**Reading 12**

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## CAPACITANCE – Part 2

### TYPES OF CAPACITORS

### AIR DIELECTRIC CAPACITORS

Capacitors using air dielectric are used in radio mainly as variable capacitors. It has been seen that capacitance is proportional to the plate area, and inversely proportional to the spacing. Even with close spacing the area of the plate must be large in order to obtain a capacitance large enough for most purposes. Instead of using two large plates, which would be inconvenient, a number of plates are interleaved as shown in figure 1. This variable capacitor is really a number of capacitors in parallel.

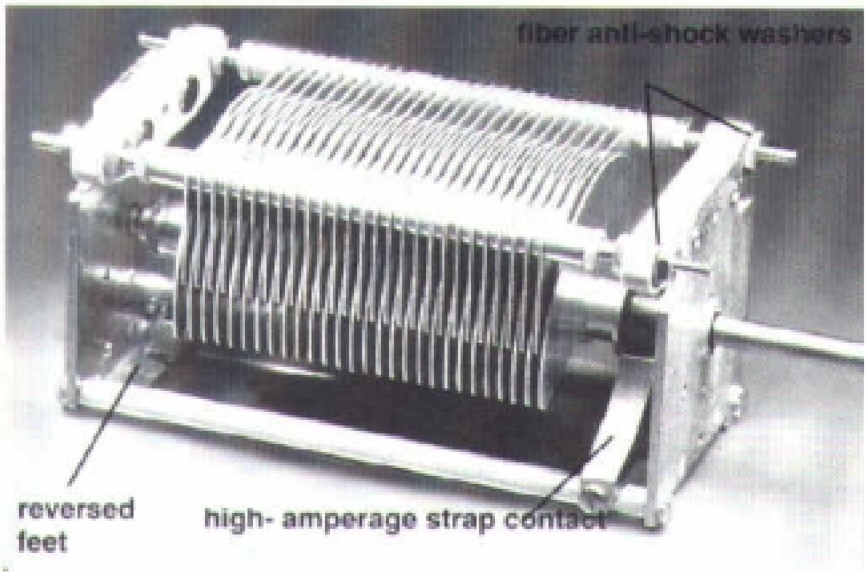


**Figure 1.**

The capacitance can easily be varied by sliding the plates in and out of mesh, since the capacitance is proportional to the cross-section of the dielectric between the plates connected to opposite terminals.

A practical capacitor is constructed with a set of fixed plates and a set of moving plates that rotate on a spindle. As the moving plates are rotated through 180$^{o}$ the meshing, and therefore the capacitance, varies from a minimum to a maximum value. The maximum value of the capacitance is generally about 500pF. It is common practice to use two or three of these capacitors ganged together on a common spindle to form the main tuning control of a receiver.

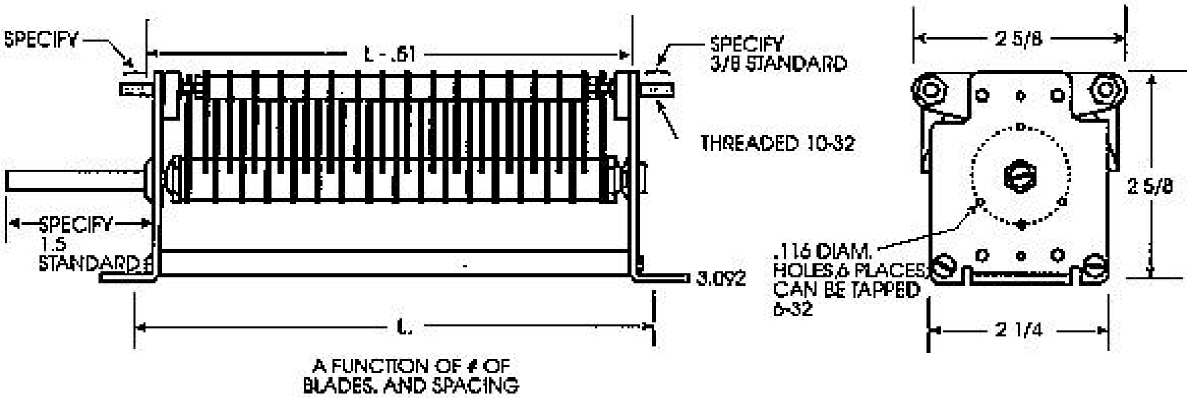


**Figure 2.**

Over the years the physical size of variable capacitors has decreased greatly due to the use of smaller spacing between the moving and fixed plates. However, with the introduction of small communication receivers and transmitters even these capacitors are too large and so solid dielectric variable capacitors have been introduced. In these capacitors, a solid dielectric in the form of thin plastic sheets is placed between the plates. In this way the capacitance is increased approximately by the value of the relative permittivity of the dielectric. The sheets are a fairly loose fit between the plates so that the moving plates can still slide over the plastic sheets (which are fixed).

In radio transmitters of significant power, air dielectric variable capacitors are the only way to go, as the air dielectric is able to withstand high radio frequency (RF) voltage.

## SILVER MICA CAPACITORS

This capacitor consists of thin mica sheets as the dielectric. The mica sheets are coated with a thin layer of silver, which forms the plates. A number of plates may be stacked together to obtain the required capacitance. The capacitor is protected by a wax, lacquer or plastic coating. These capacitors are available up to 10,000 pF and have a small loss, small tolerance (e.g. ± 1 %), are stable in capacitance value, and have a low temperature coefficient. They are mainly used where an accurate, highly stable, good quality capacitor is required.

Typical applications of a mica capacitor includes the crystal oscillator and other critical RF circuits.

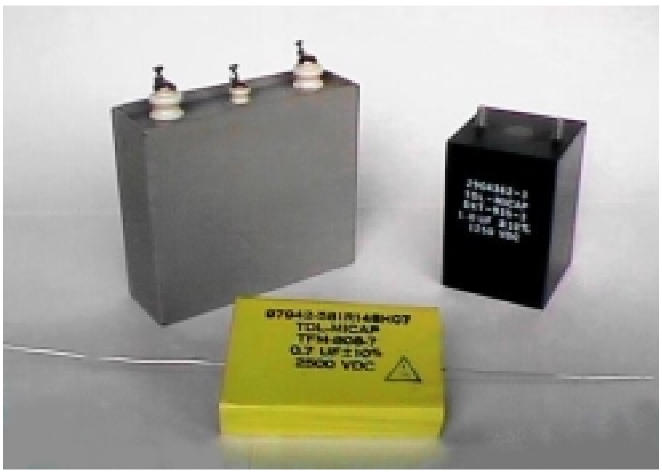

**Figure 3.**

## CERAMIC CAPACITORS

These capacitors use a ceramic for the dielectric and are very widely used as they are physically small and cheap. The term 'ceramic' covers a very large range of materials and the properties of the capacitor depend on the type of ceramic used. The permittivity of some ceramic materials is very high, say 16,000, which results in a physically small capacitor. Capacitors can be made using relatively low permittivity ceramics, which have different temperature coefficients and can be used for temperature compensation. When a high permittivity ceramic is used the temperature coefficient may be very large and not linear, i.e. varies greatly with temperature. These also have a capacitance that changes with the applied voltage, and because of this, the tolerance may be large, as much as -20% to +80%. Obviously, such capacitors must only be used where the capacitance value is not important.

The maximum working voltage may vary from, say, 100V to 10kV or more.

Ceramic capacitors are widely used owing to their small size, low cost, and because so many types are available.

## PAPER CAPACITORS

At one time paper capacitors were very common. They consisted of a metal foil for the electrodes and paper (impregnated with oil or wax) for the dielectric. Instead of a number of plates, two plates only are used, say 2 to 5 cm wide and of a length corresponding to the capacitance required. The plates and dielectric are now wound in a roll to form a tubular capacitor. Paper capacitors are rarely seen today.

## PLASTIC FILM CAPACITORS

It is constructed similar to a paper capacitor, but with a plastic film instead of paper. There are several types: polystyrene, polycarbonate, polyester, polyethylene terephthalate or polypropylene. The plates may be foil (e.g. with polystyrene) or metallised plastic film. Polystyrene ones do not normally have a case, but the others are usually enclosed in a plastic case that may be cylindrical or rectangular. The various films have different detailed characteristics but will be considered as one class.

## ELECTROLYTIC CAPACITORS

This type is used where a high value is required in a small space. It depends on the principle of depositing, by electrolytic action, an extremely thin insulating film on one plate, the film then acting as the dielectric. Since it is so thin, the capacitance for a given plate area is large. There are two basic types: aluminium and tantalum.

## ALUMINIUM CAPACITORS

These are made in a similar way to a paper capacitor, but use two aluminium plates and an absorbent paper. The paper is impregnated with a suitable electrolyte, which produces an aluminium oxide coating on the positive plate. The paper acts as a conductor and container of the electrolyte, the only dielectric being the oxide coating. The capacitance may be increased by etching the positive plate (the one with the oxide coating), thus increasing the effective area. In normal capacitors, the aluminium coating must be maintained by the application of a direct voltage across the plates in the correct direction, i.e. the capacitor is polarised. If the voltage is reversed the coating will be removed and the capacitor ruined. Working voltages vary from 3 to 500 volts, and it is important that the working voltage is not exceeded as they can explode. The capacitor passes a small leakage current, particularly when first switched on, the current re-forming the oxide layer. This current rises rapidly if the working voltage is exceeded and damage then results. The capacitors are usually fitted into aluminium cases, the case often being one of the connections. These capacitors are commonly used in transistor equipment. Values are available from, say, 1uF to 100,000uF. The tolerance is high, say, -25% to +100%, and the losses are high, particularly at high frequencies, where they should not be used.

There are some special electrolytic capacitors made that are not polarised, in which both plates have oxide coatings. They are used in a few special applications where a large capacitor is required and there is no polarising voltage, e.g. crossover networks in loudspeakers.

## TANTALUM CAPACITORS

The basic principles are the same as aluminium, with tantalum in place of aluminium. They have a better shelf life and lower leakage current, but are more expensive. There are three types: wet electrolyte sintered anode, foil electrode wet electrolyte, and solid electrolyte sintered anode. The last type is the cheapest and the more commonly used in domestic equipment, so no further details will be given of the first two types. The solid type uses a sintered tantalum anode with a solid electrolyte of manganese dioxide. It comes in various forms, in particular tubular and "tear drop" types. Capacitance values vary from 0.1 to at least 100uF with working voltages up to 50V.

## CHARGE AND DISCHARGE OF A CAPACITOR

If a capacitor C is connected to a DC supply through a resistor R, as shown in figure 4, a current will flow through R until the capacitor is charged to the voltage V. As the capacitor charges, the voltage across it will rise to 63.3 percent of its final value, E, in a time equal to C x R seconds (where C is in farads and R is in ohms). This time is known as the time constant of the circuit. The voltage across R is the difference between the supply voltage and the voltage across the capacitor, and therefore decreases as the capacitor charges. Thus, the current will also decrease, since it obeys Ohm's law regarding the resistor R.

If the supply is now disconnected the capacitor will remain charged, apart from the small leakage in the capacitor itself. It may remain nearly fully charged for hours or even days if it is a high-class capacitor. A large capacitor (say 8MF) charged to a high voltage (say 500 volts) stores considerable energy and it is unwise to touch the terminals or a nasty shock will result. If the resistor is connected across the charged capacitor it will discharge by passing a current through R, the value of the current being determined by Ohm's law. The voltage will decrease as before, decreasing by 63.3 per cent in a time equal to the time constant CR.

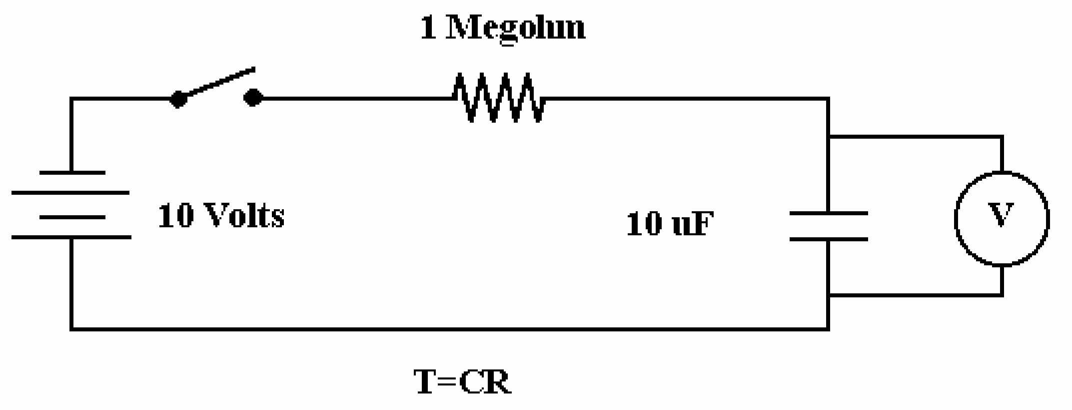


**Figure 4.**

<u>Example</u>. In figure 4, a 1 megohm resistor and a 10uF capacitor are connected in series. What is the time constant of the circuit?

$T=CR = 10 \times 10^{-6} \times 1 \times 10^{6} = 10$ seconds.

When the switch is closed, what will be the voltage on the charging capacitor after 10 seconds?

10 seconds is one time constant period. The capacitor will charge to approximately 63% of the applied voltage after one time constant period has elapsed. Hence, after 10 seconds the voltage on the capacitor will be approximately 63% of 10 volts or 6.3 volts.

I would like to pause here for a moment to emphasise something. Consider a single resistor connected across a battery with a switch, and the switch was closed. How long would it take for the supply voltage to appear across the resistor? Answer - immediately. With a capacitive and resistive circuit, however, the voltage is delayed in building up on the capacitor, determined by the RC time constant. This gives us a better definition of capacitance.

Capacitance is that property of a circuit, which opposes changes of voltage.

Going back to our circuit in figure 4. The capacitor has charged to 6.3 volts after one time constant period. How much further does if have to charge before it equals the supply voltage? The answer is: 10 - 6.3 = 3.7 volts.

During the next time constant period (10 seconds) the capacitor will charge a further 63% of the remaining voltage. That is, 63% of 3.7 volts, which is 2.331 volts. So after 20 seconds the capacitor will have charged to 6.3 + 2.331 = 8.631 volts.

In other words, the capacitor charges to 6.3 volts in one time constant period (10 Sec), and it charges a further 2.331 volts in the second time constant period. So, after 20 seconds the total voltage on the capacitor will be 8.631 volts. During the third time constant period the capacitor will again charge a further 63% of the *remaining* voltage, and so on. A capacitor can be considered to be fully charged after 5 time constants.

There is additional material on time constants in the supplementary downloads section should you wish to go a little further.

## THE CONCEPT OF LEADING CURRENT

If we had a resistor, a switch, and a battery in a series circuit, and we operated the switch, how long would it take for the voltage across, and the current through the resistor, to reach the values determined by Ohm's law? The answer is of course immediately.

However, in a resistive and capacitive circuit we have learnt about 'time constant' and the fact that a capacitor takes time to charge.

When we first throw the switch in our capacitive circuit (figure 4), the current into the capacitor is at first maximum, and the capacitor charges most during the first time constant. The instant we throw the switch the voltage on the capacitor is 0 V and rises to 63% of the applied voltage in one time constant.

Now let's get this clear. When we throw the switch, the current into the capacitor is at its maximum and the voltage is at a minimum. This is in high contrast to a resistive circuit.

The current starts off at a maximum and decreases as the capacitor charges, and the voltage on the capacitor is zero to begin with and rises to a maximum (the supply voltage) when it is fully charged.

So current and voltage in a capacitive circuit are not in sync. Current is said to lead the voltage in a capacitive circuit.

Current leads (voltage) in a capacitive circuit.

## STRAY CAPACITANCE

When we build a capacitor we want capacitance. However, all we need for capacitance is any two conductors separated by an insulator (dielectric). In any circuit there are literally hundreds of stray unwanted capacitances. Most often these are not a problem, however, sometimes they can be. We will discuss this in more detail later.

Many years ago I was teaching PMG (telephone) linesmen about fixing telephone lines. A typical telephone line is just two insulated conductors twisted together and they can go for many kilometres.

A telephone line then by its very construction is a capacitor. Suppose a telephone line is only a kilometre long. Also, that nothing is connected to the telephone line - no telephone and no exchange equipment. The line is said to be open circuit. When a linesman connects an ohmmeter to the line, they expect to see infinite resistance. This is exactly what an ohmmeter does read on a good telephone line, but not immediately. The ohmmeter will swing across and to the right and slowly fall back to infinite ohms after a few seconds. It was difficult for me to explain why this happened (to linesmen anyway).

An ohmmeter is basically a battery, resistor and a current meter connected in series. When the ohmmeter is attached to the line, the line acting like a capacitance charges, and after five time constants it is fully charged and the current meter reads zero.

Linesmen, usually without understanding the mechanism involved, use this method to get a rough idea of how long the telephone pair is.

End of Reading 12.
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