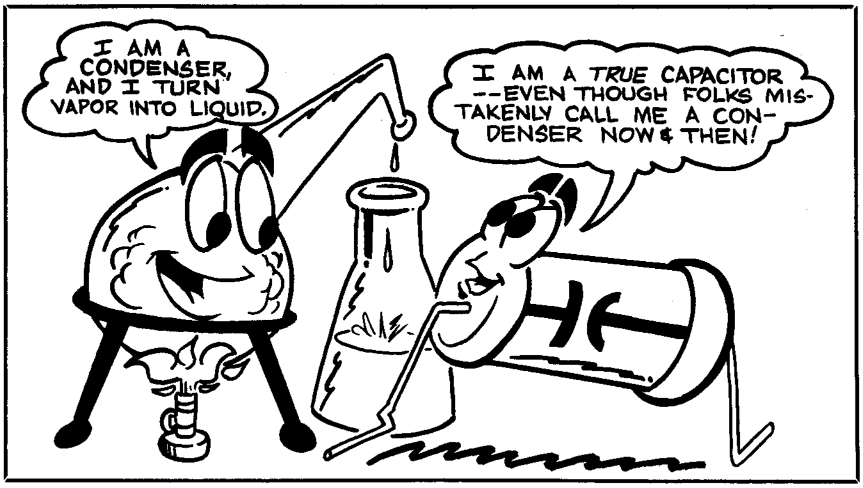
Getting to Know Capacitors



Part 4: Along with resistors, which we explored last time, capacitors are an integral part of radio electronics. Don't bypass this installment.

By Doug DeMaw,* W1FB

What purpose do capacitors serve? We could compile a long list of functions if time and page space permitted. But, for this discussion we will examine their most common applications. You may have heard people refer to them as "condensers." That misnomer has been popular since the beginning of radio, but it does not describe the function of a capacitor. A retort in a chemistry lab is a *condenser,* since it converts vapor to liquid, but a capacitor can't function that way. Rather, it stores dc energy, but permits the passage of ac energy. In other words, the device has a *capacity* for storing energy, the magnitude of which is expressed in farads (F), microfarads (μF) or picofarads (pF). Capacitors are rated in some parts of the world in nanofarads (nF) as well. A capacitor is a component that consists of two electrodes separated by a dielectric (an insulator), such as air, or some solid material.

The *dielectric* material of a capacitor is the insulating medium between the electrodes, or *plates*. Generally, it is air for variable capacitors (sometimes called tuning, trimmer or padder capacitors). The insulation in fixed-value capacitors may consist of treated paper, mica, glass, polyethylene, polystyrene, Mylar or a host of other substances. Some variable capacitors (movable plates) have a solid dielectric between the plates. Smaller trimmer or padder capacitors have thin sheets of mica between their plates.

Each type of insulation has a different characteristic (factor) with regard to the voltage it can accommodate for a given thickness before breakdown (puncture). The dielectric factor (ϵ) also determines the amount of capacitance for a specified plate spacing and area. Dry air and helium are considered to be the best dielectrics for capacitors that must be used in high-voltage circuits.

Some Names and General Descriptions

Simply, we can think of a capacitor as a device that permits the flow of ac energy, but blocks the passage of dc energy. A basic capacitor is illustrated in Fig. 1A. The more plates we add, the greater the effective capacitance for a given plate spacing (Fig. 1B). The greater the plate spacing, on the other hand, the lower the capacitance and the higher the safe voltage rating. In the case of air-dielectric and other capacitors, an arc occurs between the plates when the voltage is too high for the insulation.

We will hear about and frequently use what is known as a "paper," or "tubular" capacitor. This type consists of many layers of treated paper or other insulating

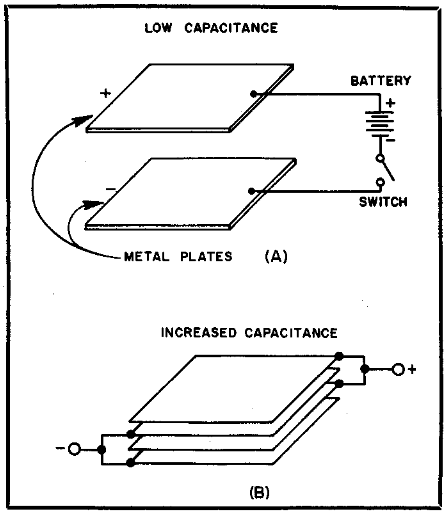


Fig. 1 — Example of a simple capacitor (A) that has two electrodes, or plates. A multi-plate capacitor is shown at B. It has greater capacitance than the example at A.

*ARRL Contributing Editor, P.O. Box 250, Luther, MI 49656

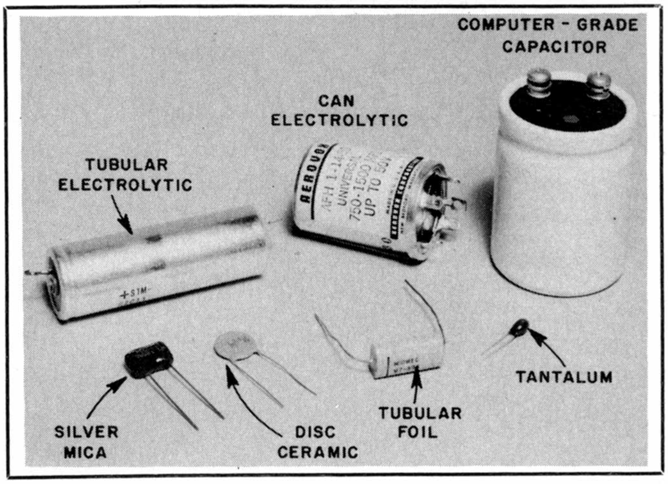


Fig. 2 — Various fixed-value capacitors are seen in this photograph.

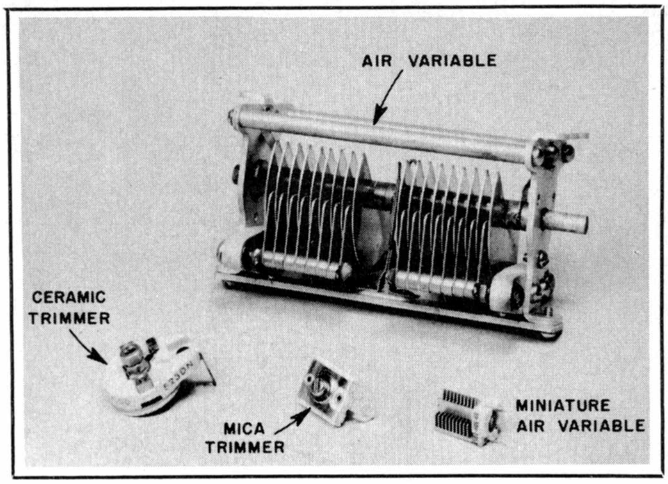


Fig. 3 — Examples of variable capacitors.

material, rolled into a cylinder. The surface of the insulation has a metallic electrode affixed to it. Two such electrodes are used in parallel, and each is insulated from the other. A wire lead is connected to one electrode, and another such lead is attached to the remaining electrode. If the capacitor is a polarized type, one terminal is marked with a minus sign (−) and the other has a plus sign (+). Some of these capacitors, when polarized, lack the plus and minus signs. Instead, there is a black band around one end of the capacitor to indicate the negative terminal. By rolling the electrodes and insulation into a tight cylinder it is possible to obtain large amounts of capacitance in a small package. This is not practical for variable capacitors.

You will hear also about "oil-filled" capacitors. These are designed for high capacitance and high voltage. The plates are insulated by an oil that has a high dielectric factor. We will find these units mainly in high-voltage power supplies.

The highest capacitance ratings can be found in what many people call "computer-grade" capacitors. These are large cylindrical units that contain a solid dielectric. They are encased in an aluminum cylinder. It is not unusual to find them with ratings of 50,000 μF or greater, and with dc-voltage ratings as high as 450.

Another type of high-capacitance device is the "tantalum" capacitor. These miniature low-voltage devices are ideal for use in printed-circuit-board assemblies because of their small size. They are considered to be high quality units, and have ratings well into the high-microfarad region.

Still another capacitor is the "vacuum" type. These units have the air evacuated from them at the time of assembly. They are built into glass containers with metal end caps. Because of this lack of true dielectric material (a vacuum), they can accommodate tremendous voltage levels without breaking down. They are expensive and large, but many amateurs use them in special circuits. Vacuum variable capacitors are also available as replacements for air variable capacitors.

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The most common of the fixed-value capacitors is the "disc ceramic." They are disc-shaped and have two wire leads coming from them. Most of these capacitors look like pieces of gum that someone has stepped on. Ceramic is used for the insulating medium. They are small and especially convenient for use on etched-circuit boards. Values as great as 0.1 μF are common, and voltage ratings as high as 1000 or greater are available for the lower-capacitance units.

Another common capacitor is the "mica" type, named for its dielectric material. The plates of the one variety are coated with silver, hence the name "silver mica." These are considered to be high quality components with reasonably good tolerance in terms of the marked values. They are often preferred to disc-ceramic capacitors when values less than, say, 2000 pF are needed in circuits that must be stable (such as in oscillators and filters for radio frequencies). They are not affected by heat as much as some other kinds of low-capacitance units. The effects of heat can be seen in a gradual change in capacitance value. Cold temperatures have a similar effect, but in an opposite direction with respect to net capacitance at a given instant. Some ceramic capacitors are specially manufactured to serve as "compensating" capacitors for various conditions of heat or cold. They are rated with particular "temperature coefficients."

You will use many capacitors that are called "electrolytics." These are designed for high values of capacitance (as are computer-grade and tantalum capacitors), and they have polarity marks on them. Electrolytic capacitors are used in power supplies (for ripple filtering) and in audio circuits as coupling and bypassing units.

Fig. 2 shows a collection of fixed-value capacitors. Variable capacitors appear in Fig. 3. To summarize this section of our lesson, we should remember that the farad (F) is the basic unit of capacitance. The μF is 10^{-6}F; the nanofarad is 10^{-9}F; the picofarad is 10^{-12}F. Learning these relationships will help us to perform pertinent mathematical exercises when we become proficient enough to start designing our own circuits.

Selecting and Using Capacitors

Some of you may have concluded after looking at schematic diagrams in *QST* that following or building a circuit is next to impossible. Not so! You need not fear the use of capacitors or resistors. Many beginners to electronics think they must use the exact item called for in the parts list; this is seldom a requirement. It is important, however, to know which types of capacitors are best for a certain kind of circuit. Table 1 provides a useful generalization concerning capacitors and the kinds of applications they are best suited for.

The value specified is not critical in many circuits. The notable exception is seen when a capacitor is part of a frequency-determining circuit (such as tuned circuits

Table 1
Common Capacitor Types and Applications

Application	*Capacitor Type*	*Frequency Range*
Radio-frequency circuits	Disc ceramic, silver mica, tubular ceramic, polystyrene and air or ceramic variables. Mica trimmers and teflon trimmers are also suitable.	50 kHz through VHF (see text).
UHF and microwave circuits	Ceramic chip capacitors. Glass piston trimmers and some small air-dielectric trimmers. Air disc variables are also used.	150 through 1296 MHz, generally.
Audio and very-low-frequency (VLF) circuits	Tantalum, electrolytic, tubular, Mylar, oil-filled and all of the above.	10 kHz through 500 kHz, generally.
Power supplies and voltage regulators	Tantalum, oil filled, computer grade, electrolytic and tubular paper.	25 Hz through 3 kHz.
Tuned circuits at radio frequencies	Air variables, mica trimmers, ceramic trimmers, glass piston trimmers and tuning diodes.	50 kHz through VHF and higher.

in transmitters and receivers), or when they are used in what is known as a "timing circuit." The voltage rating is *always* important, though. If a specific voltage rating is listed, it's alright to use a unit with a higher voltage rating; but don't install a capacitor that has a lower voltage rating.

In circuits where capacitors are used for bypassing or coupling between stages, we can usually get by with values other than those specified. For example, if a transistor emitter is bypassed to ground with a 10-µF, 6-V capacitor, we can safely use, say, a 15-µF, 25-V unit, if that's all we have on hand. Similarly, if a transmitter circuit calls for a 100-pF ceramic coupling capacitor, we may substitute a 150-pF silver-mica unit without a significant change in performance. Or, if we happen to have only a 68-pF part on hand, we might use it as a substitute.

Depending on how they are constructed, some capacitors have an unwanted characteristic known as "stray inductance." What we are seeking in a capacitor is *pure capacitance*. We do not want the elements of resistance and inductance to be present, for they affect the quality of the capacitor — especially at the higher frequencies. Unfortunately, all capacitors have resistance and inductance associated with them. Some styles are much worse than others; therefore, we should always select the units we use in accordance with Table 1. This will help to minimize the effects of the resistance and inductance that is present.

A component I did not mention earlier is called a "chip capacitor." These specially manufactured small parts have no wire leads to cause unwanted inductance. They are square or rectangular in shape and have silver-plated electrodes. The dielectric is ceramic. You can actually solder a chip capacitor directly to the copper elements of a circuit board. This keeps the connecting leads of the circuit very short. Chip capacitors are used mainly at very-high frequencies (VHF) and above. Conventional fixed-value capacitors will not function as true capacitors in some VHF circuits. The main problem associated with chip capacitors is high cost and limited availability for ham use. As an example of what we are discussing here, a silver-mica capacitor may have a marked value of 56 pF. At 3.5 MHz it will function in accordance with that marking, since stray resistance and inductance will be too small to be significant at that low a frequency. But, at 146 MHz (VHF), it might appear as a 220-pF capacitor because of the combined effects of stray resistance and inductance. To minimize these effects, the leads of all capacitors used in a radio-frequency circuit should be cut as short as possible, still allowing ample lead length for soldering. In audio and power-supply circuits, this is not a requirement.

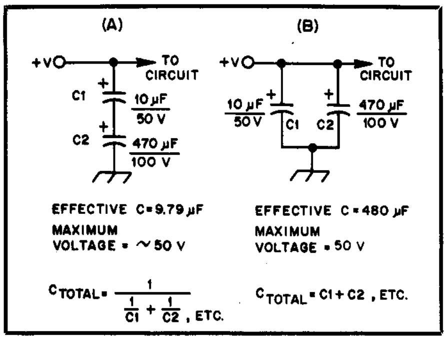

Fig. 4 — Capacitors in series are shown at A. The example at B shows capacitors in a parallel arrangement (see text).

Combinations of Capacitors

When we use capacitors in series or in parallel, we get the opposite effect than is experienced with similar configurations of resistors (Fig. 4). That is, the net value of capacitance for two capacitors hooked in parallel is the capacitance of one plus that of the other. Conversely, when we use them in a series hookup, we end up with slightly less capacitance than the marked value of the smallest one. The voltage rating of parallel-connected capacitors is that of the unit having the *lowest* voltage rating. Series-connected capacitors divide the applied voltage according to the magnitude of their capacitance. The voltage across each capacitor is proportional to the total capacitance divided by that of the individual capacitor. It is best to use capacitors of the same voltage rating to avoid problems. We will often find equalizing resistors connected across the various capacitors in a series combination. This helps to ensure an equal division of operating voltage across each unit.

Capacitors in an Actual Circuit

Fig. 5 shows a typical two-transistor circuit for use as an audio amplifier. Examples of bypass and coupling (blocking) capacitors are given. C1, C2 and C7 are coupling capacitors. Audio energy is able to pass through them, but dc voltage is blocked by the capacitors. This is just like a gate for the audio (ac) voltage, but it

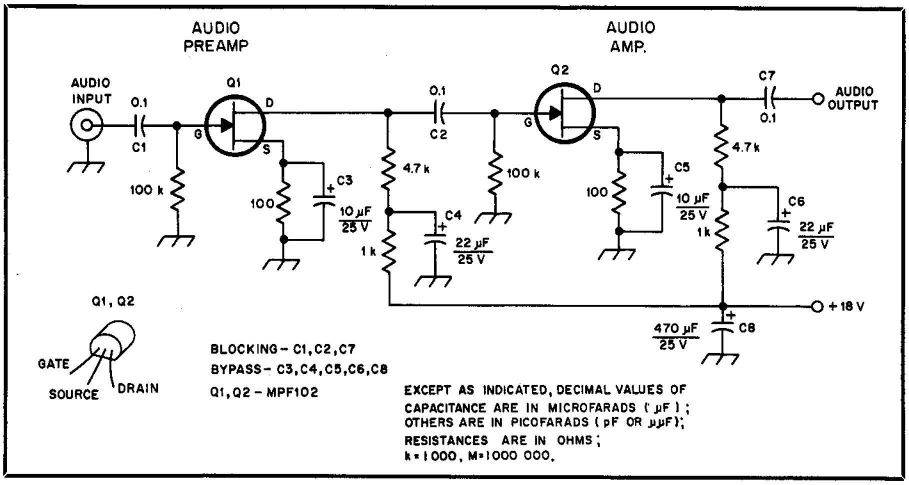

Fig. 5 — Illustration of a simple audio-amplifier circuit that uses coupling and bypass capacitors. Their functions are discussed in the text.

becomes a "brick wall" for the dc voltage. The ac voltage must pass through that branch of the circuit in order for us to have the benefits of audio amplification. But, if dc were permitted to pass through the same branch of our circuit, too much voltage would appear in the wrong places. The transistors could burn out, or amplification would not occur.

C3, C4, C5, C6 and C8, on the other hand, are bypass capacitors. We want the ac voltage to be directed to ground at these points. So, the capacitors permit this to happen while preventing dc voltage from going to ground. In other words, we are bypassing unwanted ac (audio) energy away from the circuit elements to which the capacitors are attached.

You will notice that C3, C4, C5, C6 and C8 have the polarity (+) indicated. Always be sure to hook the + sign to the plus-voltage line. The negative ends of those capacitors must go to ground. Otherwise, they could become hot, or even explode! I have had a few electrolytic and tantalum capacitors blow apart because I hooked them up backward. The sound is not unlike that of a gun going off! *Use caution.*

The polarized capacitors of Fig. 5 can be of the electrolytic, tantalum or computer-grade types with respect to satisfactory performance. The electrolytic units, preferred by most hams, will cost the least.

Still Another Type of Capacitor

A number of semiconductor diodes are available for use as "electronic capacitors." Such a device is shown in Fig. 6, as D1, which is the designator for a diode. In this circuit, the diode functions as a variable capacitor to change the frequency of the tuned circuit that includes L1 and C1. As the operating voltage (dc) is varied at the diode terminal by means of R1, the internal capacitance of the diode changes. R1 would therefore become our panel-mounted tuning control. We could use it with a dial that showed the frequency versus the setting of R1. This type of tuning element has a number of trade names connected with it, such as Varicap® and Epicap®. It is known also as a *varactor* diode. Many FM and TV sets use these diodes for tuning in the stations.

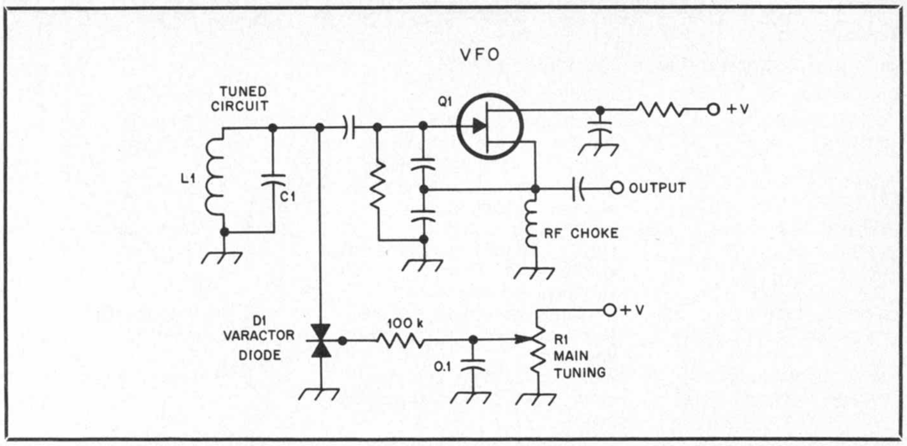

Fig. 6 — D1 in this circuit is an electronic capacitor. It is a semiconductor diode with two anodes and one cathode. You may learn how it works by reading the text.

Glossary

dielectric — an insulating medium. A nonconductor of direct current. Air, mica and ceramic are examples of dielectric materials.

electrode — a conductor that is used to establish an electrical connection to a nonmetallic part of a circuit. The plate cap on a vacuum tube is one example. A battery terminal is another.

electrolytic — an action caused by electrolysis. *Electrolyte* is the medium needed to make a device electrolytic. It is a nonmetallic conductor in which current is carried by the movement of ions. Such ionic conductors are found in wet batteries and electrolytic capacitors.

filtering — the electrical process of removing unwanted signals, ac frequencies or dc from incoming energy. Filters are used in receivers to permit the passage of desired signals while restricting the passage of unwanted, interfering signals. They are used also in transmitters to ensure purity of the output signal. Filters are used in power supplies to remove the ac ripple energy from the desired dc output voltage.

microfarad — a numerical expression for a portion of the farad, which is the basic unit of capacitance. Microfarad, expressed also as μF, is 0.000,001 farad, or 10^{-6} farad. For example, a 100-μF capacitor is 0.0001 farad.

padder — a variable capacitor, generally of small physical size and relatively low capacitance range, adjusted by means of a screwdriver or other small tool. Normally used to tune a particular circuit to a specific frequency. Sometimes padder capacitors are referred to as *trimmer* capacitors.

picofarad — abbreviated pF, a numerical part of the farad. It is 0.000,000,000,001 farad, or 10^{-12} farad.

stray inductance — unwanted inductance in a circuit. A piece of hookup wire or a printed-circuit board foil will introduce a certain amount of stray inductance. Too much stray inductance can spoil circuit performance. Becomes more pronounced as the operating frequency is raised.

tantalum — a substance used in the manufacture of certain types of capacitors. The size of the tantalum bead determines the capacitance of an individual unit. Tantalum capacitors can be made much smaller than electrolytic units of the same value.

varactor — variable-reactance diode. A semiconductor diode that functions as a voltage-variable capacitor. The capacitance of a varactor depends on applied voltage amplitude and polarity. These devices are used in place of mechanical tuning capacitors in many circuits.

very high frequency — known also as VHF. The band of frequencies that lies between 30 and 300 MHz. The 6- and 2-meter bands are examples of amateur VHF bands.

What Have We Learned?

Although we have only covered the basics of capacitors, we have discovered that they are a "must" in most electronics circuits. They can be used for many purposes, and they come in many shapes, sizes, ratings and types. Their greatest use is for bypassing (filtering) and coupling in radio circuits.

We can summarize additionally by recalling that each capacitor has a particular maximum voltage rating that we must pay close attention to. We need also to observe the polarity marked on some types. Most small capacitors are not polarized, which means we can hook either end to a circuit point.

It is not mandatory that we use the exact capacitor called for in a construction project. For the most part, we can use a value that is reasonably close to the indicated one, and no problems should be experienced. We can also substitute some kinds of capacitors for others when the need arises, consistent with the data in Table 1.

We may obtain specific values of capacitance by using two or more capacitors in series or parallel. This is handy when we do not have a particular value available for a project. A happy amateur is usually one who is an inveterate experimenter. Parts substitution is part of the game. If your circuit calls for a 100-pF variable capacitor, don't be afraid to use a 150-pF unit. It will simply extend the effective tuning range of the circuit. Using more, rather than less, is a good rule of thumb, for too little capacitance in a variable unit will restrict the tuning range. Many hams pull the plates (vanes) from a too-large variable capacitor until the maximum-capacitance value is close to the prescribed one. I've done it many times.