CAPACITOR & CAPACITANCE - ELECTRICAL CIRCUITS

Electrical circuits

The electrons within dielectric molecules are influenced by the electric field, causing the molecules to rotate slightly from their equilibrium positions. The air gap is shown for clarity; in a real capacitor, the dielectric is in direct contact with the plates. Capacitors also allow AC current to flow and block DC current.

DC sources

The dielectric between the plates is an insulator and blocks the flow of electrons. A steady current through a capacitor deposits electrons on one plate and removes the same quantity of electrons from the other plate. This process is commonly called 'charging' the capacitor. The current through the capacitor results in the separation of electric charge within the capacitor, which develops an electric field between the plates of the capacitor, equivalently, developing a voltage difference between the plates. This voltage V is directly proportional to the amount of charge separated Q. Since the current I through the capacitor is the rate at which charge Q is forced through the capacitor (dQ/dt), this can be expressed mathematically as:

$I = \frac{dQ}{dt} = C\frac{dV}{dt}$		where
		I is the current flowing in the conventional direction, measured in amperes, dV/dt is the time derivative of voltage,

		measured in volts per second, and *C* is the capacitance in farads.

For circuits with a constant (DC) voltage source and consisting of only resistors and capacitors, the voltage across the capacitor cannot exceed the voltage of the source. Thus, an equilibrium is reached where the voltage across the capacitor is constant and the current through the capacitor is zero. For this reason, it is commonly said that capacitors block DC.

AC sources

The current through a capacitor due to an AC source reverses direction periodically. That is, the alternating current alternately charges the plates: first in one direction and then the other. With the exception of the instant that the current changes direction, the capacitor current is non-zero at all times during a cycle. For this reason, it is commonly said that capacitors "pass" AC. However, at no time do electrons actually cross between the plates, unless the dielectric breaks down. Such a situation would involve physical damage to the capacitor and likely to the circuit involved as well.

Since the voltage across a capacitor is proportional to the integral of the current, as shown above, with sine waves in AC or signal circuits this results in a phase difference of 90 degrees, the current leading the voltage phase angle. It can be shown that the AC voltage across the capacitor is in quadrature with the alternating current through the capacitor. That is, the voltage and current are 'out-of-phase' by a quarter cycle. The amplitude of the voltage depends on the amplitude of the current divided by the product of the frequency of the current with the capacitance, C.

Impedance

The ratio of the phasor voltage across a circuit element to the phasor current through that element is called the impedance *Z*. For a capacitor, the impedance is given by

$$Z_C = \frac{V_C}{I_C} = \frac{-j}{2\pi f C} = -jX_C,$$

where

$X_C = \frac{1}{\omega C}$ is the *capacitive reactance*,

$\omega = 2\pi f$ is the angular frequency,

f is the frequency),

C is the capacitance in farads, and

j is the imaginary unit.

While this relation (between the *frequency domain* voltage and current associated with a capacitor) is always true, the ratio of the *time domain* voltage and current *amplitudes* is equal to X_C only for sinusoidal (AC) circuits in steady state.

See derivation Deriving capacitor impedance.

Hence, capacitive reactance is the negative imaginary component of impedance. The negative sign indicates that the current leads the voltage by 90° for a sinusoidal signal, as opposed to the inductor, where the current lags the voltage by 90°.

The impedance is analogous to the resistance of a resistor. The impedance of a capacitor is inversely proportional to the frequency -- that is, for very high-frequency alternating currents the reactance approaches zero -- so that a capacitor is nearly a short circuit to a very high frequency AC source. Conversely, for very low frequency alternating currents, the reactance increases without bound so that a capacitor is nearly an open circuit to a very low frequency AC source. This frequency dependent behaviour accounts for most uses of the capacitor.

Reactance is so called because the capacitor doesn't dissipate power, but merely stores energy. In electrical circuits, as in mechanics, there are two types of load, resistive and reactive. Resistive loads (analogous to an object sliding on a rough surface) dissipate the energy delivered by the circuit as heat, while reactive loads (analogous to a spring or frictionless moving object) store this energy, ultimately delivering the energy back to the circuit.

Also significant is that the impedance is inversely proportional to the capacitance, unlike resistors and inductors for which impedances are linearly proportional to resistance and inductance respectively. This is why the series and shunt impedance formulae (given below) are the inverse of the resistive case. In series, impedances sum. In parallel, conductances sum.

Laplace equivalent (s-domain)

When using the Laplace transform in circuit analysis, the capacitive impedance is represented in the *s* domain by:

$$Z(s) = \frac{1}{Cs}$$

where C is the capacitance, and s (= σ+jω) is the complex frequency.

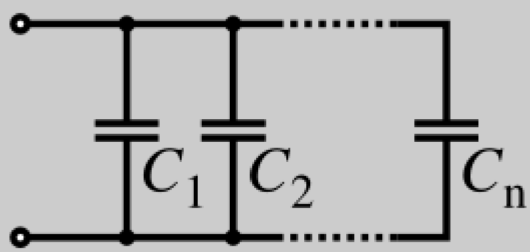
Displacement current

The physicist James Clerk Maxwell invented the concept of displacement current, d**D**/dt, to make Ampère's law consistent with conservation of charge in cases where charge is accumulating as in a capacitor. He interpreted this as a real motion of charges, even in vacuum, where he supposed that it corresponded to motion of dipole charges in the aether. Although this interpretation has been abandoned, Maxwell's correction to Ampère's law remains valid.

Networks

Series or parallel arrangements

Capacitors in a parallel configuration each have the same potential difference (voltage). Their total capacitance (C_{eq}) is given by:



$$C_{eq} = C_1 + C_2 + \cdots + C_n$$

The reason for putting capacitors in parallel is to increase the total amount of charge stored. In other words, increasing the capacitance also increases the amount of energy that can be stored. Its expression is:

$$E_{\mathrm{stored}} = \frac{1}{2}CV^2.$$

The current through capacitors in series stays the same, but the voltage across each capacitor can be different. The sum of the potential differences (voltage) is equal to the total voltage. Their total capacitance is given by:

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}$$

In parallel the effective area of the combined capacitor has increased, increasing the overall capacitance. While in series, the distance between the plates has effectively been increased, reducing the overall capacitance.

In practice capacitors will be placed in series as a means of economically obtaining very high voltage capacitors, for example for smoothing ripples in a high voltage power supply. Three "600 volt maximum" capacitors in series, will increase their overall working voltage to 1800 volts. This is of course offset by the capacitance obtained being only one third of the value of the capacitors used.

This can be countered by connecting 3 of these series set-ups in parallel, resulting in a 3x3 matrix of capacitors with the same overall capacitance as an individual capacitor but operable under three times the voltage. In this application, a large resistor would be connected across each capacitor to ensure that the total voltage is divided equally across each capacitor and also to discharge the capacitors for safety when the equipment is not in use.

Another application is for use of polarized capacitors in alternating current circuits; the capacitors are connected in series, in reverse polarity, so that at any given time one of the capacitors is not conducting...

Capacitor/inductor duality

In mathematical terms, the ideal capacitor can be considered as an inverse of the ideal inductor, because the voltage-current equations of the two devices can be transformed into one another by exchanging the voltage and current terms. Just as two or more inductors can be magnetically coupled to make a transformer, two or more charged conductors can be electrostatically coupled to make a capacitor. The *mutual capacitance* of two conductors is defined as the current that flows in one when the voltage across the other changes by unit voltage in unit time.

Source: http://www.juliantrubin.com/encyclopedia/electronics/capacitor.html