Reading 13

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CAPACITIVE REACTANCE

CAPACITOR IN A DC CIRCUIT

We have already discussed the operation of a capacitor in a DC circuit, however let's just go over the main principles again.

If a capacitor is connected to a battery (or other DC source) it will charge according to its time constant (T=CR), to the battery voltage. If a lamp were connected in series with the capacitor while it was charging, the lamp would give off light indicating that current was flowing. The lamp would be bright at first and then slowly dim to nothing as the capacitor charged. Current into the charging capacitor is high at first and then tapers off to zero when it is charged. The voltage on the capacitor is low at first and increases to the supply voltage when the capacitor is charged. We can see that the voltage across, and the current into a capacitor, are not in sync (phase). Current in a capacitive circuit leads the voltage (by 90 degrees).

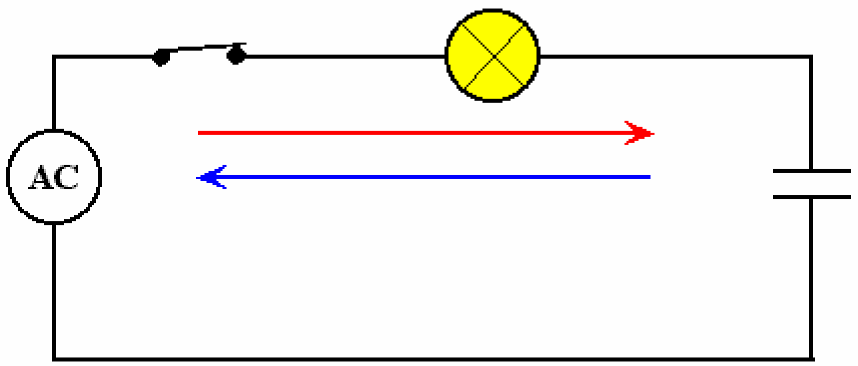
Imagine a capacitor and a lamp in series. Connect the circuit to a DC source and the lamp will light momentarily as described in the last paragraph. The capacitor is now charged and the lamp is out. Suppose now we reverse the battery (or supply terminals). The capacitor will now discharge through the lamp and the battery, and then recharge with the opposite polarity.

Imagine now continuing to do this very quickly, that is, reversing the battery every time the capacitor is charged or near to fully charged. Because the capacitor will be continually charging and discharging, there will be current flow in the circuit all the time, and the lamp will be continuously lit.

Instead of reversing the battery, it would be much easier to supply the circuit with AC voltage, which by its definition, automatically changes polarity each half cycle.

CAPACITOR IN AN AC CIRCUIT

Figure 1.



In the circuit of figure 1, a capacitor and a lamp are connected via a switch to a source of AC. The capacitor will continually charge and discharge as the AC supply changes polarity. AC current will flow in the circuit continuously and the lamp will remain lit. The red and blue arrowed lines indicate the charge and discharge currents.

So a capacitor 'appears' to allow an AC current to pass through it. I say 'appears' because while there is current flowing in the circuit all of the time, at no time does current actually flow through the capacitor. Remember it has a dielectric which will not pass current. The current flows continuously in the circuit because the capacitor is constantly charging and discharging.

Capacitance is the property of a circuit that opposes changes of voltage. A capacitor therefore has an opposition to current flow. The opposition to current flow produced by a capacitor is called capacitive reactance and is measured in ohms. The shorthand for capacitive reactance is X_C.

FACTORS DETERMINING X_C

What do you think we could do in the above circuit to increase the brightness of the lamp without changing the lamp or the supply voltage?

Firstly, let's think about the frequency of the AC supply. It helps to go to extremes and imagine a very low frequency supply. As a capacitor charges a voltage builds up on its plates, which opposes the supply voltage. This is why the charge current of the capacitor is at first very high and then tapers of to zero as the capacitor becomes charged.

If the frequency of the AC supply is high enough (polarity reversal is fast enough) then the capacitor will be in the early part of its charge cycle, where the current is greatest, when a polarity reversal take place.

A high frequency will then cause the capacitor to charge and discharge in the early part of its first time constant period, and this will cause a greater current to flow in the circuit for the same supply voltage.

We have deduced that capacitive reactance (X_C) is dependent on the frequency of the AC supply. In fact, we have deduced that the higher the frequency of the AC supply the more current flows and therefore the lower the capacitive reactance.

A larger capacitance would allow higher charge currents to flow. Therefore changing the capacitance to one of a higher value would increase the current and therefore decrease the capacitive reactance.

So the two factors determining capacitive reactance are frequency and capacitance.

EQUATION FOR CAPACITIVE REACTANCE

$X_C = 1 / 2\pi fc$

Where:

X_C = capacitive reactance in ohms.
2π = a numeric constant.
f = frequency in hertz.
c = capacitance in farads.

Look at the equation. $2\pi fc$ is in the denominator. 2π is a constant (it does not change).

We can say then, that capacitive reactance is inversely proportional to both frequency and capacitance.

In other words, if either capacitance or frequency were to double then capacitive reactance would halve. If capacitance or frequency were to halve then the capacitive reactance would double, and so on.

EXAMPLE CALCULATION.

A capacitor of 0.05uF is connected to a 10 volt AC supply that has a frequency of 500 kHz. What is the capacitive reactance in ohms and how much current will flow in the circuit?

$$X_C = 1 / 2\pi fc$$
$$X_C = 1 / (6.2831 \times 500 \times 10^{3} \times 0.05 \times 10^{-6})$$
$$X_C = 6.366 \text{ ohms}$$

The current is found from Ohm's law by substituting X_C for R in the equation.

$$I = E / X_C = 10 / 6.366 = 1.57 \text{ Amps}$$

If you are given the capacitive reactances in a circuit and you need to find the net total capacitive reactance, use the same rule for finding the total resistance of a circuit. For example, two capacitive reactances of 100 ohms in series are equal to 200 ohms, and in parallel the same combination would be 50 ohms.

To reinforce what we have learnt have a look at the circuit of figure 2.

We could deduce the voltage across the 1uF and 2uF capacitors using the proportion method. Instead, let's work out how much current is flowing in the circuit, then using Ohm's law work out the voltage across each of the capacitors.

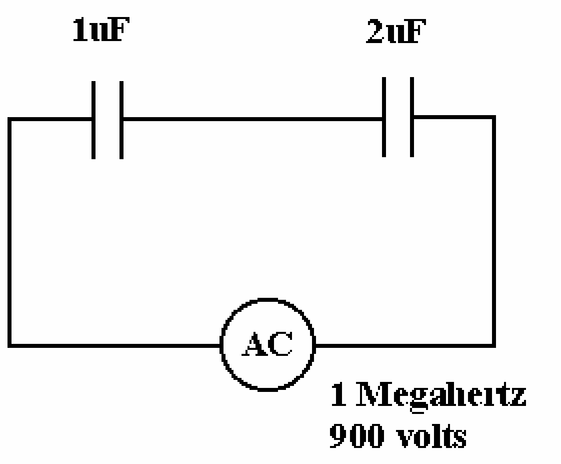


Figure 2.

Reactance of the 1uF capacitor:

$$X_{C1} = 1 / 2\pi fc$$
$$X_{C1} = 1 / (6.2831 \times 1 \times 10^{6} \times 1 \times 10^{-6})$$
$$X_{C1} = 0.159154943 \text{ ohms}$$

Reactance of the 2 uF capacitor (it should be half as much because the capacitance is double):

$$X_{C2} = 1 / 2\pi fc$$
$$X_{C2} = 1 / (6.2831 \times 1 \times 10^{6} \times 2 \times 10^{-6})$$
$$X_{C2} = 0.079577471 \text{ ohms}$$

The total capacitive reactance is the sum of the reactances:

$$X_C(\text{total}) = X_{C1} + X_{C2} = 0.159154943 + 0.079577471 \text{ ohms}$$
$$X_C(\text{total}) = 0.238732414 \text{ ohms}$$

The current flowing in the circuit is:

$$I = E / X_C(\text{total}) = 900 / 0.238732414 = 3769.911194 \text{ amps}$$

The voltage across the 1uF (it should be 600 volts):

$$E = IX_{C1} = 3769.911194 \times 0.159154943 = 599.9998392 \text{ volts}$$

The voltage across the 2uF (it should be 300 volts):

$$E = IX_{C2} = 3769.911194 \times 0.079577471 = 299.9999987 \text{ volts}$$

A GRAPH OF X_C VERSUS FREQUENCY

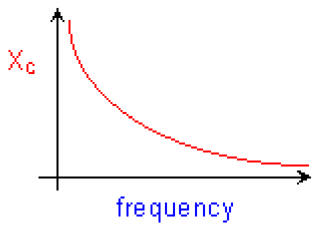


Figure 3.

As you can see from the graph in figure 3, as frequency increases capacitive reactance decreases.

A GRAPH OF X_C VERSUS CAPACITANCE

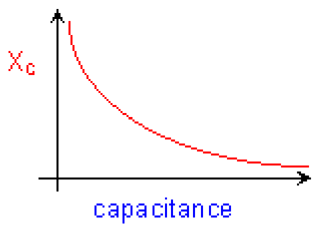


Figure 4.

Similarly, figure 4 shows that as capacitance increases X_C decreases.

POWER IN A CAPACITIVE CIRCUIT

Capacitance does not dissipate power. The only circuit property that can dissipate power is resistance.

All of the power taken from a purely capacitive circuit during the charge cycle is returned during the discharge cycle. So a pure capacitance does not dissipate any power. In practice every capacitor has some resistance in its leads and plates, so a small amount of power is dissipated.

In practical capacitors a small amount of power is lost in the dielectric, called dielectric loss. The atoms within the dielectric of a capacitor are placed under stress and do move slightly due to the electric field. Particularly at higher frequencies, the dielectric loss can become significant.

The losses in a real capacitor are due to the small amount of resistance in the leads and the plates – this is called resistive losses. Dielectric loss accounts for the greatest amount of loss and, most other losses, increases with frequency. Dielectric loss is cause by the alternating stress placed on the dielectric's atomic structure. In industry there are many examples of that utilise dielectric heating. Food as a lossy dielectric can be cooked through dielectric heating. Plastics can be welded. Laminated wooden furniture is cured through dielectric heating.

Note: "Real" means – a real world or actual capacitor as a opposed to a pure capacitor which on exists on an engineering drawing.

Revision.

The unit of capacitance is the Farad.

If a charge of 1 Coulomb produces a potential difference of 1 Volt across the plates of a capacitor, then the capacitance is 1 Farad.

Current flows into, and out of, but never through, a capacitor.

The capacitance of a capacitor is directly proportional to the area of the plates and the dielectric constant, and inversely proportional to the distance between the plates.

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

The opposition to current flow in a capacitive circuit is called Capacitive Reactance and is measured in ohms.

Capacitive reactance is inversely proportional to both frequency and capacitance.

A purely capacitive circuit does not dissipate any power.

Current leads the voltage in a capacitive circuit.

Capacitors in parallel are treated like resistors in series.

Capacitors in series are treated like resistor in parallel.

Capacitors are given a voltage rating, which if exceeded, could cause the dielectric to conduct, destroying the capacitor.

End of Reading 13.
Last revision: November 2003

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