are used principally to smooth out DC current pulses derived from an AC source. In this sense they function as storers of energy. The degree of smoothness required and the inherent circuit characteristics are used as the basis for capacitor selection.

Below 450 volts and/or 1 kc, electrolytics are an excellent choice if current requirements are fairly high. Higher voltages and/or frequencies will require paper or plastic types, and still higher will require micas or ceramics.

As is true for pure energy storage, the RC time constant of filter capacitors is of prime consideration. It must match the requirement of the over-all circuit, particularly if you are replacing a mica with a ceramic type. (Naturally, all other characteristics must match in this instance, too.)

The job of a filter capacitor is to remove all unwanted frequencies. Take an antenna filter, for example. One can select a series of capacitors and coils which will eliminate virtually all but the important range of signals needed. Air dielectric types are the most common here because of the high frequencies and very low currents. An added feature is that tuning to other frequencies is easier.

Fig. 4-3. Circuit of a typical power supply illustrating filtering action of capacitors.

Another use of filtering capacitors is in power-supply circuits, as shown in Fig. 4-3. Here the essential function is to filter out the unwanted AC variations in order to produce an essentially ripple-free DC voltage. In this circuit the input to the filter capacitors is a pulsating DC voltage with

a frequency of 120 cps. At the first impulse, capacitor C1 starts charging through the rather low resistance of the transformer winding and the conducting rectifier tube. Because of its large capacitance, C1 takes several cycles to become completely charged, however. During this period C2 is also attempting to charge, but through a slightly higher resistance since R1 is in series with it. After the first few cycles both capacitors will be charged to the supply voltage. With no load, (R_L disconnected) the voltage at the output terminals will remain constant since there is no external discharge path for the two capacitors. If the load is now connected a path will be provided, but the RC time constant of the circuit will be so long that the filters will have only a very short time (4000 microseconds at 120 cps) to discharge. Even with such a short discharge time, the output voltage will drop slightly, but will rise on the next charge cycle. This produces a slight ripple with a resultant hum in the output. As long as the ripple is low in amplitude, however, the hum will not be bothersome.

BYPASSING

It is often desirable, and sometimes necessary, to eliminate a particular frequency by bypassing it to ground. Where more than one frequency must be passed and others bypassed, other components are needed besides the capacitor. Such a situation is shown in Fig. 4-4.

Capacitor C7 and variable resistor R2 function together as a tone control in a typical radio receiver. Note that the two are connected in series from the plate of the AF amplifier to ground. Audio frequencies are present at the plate and appear across R11 for further amplification in the output stage.

R2 and C7 form an RC circuit, the impedance of which is determined by the value of the two components. With R2 adjusted for maximum resistance, a total of 1 meg will be placed in series with .005 mfd. At 1,000 cps the total impedance will be approximately 1 meg, and even at 10,000

cps it will be nearly the same. This means that regardless of frequency, any audio signal at the plate will be relatively unaffected by the tone-control network.

Reducing the resistance to zero will leave only the capacitive reactance. At 1,000 cps we find that it is nearly
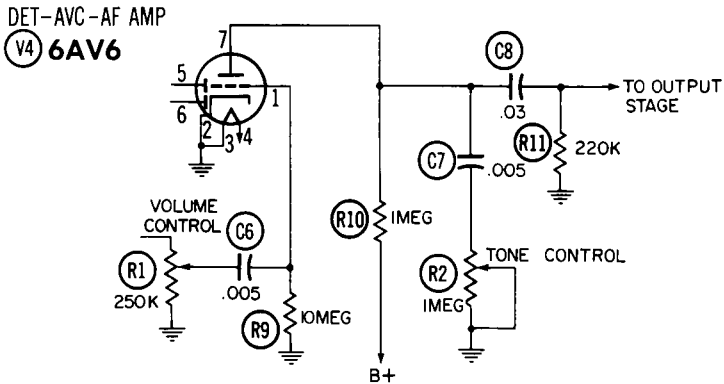

Fig. 4-4. Circuit illustrating frequency bypassing action of an RC combination.

32 K, whereas at 10,000 cps it is only 3.2 K. The higher frequencies will therefore be greatly reduced in amplitude (bypassed to ground). On the other hand, the impedance at the lower frequencies is much greater, providing ten times as much signal amplitude.
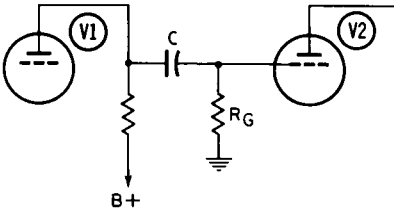
COUPLING OR BLOCKING

Besides their pure energy-storage capabilities and charge-discharge cycles (RC time constant), capacitors possess a number of other characteristics which can be either a detriment or asset, depending on the intended use. In other words, some of the very things that might otherwise be considered faults make it possible for the capacitor to do a job no other component or group of components could do as well.

Take a blocking or coupling capacitor, for example. Here the idea is to block any DC current while allowing an AC current to pass. What we are actually doing here is using a capacitor which charges to the DC level, but simply doesn't

have a fast enough reaction (RC time constant) to charge at the AC rate.

Most blocking capacitors in TV or radio sets are paper or plastic film. Cost is paramount, and the DC voltage to be blocked is within the range of these types. A typical blocking circuit is shown in Fig. 4-5.

Capacitor C keeps the DC voltage in the plate circuit from appearing on the grid of V2. In other words, C is "blocking" this voltage. At the same time we want any AC signal voltage at the plate of V1 to be transferred to the grid of V2. This can be done through the combined action of C and R_g. Hence, the capacitor has effectively "coupled" the two stages, as far as the signal is concerned.

Fig. 4-5. Use of a capacitor for blocking and coupling.

Here again the time constant formed by the two units must be considered. The RC time must be sufficiently long to prevent the capacitor from appreciably charging and discharging at any audio frequency we might want coupled to the grid of V2. This will cause most of the signal voltage to appear across R_g. If made too long, however, a positive voltage may be built up on the grid, causing distortion and possible tube failure. A compromise must therefore be made. The capacitor is kept near or below .05 mfd, and resistor values are selected to give a time constant of about 5000 microseconds.

DIVIDING

Rather than eliminating certain frequencies, it is often more desirable to divide them. The circuit in Fig. 4-6 is an example of this situation. Here the capacitors are chosen to pass one range of signals while blocking all others.
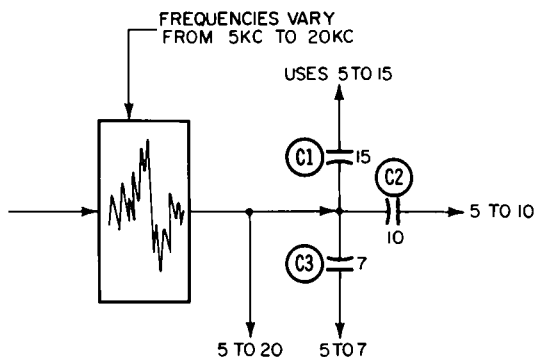
FREQUENCIES VARY
FROM 5KC TO 20KC

USES 5 TO 15

Fig. 4-6. Using capacitors as frequency dividers.

Note that C1 will pass all signals below 15 kc, C2 passes all those below 10 kc, and C3 all those below 7 kc. Thus the total 5-20 kc signal can be used for one purpose, the 5-15 kc for another, and so on. The signals that pass are only slightly affected by the capacitors and hence are usable for their intended purposes.

A practical demonstration of this principle is illustrated in Fig. 4-7. The same *sync separator* is most descriptive of the circuit action, as we shall see.

Both horizontal- and vertical-sync pulses are present at the plate of V4B. Their frequencies differ widely—15,750 cps for the horizontal but only 30 cps for the vertical pulses.
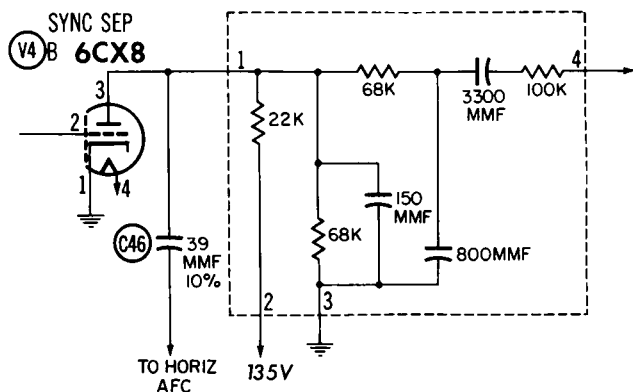

Fig. 4-7. Sync-separator circuit used in one General Electric television model.

The RC network (dotted lines) offers a higher impedance path to the 15,750 cps than does capacitor C46. Therefore, the larger portion of the horizontal-sync signal will pass through C46 to the horizontal AFC circuit, and only a negligible amount will enter the RC network.

To the low-frequency (30-cps) vertical pulses, the reverse is true—the network offers a much lower impedance path than does C46, so most of the vertical-sync pulses will pass through the RC network and into the vertical-oscillator circuit.

Here again, the choice of capacitor is determined by the characteristics desired and by the current and frequency requirements.

BUFFER

Buffers utilize the energy-absorption characteristic of a capacitor. They are commonly associated with vibrators or choppers, their purpose here being to avoid contact arcing; the same problem exists with switches and relays.

As current flows through the closed contacts of a relay or switch it reaches some maximum value and remains there. When the contacts are opened, a spark will occur; and if it is sufficiently intense or occurs repeatedly, it can damage the contact material. If the abruptly interrupted current has been flowing through an inductive circuit (a relay coil, transformer winding, etc.), the collapsing magnetic field will generate a high voltage in the inductance, and this high voltage will maintain and even intensify the arc.

Arcing can be minimized by placing a capacitor in parallel with the contacts. The excess electrons that formerly caused the arc are now used to charge the capacitor and thereby prevent damage to the points. As the contacts close, the capacitor discharges, making it ready for the next voltage surge. Fig. 4-8 illustrates a method of contact protection.

The most common type of buffer used is the paper capacitor with a value chosen that will be a function of circuit requirements. In some cases, a plastic film unit might be suit-

able, but the superior surge voltage ratings of the paper type make it more desirable.

TUNING

There are other applications where the choice of a particular capacitor type is so clear that very little discussion is required. Such is the case in tuning. The air dielectric type is predominant here, because RF frequencies are involved, stability is very important, and long mechanical life

Fig. 4-8. Using capacitors to protect relay contacts.
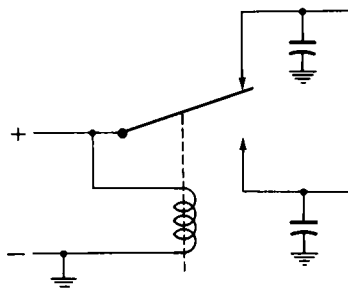
is desired. Ceramic or mica trimmer capacitors may be used to complement the air unit.

Not all tuning devices are capacitors, however; a great many are inductive units. They will not be discussed in this book, except to note their existence and to point out that they cannot be replaced directly by capacitive devices.

AC MOTOR STARTING AND RUNNING

An extremely important use for capacitors has nothing to do with radio or TV. But whether the electronic technician ever makes use of this information or not, it is of some value, if only from a personal standpoint.

For many household appliances it is desirable to have fractional horsepower motors capable of a high starting torque. Repulsion-induction motors will provide this torque, but are relatively expensive to construct. A less expensive solution is the capacitor-start motor. It has a normal set of heavy windings for running and a lighter set for starting.

A centrifugal switch connects a capacitor to the start winding to shift the phase, resulting in a high torque being developed. As soon as running speed is reached, the switch cuts the capacitor and start-winding out of the circuit, and the motor operates as a single-phase unit.

Because of the high capacitances required, aluminum electrolytics are commonly used in capacitor-start motors. The capacitor may be in a housing on the exterior of the motor frame, placed inside the frame, or fitted inside the bell of the motor frame. The latter two have been largely supplanted in recent years by the more economical and more satisfactory exterior mount.

Major causes of capacitor failure include aging and excessive start cycles, voltage, and temperature. Another major cause of failure is mechanical—if the centrifugal switch contacts fail to open, the capacitor will quickly fail. On the other hand, if they open too soon, running speed will not be reached and the start cycle will occur repeatedly until the capacitor eventually fails.

Before replacing a motor start capacitor, always check the mechanical condition of the motor for bad bearings, dirty switch, etc., first. It is always best to mount the replacement on the motor exterior even though the original was not. In this way, the capacitor will run cooler and last longer.

Motor run capacitors are used in conjunction with a low starting-torque motor like the one in a fan. Here, quietness of operation is the principal advantage, with small size a close second. Motor run capacitors are always oil-paper types. Failures are traceable primarily to excessive voltage and/or temperature.

A third type of motor is the capacitor start and run. It is used in large fans and in air conditioners, where both high starting torque and quiet operation are required. This motor is merely a combination of the two mentioned previously.

Chapter 5

CAPACITOR REPLACEMENT

There are certain precautions you should observe before replacing a capacitor. The mere fact that it has the correct value and voltage rating does not guarantee successful results.

Suppose you are called on to repair a defective TV and find that two mica capacitors have failed. Unfortunately you have no exact replacement micas with you, but you do have ceramics. Can they be used instead? The answer is a qualified yes—you can almost always replace a mica with a ceramic of equivalent value. One thing to watch, however, is tolerance.

TOLERANCE

Capacitor tolerance is expressed in per cent. Let's take the case of a ±10% unit rated at 10 mmf. This means the manufacturer guarantees this particular capacitor will have a value of no less than 9 nor more than 11 mmf. But remember, he only guarantees this at the rated voltage and at 25°C (77°F). If the temperature is higher, the capacity will also be higher, and vice versa. This is true in all types except ceramics. The capacity-temperature characteristic of ceramics doesn't follow the rules for the other types—it's engineered into the specific dielectric used. You'll have to make certain these characteristics fit the job at hand. (You'll find much of the information you need in Chapter 3.)

Before we leave tolerance, let's look at the one for a typical electrolytic. A tolerance of −10% to +50% means that a 100-mfd unit will have an actual capacity between 90 and

150 mfd. In other words, you would have to measure the capacitor to find its exact value. So remember—don't use ordinary electrolytics where capacity values are critical.

Tolerance is a measure of the over-all quality of a capacitor. It is obviously more expensive to manufacture a capacitor with a very close tolerance than with a very wide one. The most practical method of accomplishing this, from the manufacturer's standpoint, is to build a group of units to a certain specification that should result in a certain value, and then test and label them for their specific value. As the voltage rating of an electrolytic increases, the capacity tolerance becomes less. A typical range would show capacitors rated at 1 to 50 VDC and having a tolerance of -10% to $+250\%$, while above 350 VDC the tolerance would be reduced to -10% to $+50\%$. Data on specific values are available from every capacitor manufacturer, and most of the time from your electronic parts distributor.

Ceramic capacitors are rated either in per cent or in guaranteed minimum value (GMV). The percentage was explained earlier. GMV is simply the manufacturer's guarantee that the unit will have no less capacity than is stated. (Remember, this is at 25° C.)

TEMPERATURE

Let's return to the problem of substituting ceramics for micas. In addition to being careful about the tolerance, you will have to make certain the ceramic has the same electrical characteristics. In other words, you certainly wouldn't want to use a negative temperature-compensating type if it would upset the circuit. The safest thing to do would be to use an NPO type; it has a flat temperature curve.

Let's look at the other side of the coin for a moment. Suppose the capacitor that has gone bad is a ceramic, and all you have are micas. If the bad ceramic is one of the general-purpose type, go right ahead and put in the mica, because the circuit requirements are probably not too critical. But if the ceramic is one of the temperature-compensating types,

you're in trouble—a mica won't do here. Its temperature versus capacitance characteristic just doesn't match that of the temperature-compensating ceramic.

TYPE CONSIDERATION

Here's another problem. Can a paper capacitor be replaced with one of an equivalent rating in a *Mylar* type? Yes, with one exception—paper types generally make better vibrator buffers than do *Mylars*. Paper types have superior surge-current characteristics and generally a much higher corona starting voltage. However, this does not mean that paper capacitors are superior to *Mylar* types. Quite the contrary—*Mylars* are smaller and have other operating characteristics (such as humidity protection) that make them superior to paper capacitors for most applications. As a general rule, you can always replace a paper type with an equivalent *Mylar,* but be careful when trying to use a paper for a *Mylar*. The big problem will probably be lack of space, because *Mylar* capacitors as a rule are smaller.

Many inexpensive radios, and even some television receivers, use wax or paraffin-filled paper capacitors. They are more subject to moisture infiltration than the molded-case types. For this reason, the latter should be used when replacement is required. As a matter of fact, if you run into one or more bad paraffin-filled capacitors in a circuit, it's usually a good idea to check the rest of them while you're at it.

Getting back to the replacement of micas with ceramics and vice versa, you may run into a situation where a tubular ceramic needs replacement. There is no problem here—you can nearly always replace a tubular ceramic with an equivalent disc type. As a rule, the small difference in inductance will have no effect. However, this is not true if the tubular ceramic happens to be a feedthrough type—the presence of a feedthrough ceramic practically guarantees that an inductance problem exists. The only thing to do here is use an exact replacement.

A similar situation occurs with trimmer capacitors—if an air type, replace with another air type. If the trimmer is a mica, you can consider a ceramic, provided their over-all characteristics match. But be careful about switching a mica for a ceramic trimmer—the temperature characteristics of the two may differ radically.

ELECTROLYTIC SUBSTITUTION

Can you replace an electrolytic with an equivalent paper type? How about vice versa? If the value of the electrolytic is low enough, you might be able to find a paper type that would fit the available space, although it's highly unlikely. Remember, the electrolytic was no doubt chosen in the first place because of its smaller size. Also, it may have some peculiar electrical characteristic. Replacing it with a paper unit—even of the same value—could be a serious error.

The reverse is even more true. Except in the case of pure energy storage (DC), a paper type cannot be replaced with an electrolytic, even with one of equivalent value. Paper types were chosen originally because of their superior voltage characteristics, or because of polarity-reversal considerations. Remember, polarity is vitally important in an electrolytic capacitor. Even a momentary reversal could ruin one. Also, electrolytics do not have as close a tolerance as paper types.

VOLTAGE RATING

Service technicians run into all sorts of problems in a day's work. Take this one, for example. A .02-mfd 200 WVDC paper capacitor has shorted and there is no exact replacement anywhere in the shop. What would you do? You could use a 400 or even 2600 WVDC unit and no one would ever know the difference. Even a 1,000-volt unit might be all right, although it will be slightly larger and cost a bit more. Then, too, the electrical characteristics will start to change, because the voltage rating of a capacitor is determined by the thickness of its dielectric. Therefore, in order to gain the same capacitance, the unit must have a larger

plate area. This in turn may change the internal resistance. If the circuit requirements are not too critical, a 1,000-volt unit may be satisfactory. On the other hand, it may introduce other problems.

As a rule, it is safe to substitute a capacitor of a higher voltage rating. But don't try to go the other way—if a circuit requires a 600 WVDC capacitor and you use 400, you can expect more than your share of trouble.

PARALLEL CAPACITORS

Another fairly simple problem is one where a certain capacitor is called for, but only smaller values are available. For example, suppose you need an 80 mfd @ 300 VDC— simply place two 40-mfd @ 300 VDC units (or any other reasonable combination) in parallel. This brings up the possibility of upsetting the RC time constant. The fact that the internal resistances are also paralleled now results in a lower over-all resistance. Although you can parallel capacitors to increase capacitance, you cannot increase the voltage rating in this manner. The voltage rating remains the same because, unlike capacitance, voltages in parallel are not additive.

SERIES CAPACITORS

There is a stop-gap method of increasing the voltage rating, and that is to place capacitors in series. Thus, two 40-mfd, 150-WVDC capacitors in parallel will be equal to a single 80-mfd, 150-WVDC unit, or to a single 20-mfd, 300-WVDC unit if placed in series. Understand that in both cases the RC time constant may be upset, since the resistance is lower in the parallel circuit and higher in the series circuit than it would be in an equivalent single capacitor.

SHAPE CONSIDERATIONS

The shape of a capacitor is often an important consideration due to space requirements. Substitution of one shape

for another may radically change the distributed capacity. For example, it may be perfectly satisfactory to substitute a disc for a tubular ceramic. Likewise, a molded *Mylar* capacitor that has axial leads might be replaced with another that has radial ones. Trouble might develop from this substitution in critical circuits, however, due to changes in the distributed capacity.

Shape and size are also important in electrolytic replacement, especially in compact equipment where space occupied by the defective unit does not permit substitution of a different shape capacitor. The two most common types of electrolytics are the tubular and the metal can, and their performance and internal construction are identical. Hence, as long as their values are the same, they may be freely interchanged as far as electrical requirements are concerned.

MULTIPLE UNITS

Very often, two, three, or four electrolytic capacitors are furnished in a single can. In cases where only one of them fails, a satisfactory repair can usually be made by disconnecting the defective portion and soldering a single tubular in its place. This is assuming, of course, that the remaining sections have not suffered any damage due to failure of the defective section (such as from overheating). Also, if the known bad section has failed due to deterioration which has taken place over a period of time, the other sections are more subject to early failure. In such cases, it would be wiser to replace the entire unit.

When an exact replacement for a four-unit (quad) electrolytic is not on hand—a triple-unit electrolytic and a single capacitor together work just as well.

REPLACEMENT TECHNIQUES

Removing the defective capacitor and inserting the replacement is seemingly a simple operation. Yet here is where many mistakes are made.

Faulty installation can affect circuit performance even though the new unit is a perfect twin. Take the mica capacitor in Fig. 5-1. Originally it was installed at right angles to the chassis, as in Fig. 5-1A. The replacement has been installed parallel and too close to the chassis (Fig. 5-1B). A possible shift in capacitance is likely because of the dif-

A   B

CHASSIS

C
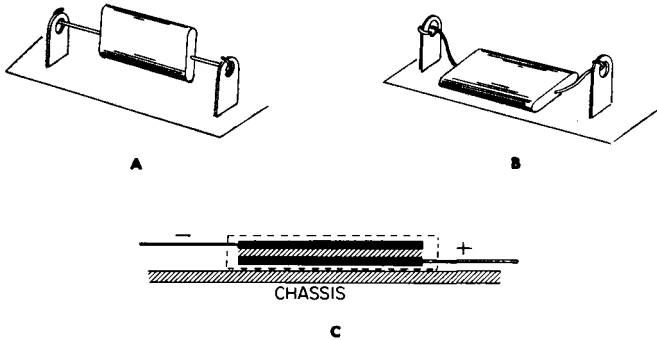
Fig. 5-1. Faulty installation of a capacitor producing undesirable coupling to chassis.

ference in the distributed capacity (Fig. 5-1C) between the metal chassis and the plates inside the capacitor.

Lead Length

Another common error is failure to recognize the effect of lead length on the resonant frequency of capacitors and their circuits. For example, changing the length from 0.5 to 0.3 inch can raise the resonant frequency of a disc ceramic by as much as 10 mc. Other types may be affected even more. Disc ceramics are pointed out because they are so common in miniature circuitry, and when components are tightly packed, there is always the temptation to make the replacement the easy way. Thus, in a critical circuit make certain the replacement's leads are the same length as the original's.

Soldering Precautions

Miniaturization has led to a new set of problems for the service technician—all components are smaller, and capacitors are no exception. Take the small *Mylar* types, for ex-

ample. Naturally they must be soldered into the circuit. But the heat of the soldering iron or gun can ruin them unless proper precautions are taken. Always use a soldering device that provides no more heat than is needed. Prolonged application of a hot iron to the lead of a *Mylar* unit can melt the dielectric or the internal solder joint between lead and plate. A deft hand is the surest way to avoid this problem.

An excellent device for preventing heat damage is a set of surgical clamps. They are sold under a variety of trade

METAL CLAMPS OR PLIERS
GRASPING LEAD AS SHOWN
WILL CONDUCT HEAT FROM
AND PROTECT
CAPACITOR
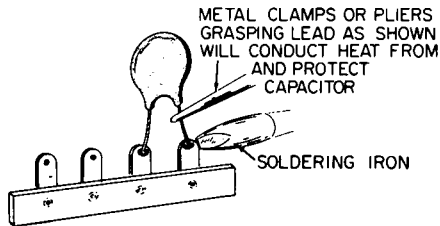
SOLDERING IRON

Fig. 5-2. Protecting capacitor from excess heat during soldering.

names, and are well worth their small cost. In essence they are clamped onto the lead, between the component and iron, and act as a heat sink (absorb excessive heat). This principle is shown in Fig. 5-2.

In summary, your best "tool" for capacitor replacement is good judgment, born of knowledge and experience. The most expedient thing to do, of course, is to always use the exact type as the original. But progress is synonymous with electronics . . . even a three-year old radio can benefit by replacing an outmoded capacitor with a more modern one.

Chapter 6

CAPACITOR TESTING

How will you know a capacitor is bad? Or for that matter, how will you know it is good?

Beyond the fact that a capacitor lead is completely burned off or broken in two, there are other ways a capacitor can become defective. It may be shorted or completely open (have no capacitance at all). Capacity may have drifted from the desired value, or the internal resistance may be too low or too high. DC leakage may also be much too high. Most of these defects can be detected fairly easily.

A few tests can be performed with the unit still in the circuit; others require that at least one lead be unsoldered.

TESTING WITH THE VOM OR VTVM

In complex circuitry, particularly where printed boards and/or miniaturized components are used, it is best to make as many in-circuit tests as possible. There's no sense unsoldering or removing components from the circuit until other tests lead you to believe that such action is necessary.

Take, for example, the coupling capacitor C8, in Fig. 6-1. If a voltage measurement indicates that a potential of 25 volts is present at the grid of V2, it is reasonable to assume that the capacitor could be leaky. But before carrying this assumption further, why not obtain additional proof? After all, a shorted V2 could be responsible for the positive grid voltage. Unless there is reason not to do so, the tube can be removed from the socket and the grid voltage measured again. If the same condition is noted, and there seems to be
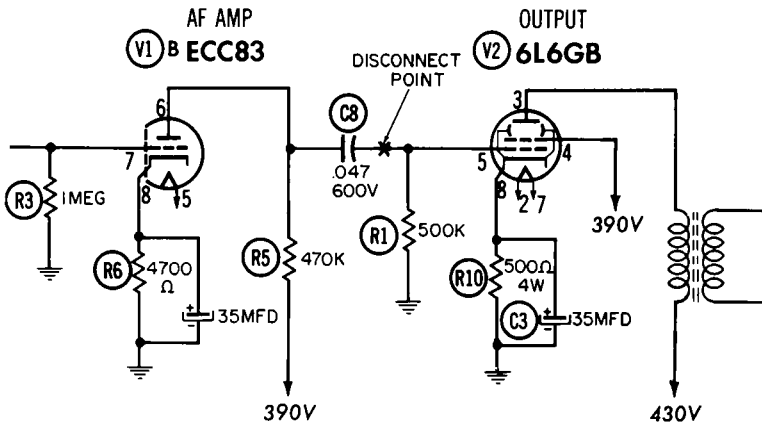
Fig. 6-1. Audio amplifier circuit.

no other contributing factor, it's time to disconnect the grid end of the capacitor from the circuit.

As shown in Fig. 6-2, there are two methods of testing for capacitor leakage, using nothing more than a VOM or VTVM. With the set turned on, and no signal coming through, you need only measure voltage or current by connecting the appropriate meter between the open end of the capacitor and ground. Normal readings, depending on ca-
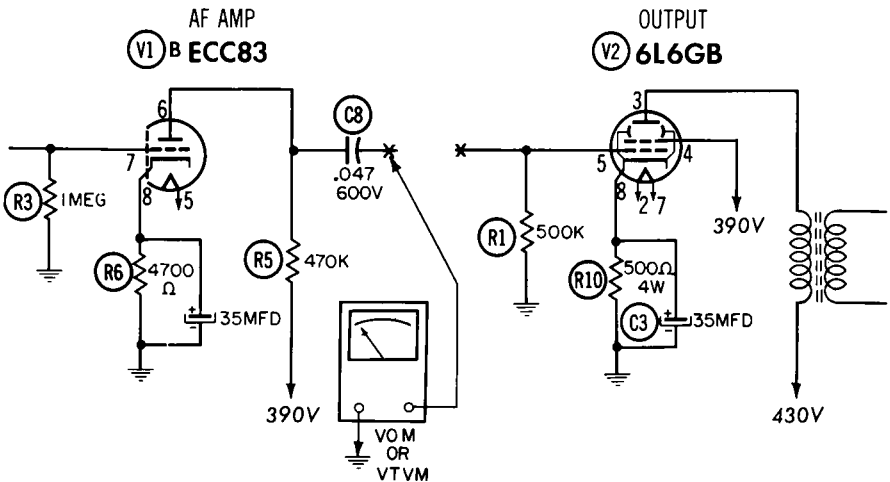

Fig. 6-2. Use of VOM or VTVM for testing capacitor leakage.

pacitor type and value, should not exceed two or three volts, or 5 to 10 ma. A word of caution in making these voltage and current measurements: a badly shorted capacitor will permit high currents to flow through the ground return path provided by the meter, so be sure to start out on a scale high enough to prevent damage to the meter.

There is one other simple, although not entirely conclusive, in-circuit test you can make for a shorted capacitor.

If a capacitor is badly shorted, you can usually discover the defect with the use of an ohmmeter. *Before making this test, make sure no voltages are present in the equipment— otherwise, damage to the meter will result.*
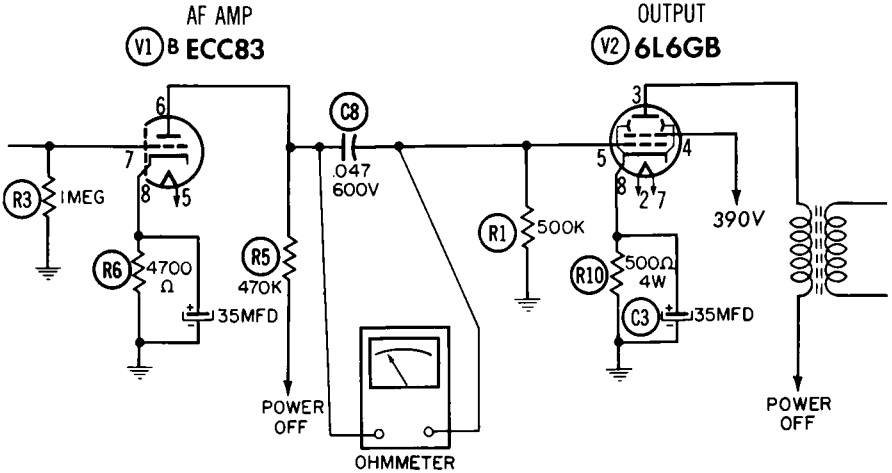
Fig. 6-3. Use of ohmmeter to detect shorted capacitor.

As shown in Fig. 6-3, merely connect the ohmmeter across the suspected unit, using the scale that provides a usable reading. In order for the test to have any validity, you must compute the resistance value for existing parallel paths. This computed value is aproximately what the meter should read. If the measured resistance is lower, either your computation of the parallel resistance path is in error, or the capacitor is leaky. Disconnecting one end of the capacitor from the circuit and making a resistance measurement only across the capacitor should prove which is true. A word of warning when testing low-voltage capacitors commonly used in tran-

sistor radios; make sure the meter voltage does not exceed the rating of the capacitor under test. There are a great number of 22½-volt meters in use, and they can ruin an otherwise good 3-volt capacitor.

The voltmeter or milliammeter tests provide a more positive means of checking for capacitor leakage than the ohmmeter measurement because normal circuit voltages are applied to the unit under test. If a capacitor is breaking down intermittently, it is more likely to do so when B+ voltages are applied; the ohmmeter measurement does not take this factor into account.

Checking for open capacitors is a fairly simple task, also. But again, by making in-circuit tests first, you can save much time and trouble. One of the best tests involves the use of an oscilloscope or AC voltmeter to check for the presence of signal. Of course, you must know what to expect in the way of waveform or voltage indications. For instance,
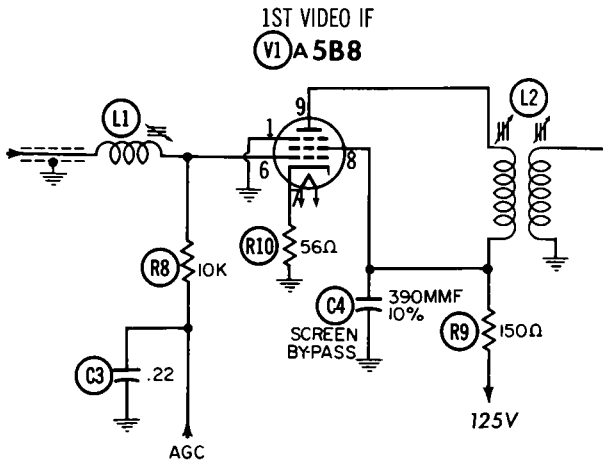
Fig. 6-4. TV video-IF stage showing screen bypass capacitor.

you would expect a coupling capacitor such as the one in Fig. 6-1 to pass practically all of the signal available from the plate of V1 to the grid of V2. On the other hand, in the circuit of Fig. 6-4, you would expect to find very little AC signal present at the screen grid. Excessive signal at this

point would indicate that the screen bypass unit (C4) was not doing its job. As with the shorts tests, disconnecting one end of the capacitor from the circuit, and making the same tests again, should provide sufficient information for you to decide whether or not the capacitor is defective.

Some indication of an open capacitor can often be obtained with the use of an ohmmeter. When disconnected from the circuit, and fully discharged, connecting an ohmmeter across the unit will cause it to charge. As was pointed out in Chapter 2, the time it takes for a capacitor to charge is governed by the value of capacitance and the amount of series resistance in the circuit. The ohmmeter itself has several thousand ohms of resistance (depending on the scale used); thus, if the capacitor is of fairly large value—say, .01 mfd or more—the time constant will be such that it can be distinctly noticeable from the change in the ohmmeter reading. On the 100K scale, for example, the initial reading for a normal capacitor may be in the neighborhood of 500K. That is, the pointer may swing over as far as mid-scale, and then swing back—rapidly at first, and then gradually more slowly—until the reading is near infinity. If you could accurately plot the resistance readings on a time scale, you would find they duplicate the capacitor charging curves discussed in Chapter 2.

As you have undoubtedly surmised by now, failure of the ohmmeter to react as described is a pretty good indication that the capacitor is open. Remember, however, that capacitor value must be sufficient to provide a measurable charging period. A value of 330 mmf might not produce more than a slight flicker of the ohmmeter needle. Incidentally, the phenomenon known as dielectric absorption, described in Chapter 2, is most likely to be encountered when using the highest scale of the ohmmeter (usually 1 meg or 10 meg). Therefore, to obtain a valid test, switch to the next lowest scale. (Dielectric absorption will not generally be encountered in mica, ceramic, or electrolytic capacitors.)

As far as capacitor value is concerned, a VOM equipped with an AC scale can be used to obtain an approximate read-

ing. Specific instructions for this measurement are usually included in the operating manual for the instrument. Some instrument scales are calibrated directly in microfarads, making measurement of capacitance values a relatively simple matter. Fig. 6-5 illustrates such a unit.

Using the ordinary VOM as a capacitor checker has its limitations. In the first place, it really wasn't designed for the job and, for this reason, is primarily useful in providing
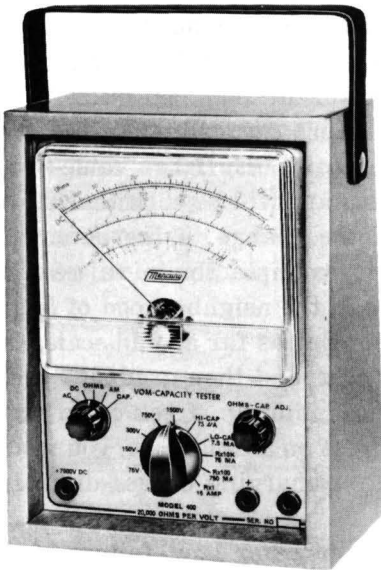
Fig. 6-5. The VOM-capacity checker manufactured by the Mercury Electronics Corp.

only preliminary information. When it comes to accurate measurements of value, leakage, power factor, etc., a regular capacitor checker is called for. There are two general types—the in-circuit and the out-of-circuit—and each has its particular applications and limitations.

IN-CIRCUIT CAPACITOR CHECKERS

The in-circuit capacitor checker will tell you at a glance whether or not a capacitor is shorted or open. But it cannot tell you the exact value of a particular capacitor. It is in essence an all-or-nothing device. Most of the time, this will

do—as far as you're concerned, either a capacitor is working or it is not. Fig. 6-6 shows an in-circuit checker.

OUT-OF-CIRCUIT CAPACITOR CHECKERS

There are circuits where the value of the capacitor can be especially critical. For instance, in a divider network a

Fig. 6-6. Simpson in-circuit capacitor checker.

slight shift in capacitance can seriously affect performance. If trouble is indicated here, the capacitor must be removed from the circuit (or, at least one lead unsoldered) before it can be accurately checked. All out-of-circuit capacitor checkers, such as the one shown in Fig. 6-7, use some modification of a balanced-bridge circuit. The principle involved is simple—a known capacitance is balanced against the unknown by coupling an appropriate variable resistance to a calibrated dial. When the needle shows that the circuit is balanced, the capacitance value can be read directly from the dial. Other checkers may use variations of this circuit,

Fig. 6-7. Paco out-of-circuit capacitor checker. This type unit is able to measure capacitor values, leakage current, power factor and resistance.

but they accomplish the same results. A basic bridge circuit, used in many out-of-circuit testers, is shown in Fig. 6-8.

The leakage resistance of capacitors varies from very high in micas and ceramics, to very low in electrolytics. Checking for a change in this characteristic can be performed only with an out-of-circuit tester or an appropriate bridge. Since
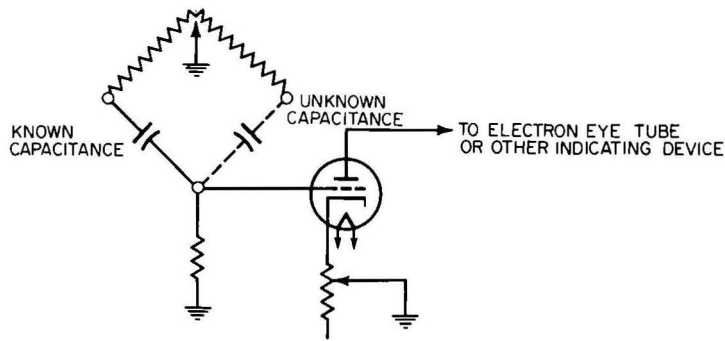
Fig. 6-8. Bridge circuit used to measure value of unknown capacitor.

values range up to 20,000 megohms, the correct test setup is required to insure accuracy.

Excessive DC leakage is a common problem with capacitors. It is usually expressed in terms of the internal resistance, because leakage is low whenever resistance is high. In electrolytics the leakage is high enough that it can be compared directly. The test for DC or AC leakage must be performed with the capacitor out of the circuit. Manufacturers of both test equipment and capacitors supply charts indicating the correct amount for each type and value. These should be used in place of any rule-of-thumb, and even then judgment will be necessary. It is essential to keep the capacitor at the temperature specified (usually $+25°C$) when checking for DC leakage; otherwise, you will obtain an inaccurate reading. AC leakage is expressed as so many milliamps at a particular frequency (usually 120 cycles per second) and temperature (such as $+85°C$).

Out-of-circuit testers are also useful for measuring the power factors of electrolytics. A bridge similar to the one in Fig. 6-8 is used. Here again, the test must be performed at rated temperatures only.

Another method of checking capacitance, described in Chapter 2, is to use the time constant. It is generally restricted to elaborate laboratory tests, mainly because a great deal of expensive equipment is involved.
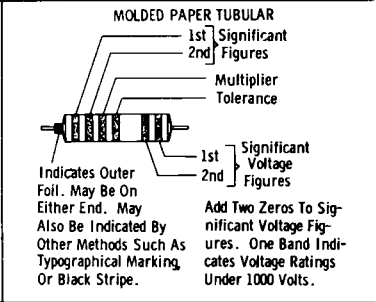

COLOR CODES AND SYMBOLS

A system of color coding to indicate capacitor values has been established and adopted by all major manufacturers of capacitors. Without such a system, confusion would result because of the myriad types of capacitors prevailing. These color codes are given in Fig. 6-9 on pages 90 and 91. Also included are the standard capacitor symbols appearing in schematic diagrams.

CAPACITOR SCHEMATIC SYMBOLS

Fixed   Variable   Polarized   Non-Polarized

Electrolytics
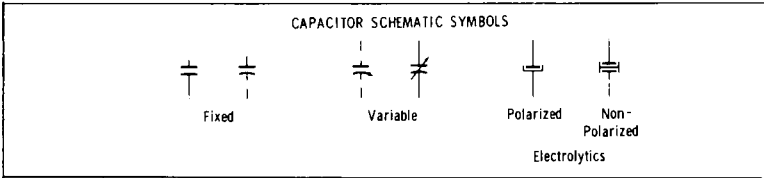
MOLDED PAPER CAPACITOR CODES
(Capacity Given In MMF)

COLOR	DIGIT	MULTI-PLIER	TOLERANCE
BLACK	0	1	20%
BROWN	1	10	
RED	2	100	
ORANGE	3	1000	
YELLOW	4	10000	
GREEN	5	100000	5%
BLUE	6	1000000	
VIOLET	7		
GRAY	8		
WHITE	9		10%
GOLD			5%
SILVER			10%
NO COLOR			20%

MOLDED PAPER TUBULAR

1st Significant
2nd Figures
Multiplier
Tolerance

1st Significant Voltage
2nd Figures

Indicates Outer Foil. May Be On Either End. May Also Be Indicated By Other Methods Such As Typographical Marking, Or Black Stripe.

Add Two Zeros To Significant Voltage Figures. One Band Indicates Voltage Ratings Under 1000 Volts.

MOLDED FLAT PAPER CAPACITORS (COMMERCIAL CODE)

1st Significant
2nd Figures
Voltage
Multiplier
Black Or Brown Body

MOLDED FLAT PAPER CAPACITORS (JAN CODE)

Silver
1st Significant
2nd Figures
Multiplier
Tolerance
Characteristic

MOLDED MICA CAPACITOR CODES
(Capacity Given In MMF)

COLOR	DIGIT	MULTI-PLIER	TOLERANCE	CLASS OR CHARACTERISTIC
BLACK	0	1	20%	A
BROWN	1	10	1%	B
RED	2	100	2%	C
ORANGE	3	1000	3%	D
YELLOW	4	10000		E
GREEN	5		5% (EIA)	F(JAN)
BLUE	6			G(JAN)
VIOLET	7			
GRAY	8			I (EIA)
WHITE	9			J (EIA)
GOLD		.1	5%(JAN)	
SILVER		.01	10%	

Class or characteristic denotes specifications of design involving Q factors, temperature coefficients, and production test requirements.
All axial lead mica capacitors have a voltage rating of 300, 500, or 1000 volts.
*or ±1.0 MMF whichever is greater.
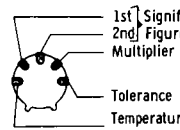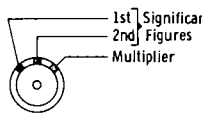
CURRENT STANDARD JAN AND EIA CODE

White (EIA)   Black (JAN)
1st Significant
2nd Figures
Multiplier
Tolerance
Class Or Characteristic
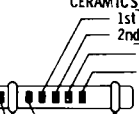
BUTTON SILVER MICA

1st (When Applicable) Sig Fig
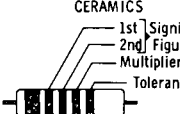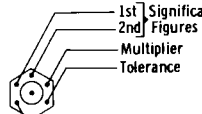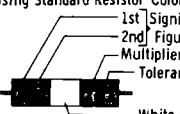2nd (or 1st)
3rd (or 2nd)
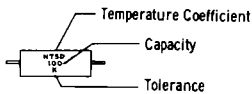Multiplier
Tolerance
Class
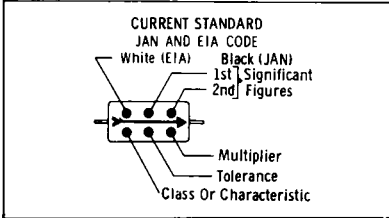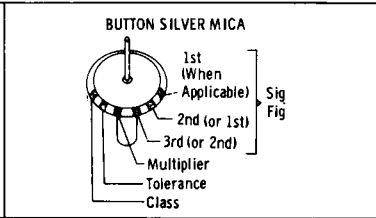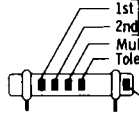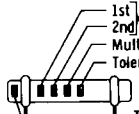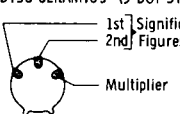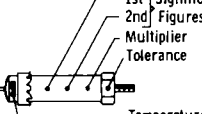
Fig. 6-9. Capacitor symbols

CERAMIC CAPACITOR CODES (CAPACITY GIVEN IN MMF)

COLOR	DIGIT	MULTI-PLIER	TOLERANCE		TEMPERATURE COEFFICIENT PPM/°C	EXTENDED RANGE	
			10MMF or LESS	OVER 10MMF		TEMP. SIGNIFICANT FIGURE	COEFF. MULTIPLIER
BLACK	0	1	±2.0MMF	±20%	0(NPO)	0.0	-1
BROWN	1	10	±0.1MMF	±1%	-33(N033)		-10
RED	2	100		±2%	-75(N075)	1.0	-100
ORANGE	3	1000		±2.5%	-150(N150)	1.5	-1000
YELLOW	4	10000			-220(N220)	2.2	-10000
GREEN	5		±0.5MMF	±5%	-330(N330)	3.3	+1
BLUE	6				-470(N470)	4.7	+10
VIOLET	7				-750(N750)	7.5	+100
GRAY	8	.01	±0.25MMF		+30(P030)		+1000
WHITE	9	.1	±1.0MMF	±10%	General Purpose		+10000
SILVER					Bypass & Coupling		
GOLD					+100(P100) (Jan)		

Ceramic capacitor voltage ratings are standard 500 volts, for some manufacturers, 1000 volts for other manufacturers, unless otherwise specified.

HIGH CAPACITY TUBULAR CERMICS INSULATED OR NON-INSULATED
- 1st ⎱ Significant
- 2nd ⎰ Figures
- Multiplier
- Tolerance
- Voltage (Optional)

DISC CERAMICS (5-DOT SYSTEM)
- 1st ⎱ Significant
- 2nd ⎰ Figures
- Multiplier
- Tolerance
- Temperature Coefficient

BUTTON CERAMICS
- 1st ⎱ Significant
- 2nd ⎰ Figures
- Multiplier

Viewed From Soldered Surface

TEMPERATURE COMPENSATING TUBULAR CERAMICS
- 1st ⎱ Significant
- 2nd ⎰ Figures
- Multiplier
- Tolerance
- Temperature Coefficient

DISC CERAMICS (3-DOT SYSTEM)
- 1st ⎱ Significant
- 2nd ⎰ Figures
- Multiplier

STAND-OFF CERAMICS
- 1st ⎱ Significant
- 2nd ⎰ Figures
- Multiplier
- Tolerance
- Temperature Coefficient

EXTENDED RANGE T.C. TUBULAR CERAMICS
- 1st ⎱ Significant
- 2nd ⎰ Figures
- Multiplier
- Tolerance
- Temp. Coeff. Multiplier
- T. C. Significant Figure

MOLDED-INSULATED AXIAL LEAD CERAMICS
- 1st ⎱ Significant
- 2nd ⎰ Figures
- Multiplier
- Tolerance
- Temperature Coefficient

FEED-THRU CERAMICS
- 1st ⎱ Significant
- 2nd ⎰ Figures
- Multiplier
- Tolerance
- Temperature Coefficient

MOLDED CERAMICS
Using Standard Resistor Color-Code
- 1st ⎱ Significant
- 2nd ⎰ Figures
- Multiplier
- Tolerance
- White Band

Distinguishes Cap-acitor From Resistor

TYPOGRAPHICALLY MARKED CERAMICS
- Temperature Coefficient
- Capacity
- Tolerance

JAN LETTER	TOLERANCE	
	10MMF or LESS	OVER 10MMF
C	±0.25MMF	
D	±0.5MMF	
F	±1.0MMF	±1%
G	±2.0MMF	±2%
J		±5%
K		±10%
M		±20%

and color codes.

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