

Part 66 Cat. B1 / B2 Module 3
ELECTRICAL FUNDAMENTALS

Vilnius-2017

If we look at electronic configuration of a carbon C atom, we see only 4 electrons in its outer shell, this leads to carbon being able to form very good bonds with other four outer electron carbon atoms as in diamond. This type of bonding, when atoms are ready both to release or accept electrons when combined in compound with other atoms of the same type (such as C , Si , Ge) each having equal possibilities to complete to noble gas, is called covalent (of equal valency) bonding.

A covalent bond is a form of chemical bonding that is characterized by the sharing of pairs of electrons between atoms. In short, attraction-to-repulsion stability that forms between atoms when they share electrons is known as covalent bonding due to formation of electrons pairs with contrary oriented magnetic moments, from electrons belonging to different atoms (**Fig. 1-5**).

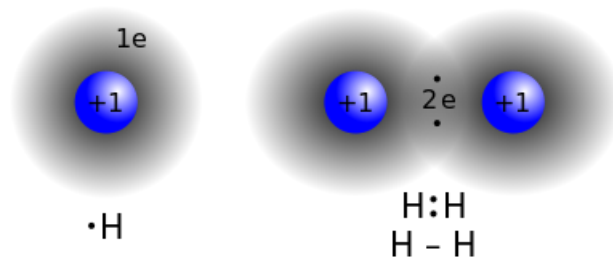


Figure 1-5. Formation of H_2 molecule

As a simple example consider formation of the hydrogen molecule H_2 . Each atom of hydrogen has one electron which could be found with the diminishing probability, relatively to the distance from the nucleus.

Molecular Structure of Conductors, Semiconductors and Insulators

Solid matter is formed by huge amounts of atoms with their electrons interacting with the nucleus they orbit, and each other. The electrons of a single free-standing atom orbit according some probabilities find them in space around nucleus. The probabilities for each pair of atoms in atomic sub-shell differ and form a discrete set of probabilities with electrons of different energy - energy levels. If several atoms are brought together into a molecule, their energy levels interact and aggregate. Such aggregation produces a number of collective levels proportional to the number of atoms. When a large number of atoms (of order 1020 or more) are brought together to form a solid, the number of identical energy levels becomes exceedingly large forming energy zones with gaps in between - bands (**Fig. 1-6**).

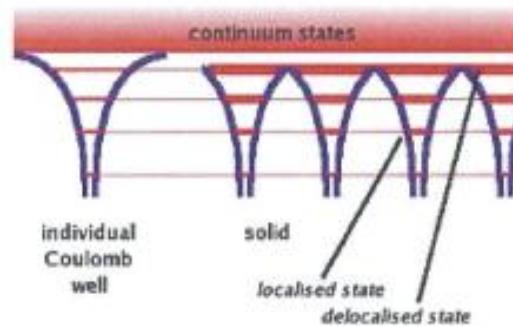


Figure 1-6. Band formation in solids (identical atoms)

Any solid has a large number of bands. In theory, it can be said to have infinitely many bands. However, all but a few lie at energies so high that any electron that reaches those energies escapes from the solid.

These bands are usually disregarded. Bands have different widths, based upon the properties of the Electron sub-shells from which they arise. Also, allowed bands may overlap, producing (for practical purposes) a single large band.

In all the solids (it does not matter if it is a insulator, semiconductor or conducting metal) the uppermost occupied band is called the valence band by analogy to the valence electrons of individual atoms. The lowermost unoccupied band is called the conduction band because only when electrons are excited (due to thermal moution or by another factor) to the conduction band, current can flow in these materials. The space (distance) between the valence band and the conduction band is called restricted or forbidden band, which cannot contain any electrons.

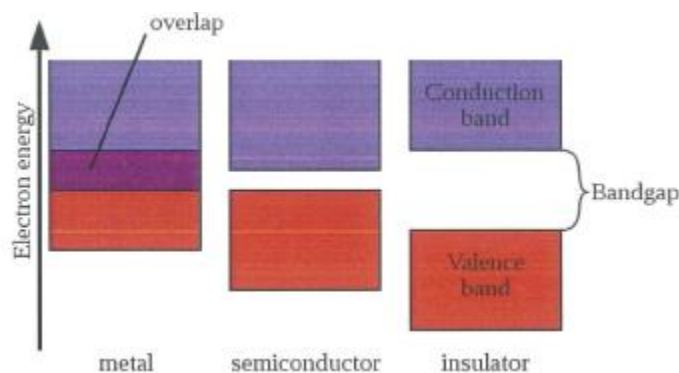


Figure 1-7. Electronic band structure of solids

The difference between insulators and semiconductors is only that the forbidden band gap between the valence band and conduction band is much larger in an insulator (**Fig. 1-7**), so that fewer electrons are found there (in conduction band) and the electrical conductivity is negligible. The restricted band in semiconductors is small enough. Because one of the main mechanisms for electrons to be excited to the conduction band is due to thermal energy, the conductivity of semiconductors is strongly dependent on the temperature of the material.

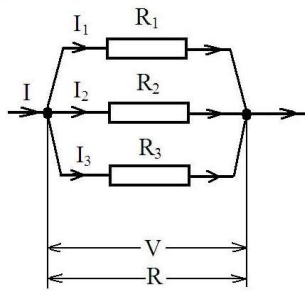


Figure 6-9. Three resistors in parallel

Suppose the combined resistance is R and the total current I is made of three individual currents as

$$I = I_1 + I_2 + I_3 = \frac{V}{R} = \frac{V}{R} + \frac{V}{R_2} + \frac{V}{R_3}$$

This gives us

$$\frac{1}{R} = \frac{1}{R} + \frac{1}{R_2} + \frac{1}{R_3}$$

This formula may be extended for any number of resistors. The case of two resistor is the common:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \quad \rightarrow \quad R = \frac{R_1 R_2}{R_1 + R_2}$$

Now go to the problem with cells connected in series and parallel. It may be easily solved using Ohm's Law. Let's take two circuits with identical elements of 1Ω resistance and $1.5V$ cells with 2Ω internal resistance (**Fig. 6-10**).



Figure 6-10. Serial (A) and parallel (B) connection of equivalent cells

When two cells are connected in series (**Fig. 6-10A**) the current flowing through the cells and the resistance is the same. The total EMF (electrical pressure) of two cells in series must be the sum of their individual pressures and thus is $3V$.

The total resistance of this circuit is

$$R_{TOT} = 2 \times R_{CELL} + R_{RESISTOR} = 2 \times 2 + 1 = 5 (\Omega).$$

According Ohm's Law

$$I = \frac{V_{EMF}}{R} = \frac{3V}{5\Omega} = 0.6A$$

According two branching pipes model when two cells are connected in parallel (**Fig. 6-10B**), they give more electric flow (current) under the same pressure.

Their resistance

$$R = \frac{R_1 R_2}{R_1 + R_2} = \frac{2\Omega \times 2\Omega}{2\Omega + 2\Omega} = 1\Omega.$$

The total resistance $R_{TOT} = 2\Omega$ and the current flowing in the circuit (**Fig. 6-10B**) is:

$$I = \frac{EMF}{R_{TOT}} = \frac{1.5V}{2\Omega} = 0.75(A)$$

So, the largest current is when two cells are connected in parallel (according the pipe analogy).

Kirchhoff's Circuit Laws

Kirchhoff's circuit laws are a pair of laws that deal with the conservation of charge and energy in electrical circuits, and were first described in 1845 by Gustav Kirchhoff. Widely used in electrical engineering, they are also called Kirchhoff's rules or simply Kirchhoff's laws.

Kirchhoff's Current Law (KCL)

The current entering any junction is equal to the current leaving that junction

$$i_1 + i_4 = i_2 + i_3$$

as it is illustrated on **Fig. 6-11**:

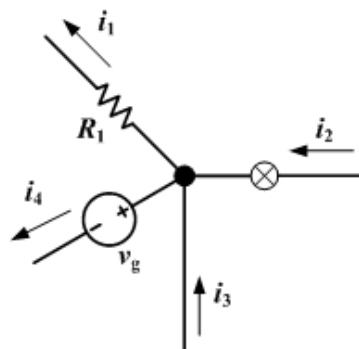


Figure 6-11. Illustration of Kirchhoff's Current law

This law is also called Kirchhoff's 1st law, Kirchhoff's point rule, Kirchhoff's junction rule, and Kirchhoff's 1st rule. It is obvious the rule is just the well-known *principle of conservation of electric charge*:

*At any point in an electrical circuit where charge density is not changing in time,
the sum of currents flowing towards that point is equal to the sum of currents
flowing away from that point*

A charge density changing in time would mean the accumulation of a net positive or negative charge, which typically cannot happen to any significant degree because of the strength of electrostatic forces: the charge buildup would cause repulsive forces to disperse the charges.

However, a charge build up can occur in a capacitor, where the charge is typically spread over wide parallel plates, with a physical break in the circuit that prevents the positive and negative charge accumulations over the two plates from coming together and cancelling. In this case, the sum of the currents flowing into one plate of the capacitor is not zero, but rather is equal to the rate of charge accumulation. In circuit analyses, however, the capacitor as a whole is typically treated as a unit, in which case the ordinary current law holds since the net charge is always zero.

Kirchhoff's Voltage Law (KVL)

The sum of all the voltages around the loop is equal to zero

$$v_1 + v_2 + v_3 + v_4 = 0$$

as it is illustrated on **Fig.6-12**:

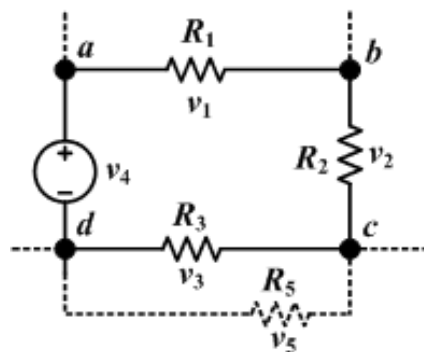


Figure 6-12. Illustration of Kirchhoff's Voltage law

This law is also called Kirchhoff's 2nd law, Kirchhoff's loop rule, and Kirchhoff's second rule. It is a consequence of the *principle of conservation of energy that*:

The directed sum of the electrical potential differences around a circuit must be zero

Otherwise, it would be possible to build a perpetual motion machine that passed a current in a circle around the circuit.

Series Circuits

A series circuit is one in which there is only one path for the current to flow from one terminal of the voltage source to the other. To understand a series DC circuit, we must be able to measure the values of voltage, current, resistance, and power in the circuit.

A simple series circuit made up of two 1.5 V flashlight batteries in series as the power source, and a bulb as the load (**Figure 6-13A**).

Two batteries have 3 volts of electrical pressure. Their use forces 0.46 amp of current flow through the bulb.

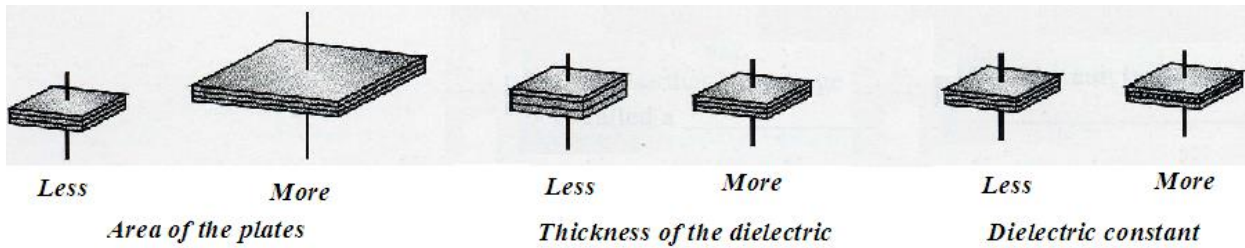


Figure 9-8. The three things affecting the capacity of a capacitor

Types of Capacitors

There are two basic types of capacitors used in electrical circuits: fixed and variable. The fixed one could be divided into non-electrolytic (mica-, paper- and ceramic capacitors) and electrolytic capacitors.

Mica Capacitors

They are made of metal foil plates that are separated by sheets of mica. The assembly is encased in molded plastic. A cut-away view of a mica capacitor is shown on **Fig. 9-9**.

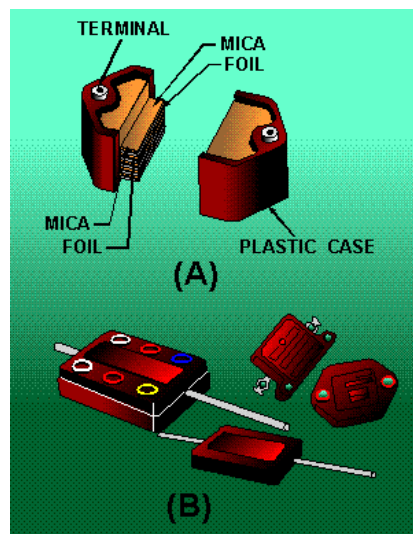


Figure 9-9. A cut-away (A) and common (B) view of a mica capacitor

Because the capacitor parts are molded into a plastic case, corrosion and damage to the plates and dielectric are prevented. In addition, the molded plastic case makes the capacitor mechanically stronger. Various types of terminals are used on mica capacitors to connect them into circuits. These terminals are also molded into the plastic case.

Mica is an excellent dielectric and can withstand a higher voltage than can a paper dielectric of the same thickness. Common values of mica capacitors range from approximately 50 pF to 0.02 μ F.

Paper Capacitors

They are made of flat thin strips of metal foil conductors that are separated by waxed paper (**Fig. 9-10**).

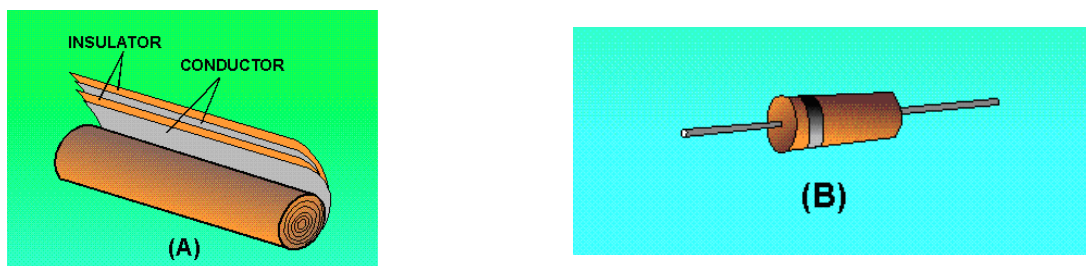


Figure 9-10. Construction (A) and common (B) view of a paper capacitor

Paper capacitors usually range in value from about 300 pF to about 4 μ F. The working voltage of a paper capacitor rarely exceeds 600 V. Paper capacitors are sealed with wax to prevent the harmful effects of moisture and to prevent corrosion and leakage.

Many different kinds of outer covering are used on paper capacitors, the simplest being a tubular cardboard covering. Some types of paper capacitors are encased in very hard plastic. These types are very rugged and can be used over a much wider temperature range than can the tubular cardboard type.

Ceramic Capacitor

It contains a ceramic dielectric. One type of ceramic capacitor (**Fig. 9-11**) uses a hollow ceramic cylinder as both the form on which to construct the capacitor and as the dielectric material. The plates consist of thin films of metal deposited on the ceramic cylinder.

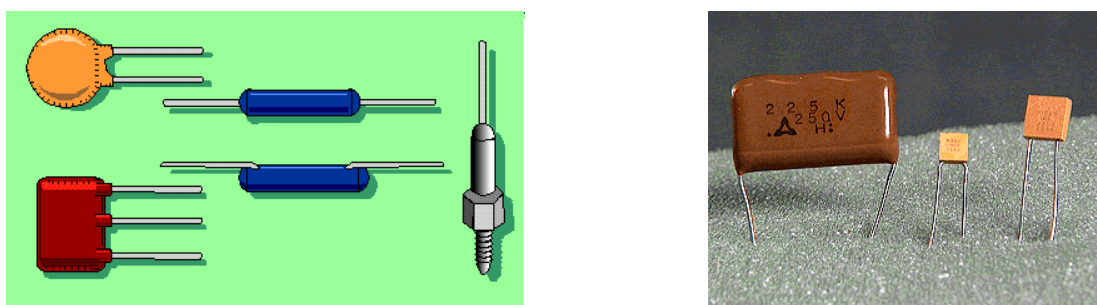


Figure 9-11. Ceramic capacitors

A second type of ceramic capacitor is manufactured in the shape of a disk or a rectangle. After leads are attached to each side of the capacitor, the capacitor is completely covered with an insulating moisture-proof coating. Ceramic capacitors usually range in value from 1 pF to 0.01 μ F and may be used with voltages as high as 30,000 volts.

Variable Capacitor

It is constructed in such manner that its value of capacitance can be varied. A typical variable (adjustable) capacitor is the rotor-stator type. It consists of two sets of metal plates arranged so that the rotor plates move between the stator plates. Air is the dielectric. As the position of the rotor is changed, the capacitance value is likewise changed. This type of capacitor is used for tuning most radio receivers (**Fig. 9-12A**).



Figure 9-12. Variable rotor-stator type (A) and trimmer (B) capacitor

Another type of variable capacitor is trimmer capacitor. It consists of two plates separated by a sheet of mica. A screw adjustment is used to vary the distance between the plates, thereby changing the capacitance.

One popular type of variable capacitor used in aircraft is the fuel tank probe used in capacitor-type fuel quantity indicating systems. Concentric metal tubes are used as the two plates of the capacitor, and the fuel or the air above the fuel is the dielectric. Air has a dielectric constant of one, and the fuel has a constant of approximately two. The capacity of the probe varies as the fuel level and the density of the fuel changes.

Electrolytic Capacitor

It contains an electrolyte and is used where a large amount of capacitance is required. This electrolyte can be in the form of a liquid (wet electrolytic capacitor - no longer in popular use).

A dry electrolytic capacitor (**Fig. 9-13**) consists essentially of two metal plates separated by the electrolyte. In most cases the capacitor is housed in a cylindrical aluminum container which acts as the negative terminal of the capacitor. The positive terminal (or terminals if of the multi-section type) is a lug (or lugs) on the bottom end of the container.



Figure 9-13. Construction (A) and common (B) view of an electrolytic capacitor

voltage; therefore, it is called "counter-electromotive force" (by Lenz's law). With a lower overall voltage across the armature, the current flowing into the motor coils is reduced.

If it is assumed that a motor is 100% efficient with no friction or windage losses, the speed of the armature will increase until the back electromotive force is equal to the applied electromotive force, i.e. there will be no net electromotive force, no current flow and hence, no net force. The armature will spin at a constant rate, of its own accord.

Inductance

Inductance (or electric inductance) is a measure of the amount of magnetic flux produced for a given electric current. The term was coined by Oliver Heaviside in February 1886. The SI unit of inductance is the Henry (symbol: H), in honor of Joseph Henry. The symbol L is used for inductance, possibly in honor of the physicist Heinrich Lenz.

When electrons flow in a conductor, a magnetic field surrounds the conductor (**Fig. 11-5**). When the current flowing in the conductor changes, the magnetic field builds up or collapses. As it does, it cuts across the conductor and induces, or creates, a current in it. This induced current flows in a direction opposite to that of the current which caused it.

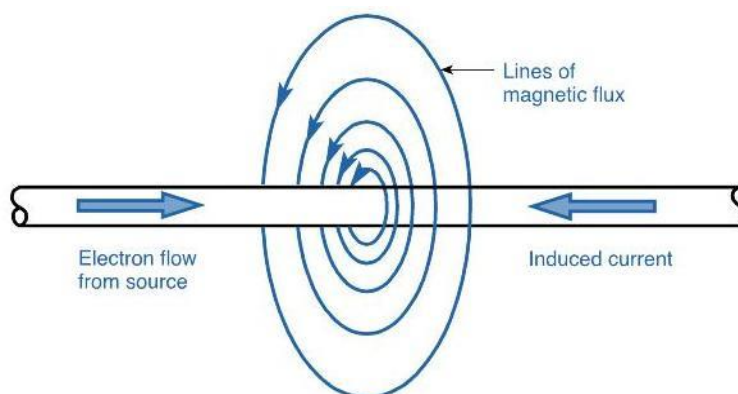


Figure 11-5. Inductance in linear conductor

The inductance (**Fig. 3.11.5**) has the following relationship:

$$L = \frac{\Phi}{I}$$

where

L - the inductance in Henry;

I - the current in amperes and

Φ - is the magnetic flux in Weber.

Strictly speaking, the quantity just defined is called self-inductance, because the magnetic field is created solely by the conductor that carries the current.

As the current produced by magnetic flux Φ , is directed against the electron flow there is an EMF directed in the opposite (counter) direction called counter EMF or CEMF. Counter EMF is a voltage developed in an inductor by a pulsating current.

All electrical circuits possess self-inductance. This opposition (inductance), however, only takes place when there is a change in current (**Fig. 11-6**).

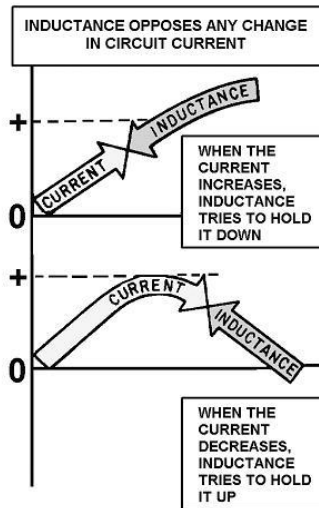


Figure 11-6. Inductance and changes in current

Inductance does *not* oppose current, only a *change* in current. The property of inductance can be increased by forming the conductor into a loop. In a loop, the magnetic lines of force affect more of the conductor at one time (**Fig. 11-7**). This increases the self-induced EMF.

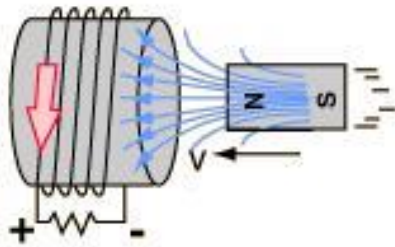


Figure 11-7. Magnetic field acting on solenoid

So when a conductor is coiled upon itself N number of times around the same axis (forming a solenoid), the current required to produce a given amount of flux is reduced according Lenz Law by a factor of N compared to a single turn of wire. Thus, the inductance of a coil of wire of N turns is given by:

$$L = \frac{\lambda}{I} = N \frac{\Phi}{I}$$

where

λ - is the total “flux linkage”.

3.14. RESISTIVE (R), CAPACITIVE (C) AND INDUCTIVE (L) CIRCUITS

In previous sub-modules resistance and resistors, capacitance and capacitors, inductance and inductors were studied along with DC and AC theoretical questions. Now the information will be gathered together and studied with respect to circuits containing resistors (resistive circuits), capacitors (capacitive circuits), inductors (inductive circuits) and circuits where these components are intermixed.

Purely Resistive AC Circuit

Many AC circuits contain resistance only. In those circuits alternating current and voltage change are in phase (**Fig. 14-1**) and in each moment their ratio is constant as in the case of DC current.

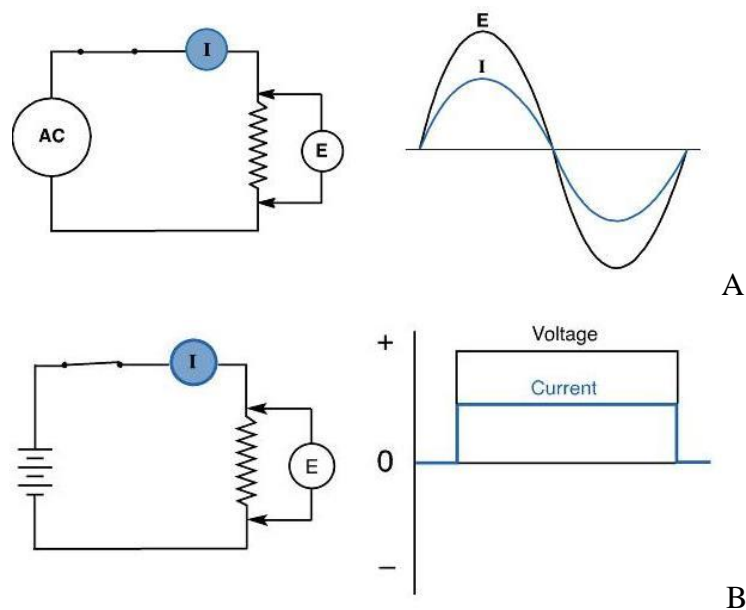


Figure 3.14.1. Similarities in AC (A) and DC (B) resistive circuits

The rules for these circuits are the same rules that apply to DC circuits. Resistors, lamps, and heating elements are examples of resistive elements. When an AC circuit contains only resistance, Ohm's law, Kirchhoff's law, and the various rules that apply to voltage, current, and power in a DC circuit also apply to the AC circuit. The Ohm's law formula for an AC circuit can be stated as:

$$I_{Eff} = \frac{V_{Eff}}{R}$$

All AC voltage and current values are given as effective values. The formula for Ohm's law can also be stated as:

$$I_{Avg} = \frac{V_{Avg}}{R}, I_{Max} = \frac{V_{Max}}{R} \text{ and } I_{Peak-to-peak} = \frac{V_{Peak-to-peak}}{R}$$

The AC values (*Eff*, *rms* or other) couldn't be mixed. If solved for effective values, all values in use must be effective values. Similarly, when solving for average values, all values in use must be average values.

Lets' take a series circuit consists of two resistors ($R_1 = 5\Omega$ and $R_2 = 15\Omega$) and an alternating voltage source of 120 volts. What is I_{Avg} ?

$$R_T = R_1 + R_2 = 20\Omega$$

The alternating voltage is assumed to be an effective value (since it is not specified to be otherwise).

Apply the Ohm's law formula:

$$I_{Eff} = \frac{V_{Eff}}{R} = \frac{120}{20} = 6(A)$$

There is a need for average value of current (I_{Avg}). To convert the I_{Eff} to the I_{Avg} , first the peak or maximum value of current, I_{Max} needs to be determined:

$$I_{Max} = 1.414 \times I_{Eff} = 1.414 \times 6A = 8.484A$$

Now find I_{Avg} . Substitute 8.484 amperes in the I_{Avg} formula:

$$I_{Avg} = 0.636 \times I_{Max} = 0.636 \times 8.484 = 5.4 (A)$$

The Ohm's law formulas could be used to solve any purely resistive AC circuit problem. They are used in the same manner as to solve a DC circuit problem.

When DC flows in a resistance, the amount of electrical power converted into heat:

$$P = I^2R \text{ (Watts)}$$

AC having a maximum value of 1A does not maintain a constant value, the AC will not produce as much heat in the resistance as will a DC of 1 A. Power in a DC circuit and in an AC circuit in which all of the current and voltage are in phase, is the product of the current and the voltage:

$$P = I \times V$$

As further the only one question exists - are the values of V and I the same for DC and AC? As in the case of Ohm's Law AC values for V and I are the effective values:

$$V_{Eff} = 0.707 \times V_{Max} \text{ and } I_{Eff} = 0.707 \times I_{Max}$$

$$P = I_{Eff} \times V_{Eff}$$

Capacitive Reactance in an AC Circuit

A capacitor blocks the flow of DC, but AC flows into and out of it and is not blocked. In an AC circuit, a capacitor drops voltage and shifts the phase of the current, but it does not use power nor produce heat.

In **Fig. 14-2**, the basic relationship between current and voltage in a circuit is presented. It contains a battery, a switch, and a capacitor.

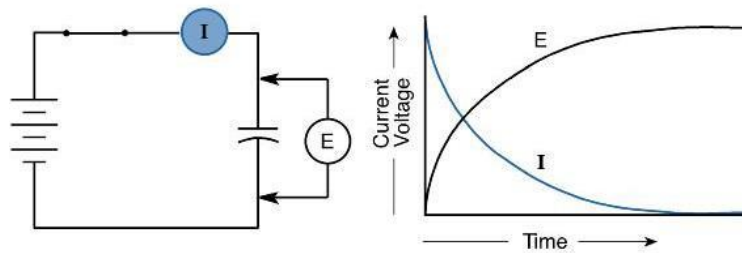


Figure 14-2. Capacitor charging in AC circuit

When the switch is closed, current immediately begins to flow at its maximum rate because the capacitor appears to be a closed circuit between the two terminals of the battery. But as electrons enter the capacitor, they pile up on one of the plates because they cannot get across, and as they pile up, the voltage across the capacitor begins to rise. As the voltage raises, the current drops off, and when the capacitor is fully charged - that is, when the voltage across the capacitor is equal to the source voltage - no more current can flow. The capacitor now acts as an open circuit.

From this example, it is easy to see that current must flow in a capacitive circuit before any voltage appears across the capacitor. In a purely capacitive AC circuit, the current must flow for 90 electrical degrees before the voltage across the capacitor begins to rise.

Alternating current is continually changing its amplitude and periodically reversing its direction of flow. If a capacitor is connected across a source of AC, current must flow into it before any voltage appears across it.

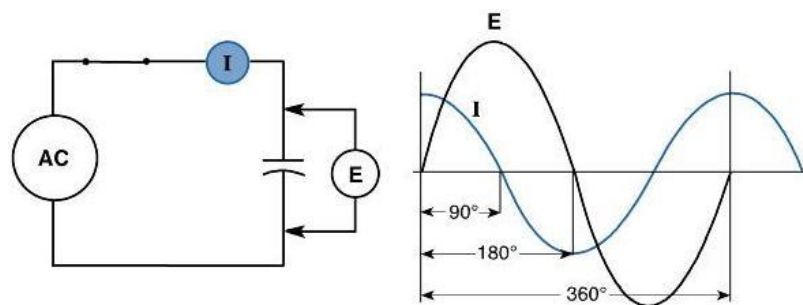


Figure 14-3. Charge flows into capacitor before any voltage appears

Alternating current is continually changing its amplitude and periodically reversing its direction of flow. If a capacitor is connected across a source of AC, current must flow into it before any voltage appears across it. At the 90°-position (**Fig. 14-3**), the capacitor is fully charged. The voltage across it is at a maximum, and the current flow has dropped to zero. The capacitor now begins to discharge and current flows through the circuit in the opposite direction. As the current flow increases, the voltage drops off until at 180°, the current is maximum, and the voltage across the capacitor is zero. The current in a purely capacitive circuit leads the voltage by 90°.

A capacitor and an inductor, in parallel, form what is called a *tank circuit*. This type of circuit is used as the frequency controlling portion of some oscillators.

L-C Filters as LC-circuit Components

One of the more important uses for inductors and capacitors in electrical circuits is that of electronic filters. These circuits control the flow of current in the load as a function of the frequency of the alternating current.

Each family can be used to specify a particular pass band in which frequencies are transmitted, while frequencies in the stop band (i.e. outside the pass band) are more or less attenuated:

- Low-pass filter - low frequencies are passed, high frequencies are attenuated.
- High-pass filter - high frequencies are passed, low frequencies are attenuated.
- Band-pass filter - only frequencies in a frequency band are passed.
- Band-stop filter - only frequencies in a frequency band are attenuated.
- All-pass filter - all frequencies are passed, but the phase of the output is modified.

Low-pass Filter

A low-pass filter is a filter that passes low frequencies but attenuates (or reduces) frequencies higher than the cutoff frequency. The actual amount of attenuation for each frequency varies from filter to filter. It is sometimes called a high-cut filter, or treble cut filter when used in audio applications.

Electronic low-pass filters are used to drive subwoofers and other types of loudspeakers, to block high pitches that they can't efficiently broadcast.

A simple circuit that will serve as a low-pass filter consists of a resistor in series with a load, and a capacitor in parallel with the load (**Fig. 16-6**). The capacitor exhibits reactance, and blocks low-frequency signals, causing them to go through the load instead.

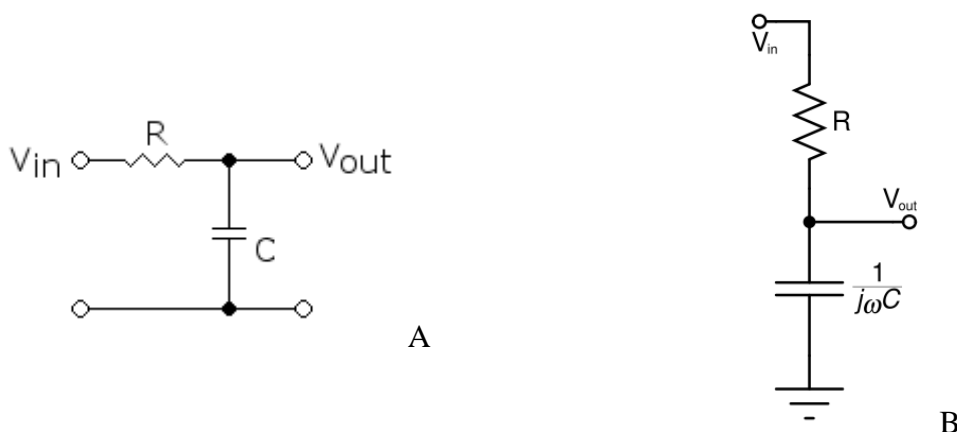


Figure 16-6. An equivalent schemes of low-pass filter

At higher frequencies the reactance drops, and the capacitor effectively functions as a short circuit. The combination of resistance and capacitance gives the time constant of the filter $\tau = RC$.

One way to understand this circuit is to focus on the time the capacitor takes to charge. It takes time to charge or discharge the capacitor through that resistor (**Fig. 16-7**):

- At low frequencies, there is plenty of time for the capacitor to charge up to practically the same voltage as the input voltage;
- At high frequencies, the capacitor only has time to charge up a small amount before the input switches direction. The output goes up and down only a small fraction of the amount the input goes up and down. At double the frequency, there's only time for it to charge up half the amount.

At low frequencies the attenuation approaches zero and at high frequencies V_{Out} diminishes in exponential way (**Fig. 16-7**).

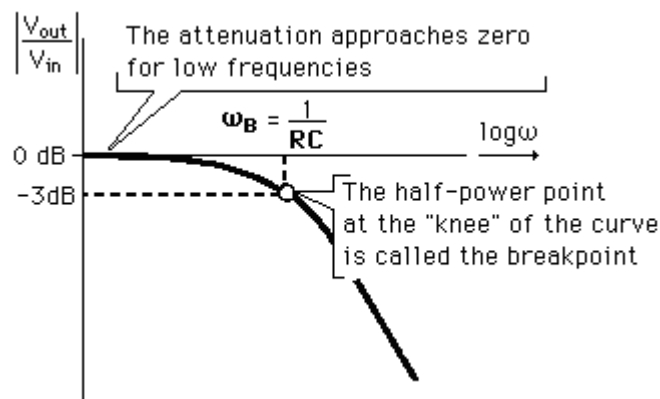


Figure 16-7. Attenuation in low-pass filter

Another way to understand this circuit is with the idea of reactance at a particular frequency:

- Since DC cannot flow through the capacitor, DC input must "flow out" the path marked V_{Out} (analogous to removing the capacitor);
- Since AC flows very well through the capacitor - almost as well as it flows through solid wire – in this case AC input "flows out" through the capacitor, effectively short circuiting to ground (analogous to replacing the capacitor with just a wire).

It should be noted that the capacitor is not an "on/off" object (like the block or pass fluid). The capacitor will variably act between these two extremes.

Synchronous Motors

The construction of the synchronous motors is essentially the same as the construction of the salient-pole alternator. In fact, such an alternator may be run as an AC motor (**Fig. 18-8**).

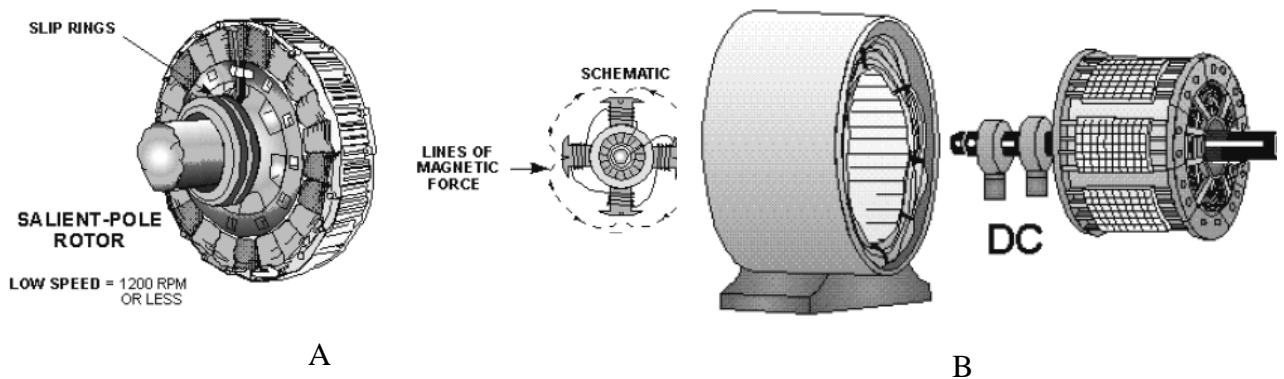


Figure 18-8. Salient-pole alternator (A) and (B) revolving field synchronous motor

Synchronous motors have the characteristic of constant speed between no load and full load. They are capable of correcting the low power factor of an inductive load when they are operated under certain conditions. They are often used to drive DC generators. Synchronous motors are designed in sizes up to thousands of horsepower. They may be designed as either single-phase or multiphase machines.

The rotor of synchronous motor will follow the stator field, because the attraction between the rotor and stator fields exist. A shaft would rotate at the same speed as the rotating field. This speed is known as synchronous speed which is constant or zero. It depends on the current frequency and pole number on the stator.

For synchronous motor connected to 3-phase 60 Hz AC the speed in rpm:

$$n_s = \frac{60f}{p}$$

where:

f - the supply frequency in Hz and

p - the number of poles.

The number of poles is determined of motor design and does not influence the rotational speed of particular motor. It is clear that the rotational speed of synchronous motors could be managed by changing the frequency of applied AC.

The application of three-phase AC power to the stator causes a rotating magnetic field to be set up around the rotor. The rotor is energized with DC (it acts like a bar magnet). The strong rotating magnetic field attracts the strong rotor field activated by the DC. This results in a strong turning force on the rotor shaft. The rotor is therefore able to turn a load as it rotates in step with the rotating magnetic field.

It works this way once it's started. However, one of the disadvantages of a synchronous motor is that it cannot be started from a standstill by applying three-phase AC power to the stator. When AC is applied to the stator, a high-speed rotating magnetic field appears immediately. This rotating field rushes past the rotor poles so quickly that the rotor does not have a chance to get started.

In effect, the rotor is repelled first in one direction and then the other. A synchronous motor in its purest form has no starting torque. It has torque only when it is running at synchronous speed.

A squirrel-cage type of winding is added to the rotor of a synchronous motor to cause it to start. The squirrel cage is shown in **Fig. 18-9B**. It is so named because it is shaped and looks something like a turnable squirrel cage. Simply, the windings are heavy copper bars shorted together by copper rings.

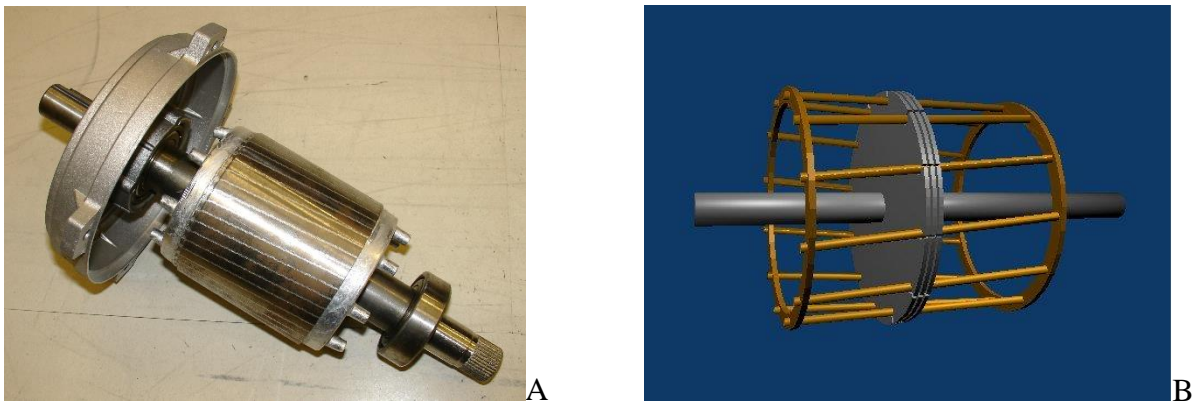


Figure 18-9. A real salient-pole squirrel cage rotor (A) and a squirrel cage (B)

A low voltage is induced in these shorted windings by the rotating three-phase stator field. Because of the short circuit, a relatively large current flows in the squirrel cage. This causes a magnetic field that interacts with the rotating field of the stator. Because of the interaction, the rotor begins to turn, following the stator field; the motor starts.

To start a practical synchronous motor, the stator is energized, but the DC supply to the rotor field is not energized. The squirrel-cage windings bring the rotor to near synchronous speed. At that point, the DC field is energized. This locks the rotor in step with the rotating stator field. Full torque is developed, and the load is driven. A mechanical switching device that operates on centrifugal force is often used to apply DC to the rotor as synchronous speed is reached.

The practical synchronous motor has the disadvantage of requiring a DC exciter voltage for the rotor. This voltage may be obtained either externally or internally, depending on the design of the motor.

Induction Motor

The induction motor is the most commonly used type of ac motor. Its simple, rugged construction costs relatively little to manufacture. The induction motor has a rotor that is not connected to an external source of voltage. The induction motor derives its name from the fact that ac voltages are

induced in the rotor circuit by the rotating magnetic field of the stator. In many ways, induction in this motor is similar to the induction between the primary and secondary windings of a transformer. Large motors and permanently mounted motors that drive loads at fairly constant speed are often induction motors. Examples are found in washing machines, refrigerator compressors, bench grinders, and table saws.

The stator construction of the three-phase induction motor and the three-phase synchronous motor are almost identical. However, their rotors are completely different (**Fig. 18-10**).

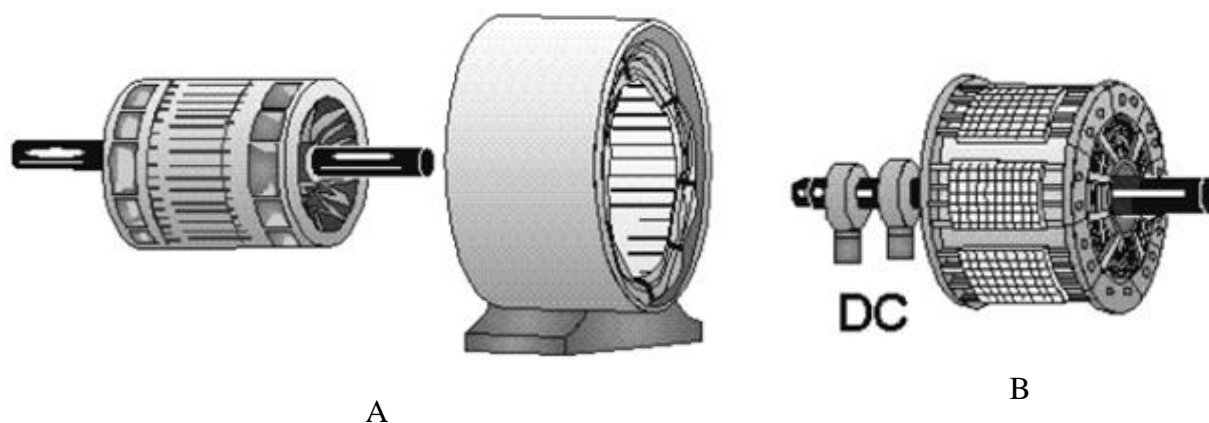


Figure 18-10. Rotors of three-phase induction (A) and synchronous (B) motors

The induction rotor is made of a laminated cylinder with slots in its surface. The windings in these slots are one of two types (**Fig. 18-11**). The most common is the squirrel-cage winding. This entire winding is made up of heavy copper bars connected together at each end by a metal ring made of copper or brass. No insulation is required between the core and the bars. This is because of the very low voltages generated in the rotor bars. The other type of winding contains actual coils placed in the rotor slots. The rotor is then called a wound rotor.

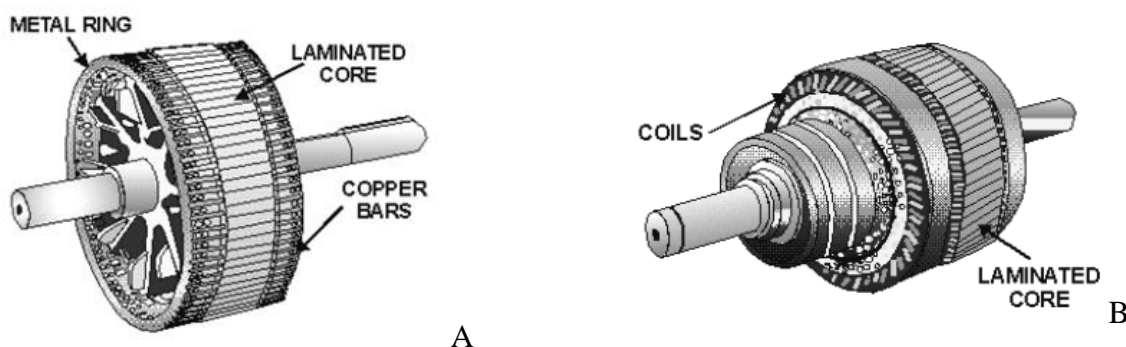


Figure 18-11. Squirrel-cage (A) and wound (B) rotors of induction motor

Regardless of the type of rotor used, the basic principle is the same. The rotating magnetic field generated in the stator induces a magnetic field in the rotor. The two fields interact and cause the rotor to turn. To obtain maximum interaction between the fields, the air gap between the rotor and stator is very small.