

Schematic Symbols



Capacitor



Polarized DC Capacitor
Plus sign indicates proper connection polarity



Adjustable Capacitor
Tuning and trimming very small values only



Oil-filled AC Capacitor
17.5 mfd @ 280 volts



Non-polarized Mica
0.1 mfd @ 100 volts



Polarized Electrolytic
Note lead polarity mark
470 mfd @ 50 VDC



Adjustable Capacitor
10 - 30 picofarads

Capacitor Characteristics

- A capacitor consists of two plates separated by an insulating medium known as a dielectric. (A dielectric is similar to an insulator but is more electrically “flexible”. All dielectrics are insulators, but not all insulators make good dielectric material.)
- A capacitor is a device which stores an electrostatic charge.

CAUTION: All power capacitors must be fully discharged before working on the equipment!

- Capacitors are rated in Farads - named after the scientist Michael Faraday. By definition: a one (1) Farad capacitor will store a one (1) Coulomb charge when connected across a one (1) Volt potential. The farad is a very large quantity, so capacitors are rated in picofarads (10^{-12} farads), nanofarads (10^{-9} farads), or microfarads (10^{-6} farads). The abbreviations pf for picofarads, nf for nanofarads, and mf or mfd for microfarads, are commonly used.
- Electrolytic capacitors can be applied to DC circuits only and must be connected in the circuit with the correct polarity in order for the dielectric material to properly form. The capacitor case will indicate the required lead polarity. With a electrolytic capacitor it is possible to manufacture capacitors of large microfarad ratings (up to several thousand microfarads) in a relatively small case.

CAUTION: Improperly connected electrolytic capacitors may explode!

- Capacitors used on AC systems must be of the non-polarized type.
- All capacitors have a “working voltage” voltage which cannot be exceeded.
- In an electrical circuit a capacitor opposes a change in voltage.
- In an electrical circuit a capacitor will block Direct Current (DC) and will pass Alternating Current (AC).
- Many electrical components, other than capacitors, exhibit a certain amount of capacitance. For example: high voltage cable which has an inner conductor and an outer shield can act as a capacitor and will store a considerable charge. (The cable conductor acts as one capacitor plate, the shield becomes the second capacitor plate, and the cable insulation constitutes the capacitor dielectric.)

CAUTION: All cables, motor windings, and other components which can exhibit capacitance must be discharged before working on the components or associated circuitry!

Capacitors Factors Determining Capacitance

The formula for determining the capacitance of a capacitor is given below left. A table of some typical capacitor dielectric materials along with the approximate dielectric constant K is included below right. As the dielectric constant K is in the numerator of the formula, the capacitance C of the capacitor is directly proportional to this value. An increase in the value of K will result in an increase in capacitance.

Capacitance Parallel Plate Capacitor

$$C = 0.224 \frac{K S (N - 1)}{d}$$

Where

C = Capacitance in picofarads

K = Dielectric Constant

S = Area of one plate in square inches

N = Number of plates

d = Distance between plates in inches

Dielectric Constants	
Kind of Dielectric	Approx K Value
Air (at atmospheric Pressure)	1.0
Bakelite	5.0
Cambric	4.0
Fiber	5.0
Glass	8.0
Mica	6.0
Paraffin Coated Paper	3.5
Porcelain	6.0
Pyrex	4.5
Quartz	5.0
Rubber	3.0
Wood	5.0
These values are approximate since true values depend on grade of material used , moisture content, temperature, and frequency characteristics.	

The distance d between the plates is in the denominator of the capacitance formula, so the capacitance C will be inversely proportional to this value. The adjustable trimmer capacitor pictured below left has a mica dielectric material and the capacitance is varied by adjusting the screws which change the distance d between the plates. Tightening the screws brings the plates closer together, causing the capacitance to increase; loosening the screws allows the plates to separate, resulting in a decrease in capacitance. A non-metallic tuning wand must be used to prevent affecting the adjustment.



Trimmer Capacitor



Tuning Capacitor

The capacitance of a capacitor is directly proportional to the effective area S of the plates. The tuning capacitor pictured above right utilizes this formula parameter for achieving a change in capacitance. As the shaft is rotated, a change in the plate mesh between the rotor and stator plates will result in a change in the plate area.

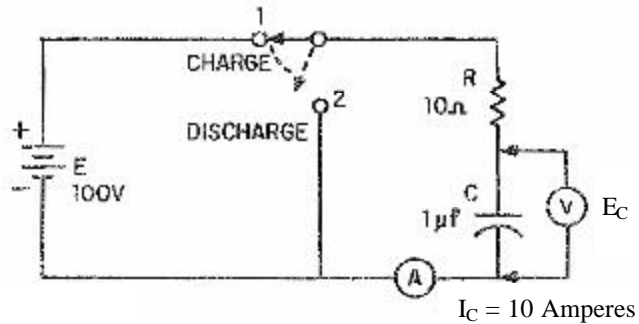
The length of time it takes for a capacitor to charge to 63.2% of the supply voltage is the **RC Time Constant**. (The 63.2% figure is used because the charging curve, as shown below, is logarithmic and it is difficult to tell exactly when the capacitor is fully charged - the 63.2% value can be more readily determined.) The Time Constant Formula is: **$T = RC$**
 Where: T = the time in seconds to reach 63.2% charged, R = the resistance in Ohms, and C = the capacitance in farads.
 For electronic work, a more usable set of values (making a decimal point change) is: T = time in milliseconds, R = resistance in k ohms, and C=capacitance in microfarads. It takes approximately five (5) time constants for a capacitor to become fully charged.

RC Charge and Discharge Circuit

The circuit at the right can be used to illustrate the RC Time Constant.

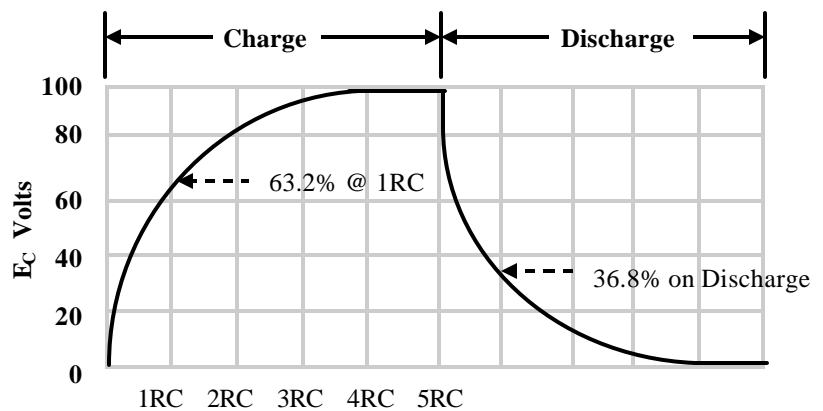
When the switch is moved to the *Charge* position, the capacitor C begins to charge through the resistor R. The larger the ohmic value of R, the longer it will take the capacitor to charge.

With the capacitor fully charged ($E_C = 10$ Volts), when the switch is moved to the *Discharge* position the capacitor will discharge through R.



Voltage Charge / Discharge Curve

As shown at the right, a capacitor **opposes** a change in voltage. When the switch is closed current begins to flow immediately to the capacitor, but the voltage across the capacitor builds at a logarithmic rate and the length of time for the capacitor to charge is determined by the rating of the capacitor and the size of the series resistor in accordance with the formula $T=RC$.



Circuit Applications

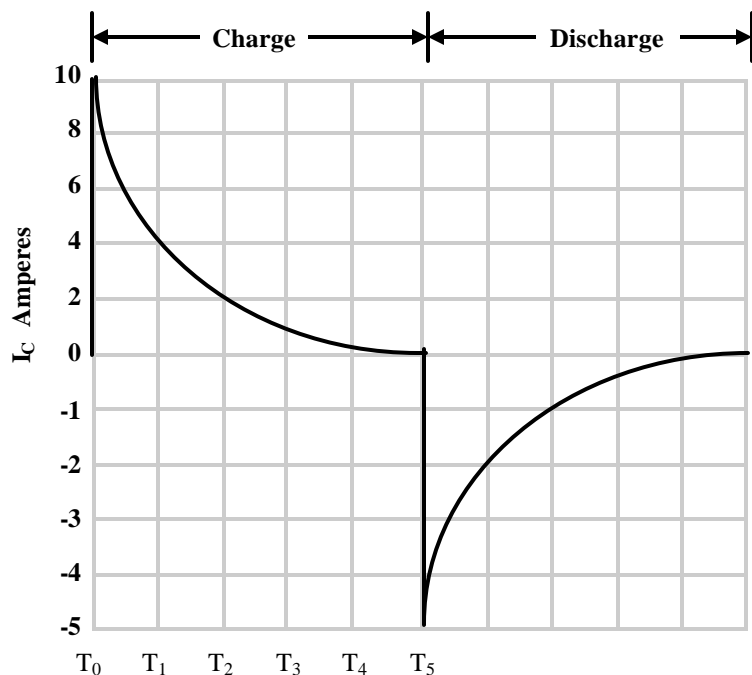
RC Time Constant Circuits have many applications. Analog time delay relays, for example, rely on this principle. The relay time delay is set by an adjustable resistor which is in series with the timing capacitor. When the firing voltage of a transistor or SCR is reached, an output relay is energized.

Free-running oscillators based on this principle generate a characteristic "sawtooth" waveform.

Capacitor Charge / Discharge Current

The graph at the right shows the immediate rise in charging current when the switch is placed in the *Charge* position. The current then decays to zero amps as the capacitor becomes fully charged.

When the switch is moved to the *Discharge* position, the current instantaneously reverses in direction and then decays to zero as the capacitor become fully discharged.



- Capacitive Reactance is the opposition to the flow of current in an electrical circuit due to capacitance and is measured in Ohms.
- The symbol for reactance is **X**; capacitive reactance is represented by **X_C**
- The formula for capacitive reactance is:

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

Where:

X_C = Capacitive reactance in ohms

f = Frequency in hertz

C = Capacitance in farads

2π = 6.28 [Note: the value of pi (π) is 3.1416]

- As illustrated by the formula above, capacitive reactance is inversely proportional to frequency.
- Direct Current (DC) will not flow through a capacitor because the frequency of pure DC (having no ripple or changes in amplitude) is zero hertz, therefore the value of capacitive reactance in ohms is, theoretically, infinite (there is always some small amount of leakage current through the capacitor dielectric). A capacitor is said to “block” direct current. Even though direct current will not flow through a capacitor, the impressed voltage will cause an electrostatic charge to accumulate on the plates and the capacitor will store an electrical charge according to the formula:

$$Q = CE$$

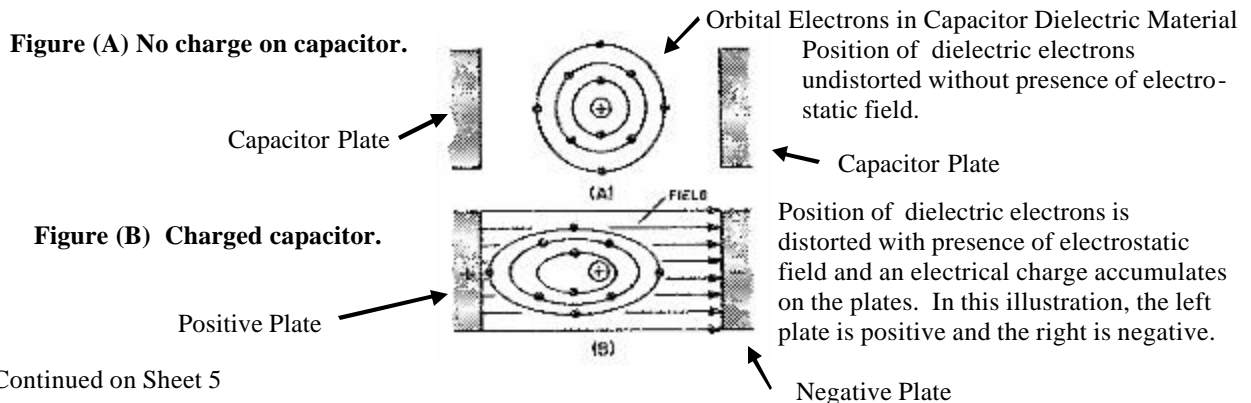
Where:

Q = Quantity stored in coulombs

E = Potential across the capacitor in volts

C = Capacitance in farads

- The drawing below illustrates how an electrostatic charge accumulates on the plates of a capacitor.



Continued on Sheet 5

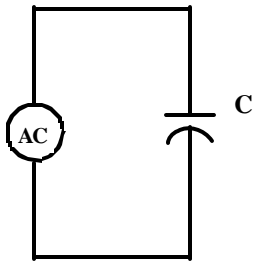
Continued from Sheet 4

In a purely capacitive circuit, the circuit current will lead the applied voltage by 90°. This is a theoretical condition, since any circuit will have some value of resistance or inductive reactance in addition to the capacitance.

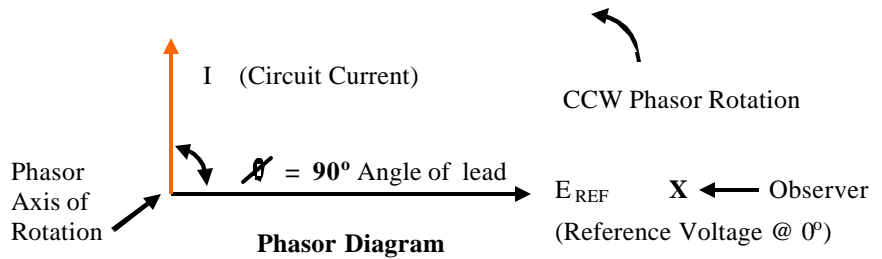
In this circuit the current is all reactive and no work will be done. Single-phase power in watts in an AC circuit is: $P = E \times I \times \cos \theta$ The phase angle in this case is 90°. Since $\cos 90^\circ = 0$, the circuit power therefore equals zero.

Remember:

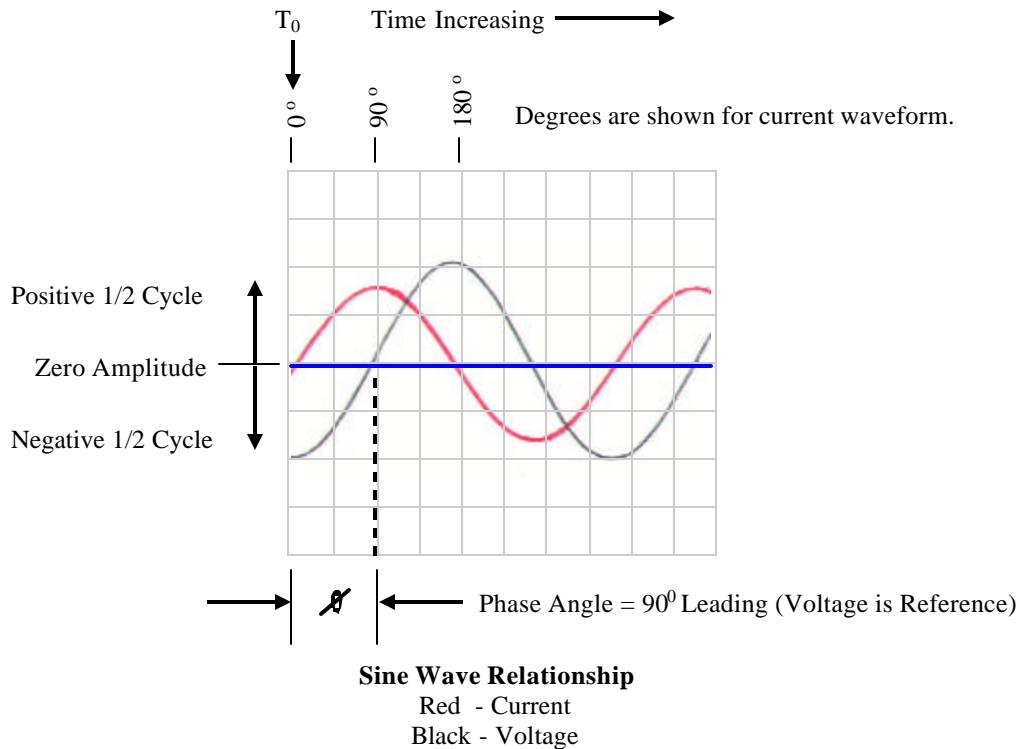
- There are 360 degrees in a sine wave.
- Electrical Phasors rotate counter-clockwise (CCW).
- Phasors (electrical vectors) show two things: (1) magnitude, and (2) direction.
- The symbol Theta θ is used to represent phase angle.



Circuit Diagram



If the observer stands at point X above and watches the phasors rotate CCW, the current phasor will appear first, followed 90° later by the voltage phasor.



In the above drawing, the current crosses zero and goes positive 90° before the voltage crosses zero and goes positive.