

ELECTROTECHNICH LAB.

PART 2

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CIRCUIT THEOREMS

The number of sources and loads can be in 4 types in electrical circuits.

- 1 - Single source, single load,
- 2 - Single source, multiple load,
- 3 - Multiple source, single load,
- 4 - Multiple source, multiple load.

In electrical circuits, the sources and the loads can be connected in series, parallel or mixed. Ohm and Kirchhoff laws are valid in all the solution methods of electrical circuits. There are some practical methods derived from Ohm's and Kirchhoff's laws in the analysis of the electrical circuits. These methods are called the "circuit theorems".

The circuit theorems are used in solutions of the direct current (DC) circuits and the alternative current circuits (AC).

The most common ones of the circuit theorems are as follows.

- 1- Superposition theorem,
- 2- Thevenin theorem,
- 3- Norton theorem.

The theorems shown above will be discussed respectively.

5.1 SUPERPOSITION THEOREM

The superposition theorem is used in circuits having multiple sources in order to find the voltage at a junction point. While analyzing the circuit, in each step only one of the sources is considered and the rest of the sources are killed (voltage sources are short circuited and the current sources are open circuited). Let's determine the voltage at the A junction point in the circuit of Figure 5.1 with respect to the ground.

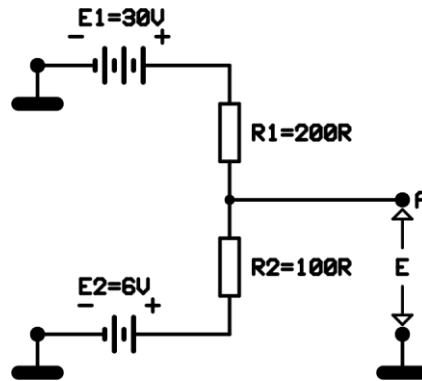


Figure 5.1

The circuit in Figure 5.1 is basically a voltage divider. Firstly, let's find the effect of the E1 source on the circuit. For this purpose, the E2 source is removed from the circuit and its terminals are short circuited.

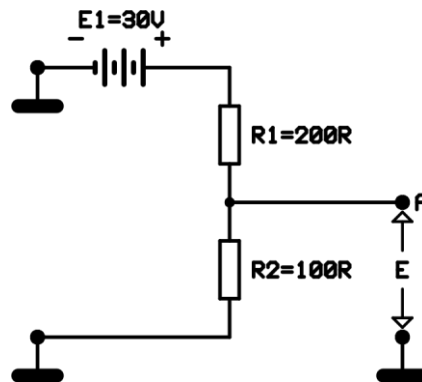


Figure 5.2

Considering Figure 5.2, the voltage is across the "R2" pins. As this voltage is created by E1, we call this voltage E1A and let's determine this voltage using voltage division method.

$$E1A = \frac{R2}{R1 + R2} \cdot E1$$

$$E1A = \frac{100}{200 + 100} \cdot 30 = \frac{100}{300} \cdot 30 = 10 \text{ Volts.}$$

This time, let's kill E1 to find the effect of E2 on the circuit. To kill E1, we remove it and short circuit its terminals.

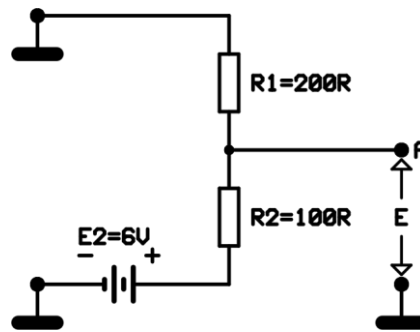


Figure 5.3

We call the voltage at the A point "E2A" as it is created by E2. Let's again determine this voltage using voltage division method.

$$E2A = \frac{R1}{R1 + R2} \cdot E2$$

$$E2A = \frac{200}{100 + 200} \cdot 6$$

$$E2A = \frac{200}{300} \cdot 6$$

$$E2A = 4\text{Volt.}$$

The voltage of the A point with respect to the ground is the summation of these two voltages.

Calling this voltage the superposition voltage and denote as "EP", we find:

$$EP = EA1 + EA2$$

$$EP = 10 + 4$$

$$EP = 10 + 4$$

$$EP = 14 \text{ Volts.}$$

In this circuit, the two sources are connected in order to increase the voltage drop on the load. If the polarities of one of the sources are reversed, then the voltage on the load is decreased.

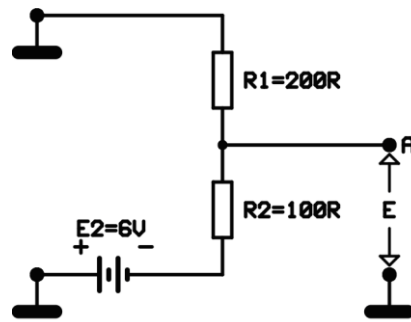


Figure 5.4

In figure 5.4, the polarities of E2 are reversed. There is no change in the circuit analysis till the point where the E1 source is removed. Mathematically again $E1A = 10V$.

As we did before, let's remove E1 in order to find the effect of E2 on the circuit. Let's short circuit the pins of the source. This situation is seen in Figure 5.4.

If we connect a digital voltmeter to the circuit in a way that the - pin is on the ground and the + pin is at the A point, we see that the voltage seen in the voltmeter will be negative.

Therefore the circuit is negative feedback voltage divider. The voltage at the A junction point is again called "E2A" as it is created by the E2 source. Let's again determine this voltage using the voltage division method.

$$E2A = \frac{R1}{R1 + R2} \cdot E2$$

$$E2A = \frac{200}{100 + 200} \cdot (-6)$$

$$E2A = \frac{200}{300} \cdot (-6)$$

$$E2A = -4\text{Volt.}$$

The voltage of the A point with respect to the ground is the summation of the two voltages that we found.

Calling this voltage the superposition voltage "EP", we find:

$$EP = EA1 + EA2$$

$$EP = 10 + (-4)$$

$$EP = 10 - 4$$

$$EP = 6 \text{ Volts.}$$

5.2 THEVENIN THEOREM

One of the most common methods used in the analysis of the electrical circuits is the Thevenin Theorem. Using this method, no matter how complicated the electrical circuit is, it can be converted to a single voltage source "E_{Th}" and a resistor "R_{Th}" serially connected to it.

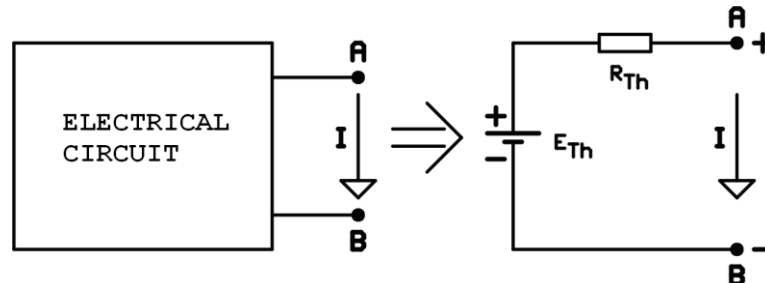


Figure 5.8

The "E_{Th}" voltage in Figure 5.8 is the open circuit voltage of the "A" and "B" points. R_{Th} is the equivalent resistance between A and B points when the source is killed. This simple circuit illustration is called the "Thevenin equivalent circuit". The circuit analysis can easily be done after the equivalent circuit is constructed.

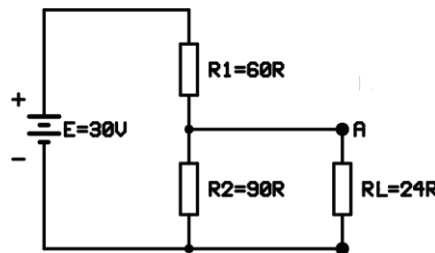


Figure 5.9

Determine the voltage across the load resistor in Figure 5.9 using the Thevenin Theorem.

The voltage across the terminals of the "R₂" resistor is the open circuit voltage at the "A" and the "B" points.

At the same time, this is the Thevenin voltage, E_{Th}.

$$E_{R2} = E_{AB} = E_{Th}$$

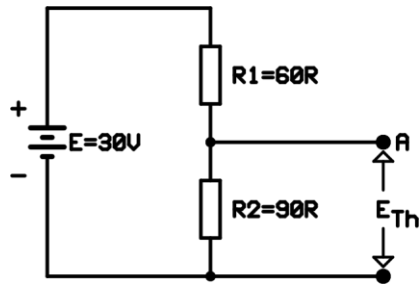


Figure 5.10

The open circuit is seen in Figure 5.10.

$$E_{R2} = E_{AB} = E_{Th}$$

Let's calculate this voltage using voltage division.

$$E_{Th} = \frac{R_2}{R_1 + R_2} \times E = \frac{90}{60 + 90} \times 30 = 18 \text{ Volts.}$$

In order to find the Thevenin resistance (R_{Th}) of the circuit, the source is removed from the circuit and its terminals are short circuited. At this point, the resistance at the "A" and the "B" points is the Thevenin Resistance, " R_{Th} ".

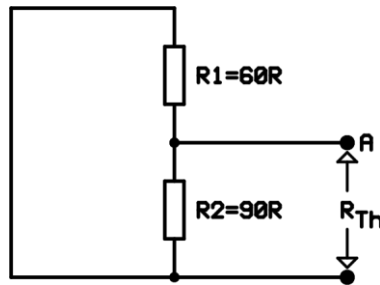


Figure 5.11

In Figure 5.11, the R_1 and the R_2 resistors are parallel to each other. The equivalent resistance of the parallel two resistors can most easily be found by multiplying two values and then dividing the result to the sum of the resistances.

$$R_{Th} = \frac{R_1 \cdot R_2}{R_1 + R_2} = \frac{60 \cdot 90}{60 + 90} = 36 \Omega$$

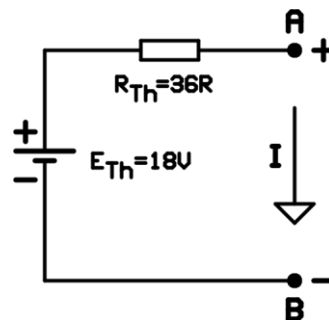


Figure 5.12

The Thevenin Equivalent of the circuit is seen in Figure 5.12. As seen, till this point the load has not yet been used. At this point, the load is connected to the Thevenin circuit and the voltage on the load, "EL" and the current passing through the load, "IL" are determined.

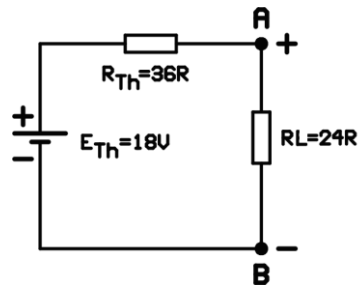


Figure 5.13

In Figure 5.13, the R_{Th} and the R_L resistors are in series. Therefore the circuit current flows through the load.

$$I_L = \frac{E_{Th}}{R_L + R_{Th}}$$

$$I_L = \frac{18}{36 + 24} = 0,3 \text{ Amper.}$$

The voltage at the load terminals is determined with the voltage division method.

$$E_L = \frac{R_L}{R_L + R_{Th}} \cdot E_{Th}$$

$$E_L = \frac{24}{24 + 36} \cdot 18 = 7,2 \text{ Volts.}$$

The voltage at the load ends can more practically be found with the Ohm's law.

$$E_L = I_L \cdot R_L$$

$$E_L = 0,3 \cdot 24$$

$$E_L = 7,2 \text{ Volts.}$$

5.3 NORTON THEOREM

Norton Theorem: One of the most common methods used in the analysis of the electrical circuits is the Norton Theorem. Using this method, no matter how complicated the electrical circuit is, it can be converted to a single current source, " I_N ", and a resistor, " R_N ", connected to it in parallel.

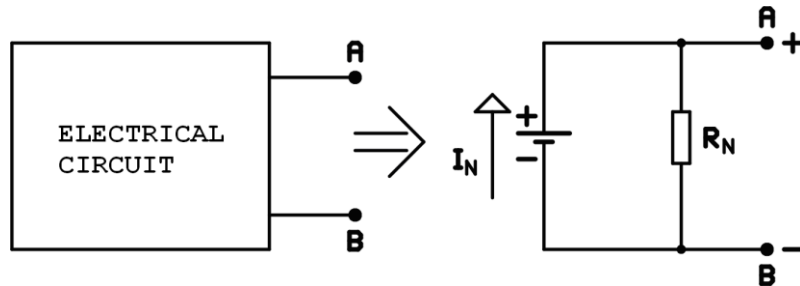


Figure 5.17

I_N current in Figure 5.17 is the current passing when the "A" and "B" points are short circuited. R_N resistance is the resistance seen looking through the "A" and "B" points. The representation of the electrical circuit in this manner is called the "Norton Equivalent Circuit". Then, solution of the circuit can easily be done.

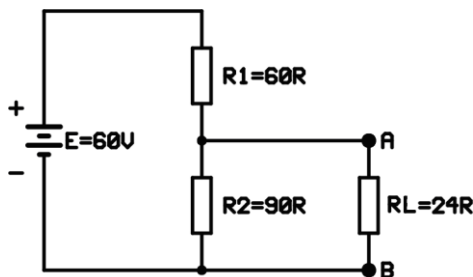


Figure 5.18

Let's determine the current passing through the load resistor in Figure 5.18 using the Norton Theorem.

In order to convert the circuit to the Norton Equivalent Circuit, the load resistor is removed from the circuit and its terminals are short circuited. Then the Norton current " I_N " is found.

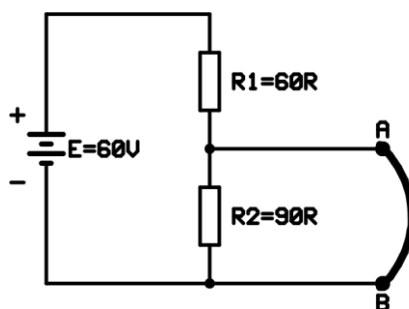


Figure 5.19A

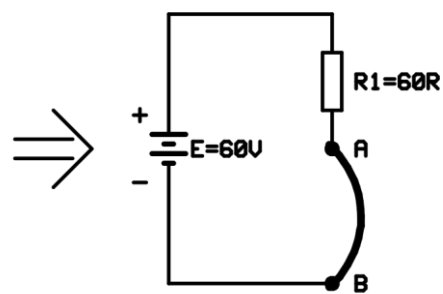


Figure 5.19B

When the A and B points are short circuited, the R2 resistor will have no effect on the circuit. This situation is seen in Figure 4.35B. The Norton current "IN" is found using the Ohm's law.

$$I_N = \frac{E}{R1} = \frac{60}{60} = 1 \text{ Ampere}$$

The source is removed from the circuit in order to find the Norton Resistance, RN. The pins of the circuit connected to the source are short circuited and the resistance between "A" and "B" points is calculated.

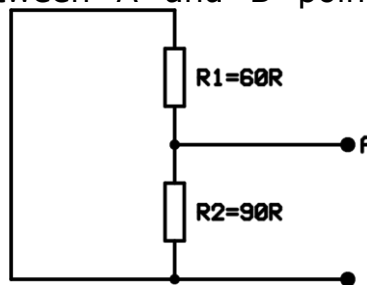


Figure 5.20

In Figure 5.20, R1 and R2 are parallel resistors. The overall resistance of the circuit is "RN".

$$R_N = \frac{R1.R2}{R1+R2} = \frac{60.90}{60+90} = 36 \text{ R}$$

After the Norton current and the Norton resistance are found, the "Norton equivalent circuit" can be drawn.

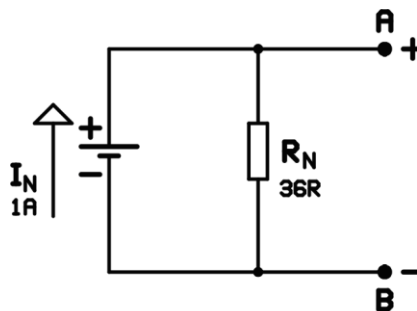


Figure 5.21

Then, the load resistor is connected to the Norton equivalent circuit and solution is done.

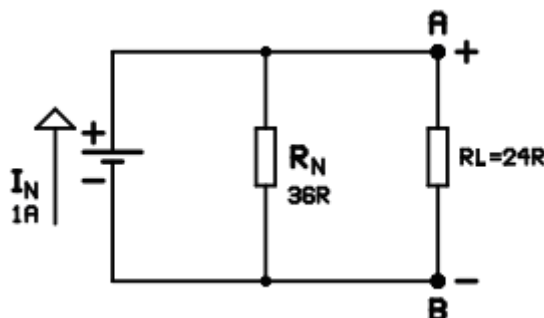


Figure 5.22

The branch currents in Figure 5.22 are calculated using current division method. The current division method is a practical method that is also derived from the Ohm's and the Kirchoff's laws. This method resembles the voltage division method.

$$I_L = \frac{R_N}{R_L + R_N} \cdot I \quad \text{and} \quad I_N = \frac{R_L}{R_L + R_N} \cdot I .$$

In the formulas, the code of the branch current and the resistor codes at the numerator are reversed. That is because that the current and the resistance values are inversely proportional.

$$I_L = \frac{R_N}{R_L + R_N} \cdot I = \frac{36}{24 + 36} \cdot 1 = 0.6 \text{ Ampere}$$

$$I_N = \frac{R_L}{R_L + R_N} \cdot I = \frac{24}{24 + 36} \cdot 1 = 0,4 \text{ Ampere}$$

The voltage at the load ends are found using the Ohm's law.

$$E_L = I_L \cdot R_L$$

$$E_L = I_L \cdot 24$$

$$E_L = 0,6 \cdot 24$$

$$E_L = 14,4 \text{ Volts.}$$

COILS

6.8 COILS IN DIRECT CURRENT

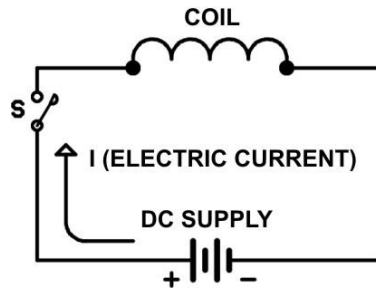


Figure 6.14

In figure 6.14, there is an electric circuit consisting of DC supply, coil and switch. When the "S" switch is closed, initially, coil resists the current. After a short time current reaches its normal value. The change in the magnitude of current in that short period of time results in the generation of a magnetic field in and around the coil. This magnetic field generates a second electric energy supply on the coil, this energy has opposite poles to the circuit supply. The energy of the newly created supply is called electromotive force (EMF). Because of the fact that its poles are opposite to the supply it is called "**counter EMF**". The graphic at figure 6.15 is developed as an observation of the events after the switch is closed until the current reaches the normal value.

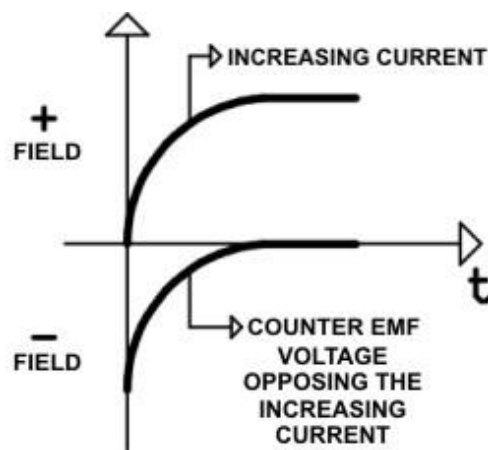


Figure 6.15

After the circuit current reaches normal value, the opposition presented by the coil to the current is just the ohmic resistance of the coil. Ohmic resistances of high-quality coils are at minimum. Numerically, the ohmic resistances of coils are under 300R. So, maximum current will pass through the circuit.

If "S" switch is opened or circuit current is decreased because of any reason, this time counter EMF will attempt to support circuit current to continue. This support of counter EMF is shown graphically in figure 6.16

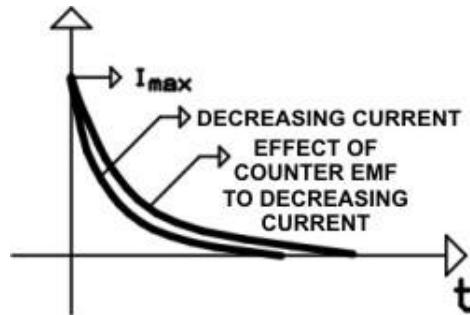


Figure 6.16

It is clear that, coils are components which can store electric energy when they are in variable electromagnetic field. Coils are used in DC filter circuits because they have a counter effect to the decrease or increase of current. Filter circuits are the ones that filter or stabilize the DC.

The resistance of coils to the AC is much greater than to the DC. The reason for this is that the direction of AC changes constantly and, in turn, the current passing through the coil changes constantly. The resistance that is presented to the AC by the coils is called "**inductive reactance**". Inductive reactance increases directly proportionate to the frequency. Coils in AC are used in transformers, engines, contactors, electron magnets, etc..

Coils are used in devices which there is both AC and DC. They are used for directing the AC or differing AC from DC.

Resistance and the ability of coils to store energy depend on the value of coils. Coils are symbolized by "**L**" and their unit is "**Henry**". Henry is symbolized by "**H**".

"Henry, is a unit of inductance in which an induced electromotive force of one volt is produced when the current is varied at the rate of one ampere per second"

Coil values are also called as "**inductance**". The inductance is large in high frequency circuits..

Because of this, the lower multipliers are mostly used in electronics. In figure 6.17, the lower multipliers and their mathematical conversion can be seen.

UPPER MULTIPLES	LACKING	
MAIN UNIT	(L) HENRY	
LOWER MULTIPLES	(mH) MILI HENRY	1 000mH = 1H
	(μH) MICRO HENRY	1 000μH = 1mH

Figure 6.17

Generally, coils with high inductance are used in electrics and coils with low inductance are used in electronics. In lower frequencies (up to 20 KHz) and in DC, the inductances of coils are larger. Higher inductance coils have larger turns and their kernel have larger conductivity. Kernels increase coils inductance directly proportional with their conductivities. There exist carcass and air between coil and its kernel. Conductivity in this subject is ratio of magnitude of the force vector between poles of a magnet when there is that material and air. It is also called as permeability. It is shown with the letter " μ " (**mui**). " μ " (**mui**) is generally small. Metals have low resistivity.

Non-metal materials with high permeability are developed through experiments

For example; Ferro- ferrite (**Fe₃ O₄**), copper-Ferro- ferrite (**Cu Fe₂O₄**), lead-Ferro-Ferit (**Pb Fe₂O₄**) and iron combinations have resistivity nearly 10^8R and magnetic permeabilities are between 100-200. These cores are called "**ferreous**" cores. Ferrite is a nonmetal with high conductivity. Ferrite cores have conductivities between 10 and 200.

In high frequency circuits (**larger than 20 KHz**), silisium iron combination is not used since they have higher loss, ferrite core coils are used instead.

In high frequency or a certain frequency band circuits, adjustable core coils are used. In this kind of coils, core is screwed in coil and inductance is adjusted. In lower inductance coils, cores which have lower conductance than air are used. Brass is an example of this kind of material. It reduces the coil inductance.

Coils with different cores have different symbols. These symbols are shown in figure 6.18

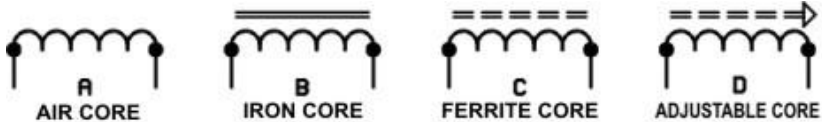


Figure 6.18

Coils with higher inductance can be achieved by using a structure that will capture magnetic forces inside and outside the coil.

Figure 6.19 shows two such different coil structures.

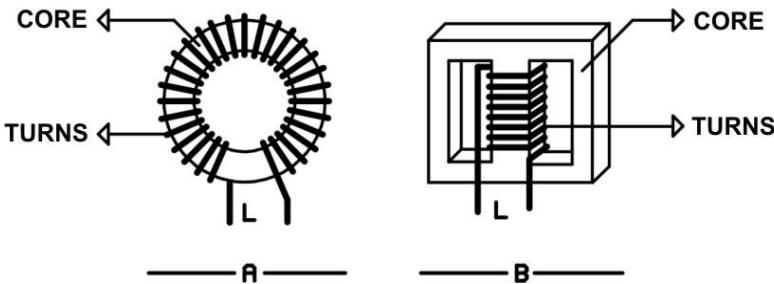


Figure 6.19

The coil in figure 6.19A is called "**troid coil**" troid coils are used in SMPS (**S**witch **M**ode **P**ower **S**upply) circuits. The coil in figure 6.19B is called "**transformator type**" coil. These coils are used in transformers and filter circuits.

Other commonly used coil types are "**axial**" and "**radial**" coils. Structure of axial coils is just like resistors. Connection terminals are at the edges. Radial coils look like a cylinder and connection terminals are on the same side of cylinder. Very small sized axial and radial coils are produced in order to be used in circuits montaged on surfaces.

Axial, radial, troid and transformator type coils are seen in figure 6.20



Figure 6.20

6.9 INDICATION OF INDUCTANCE VALUE OF COILS

Inductance values of coils are indicated by two methods. These are:

- 1- Color code method
- 2- Numerical code method.

The unit used in both methods is microHenry (μH).

Color code method: this method is used for axial type coils. It is the same as four band resistance color code. Let's give an example:

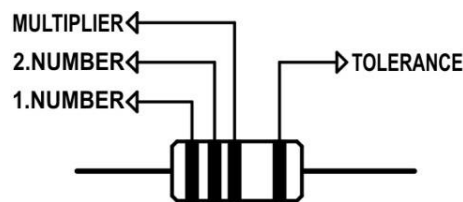


Figure 6.21

The colors of the coil in figure 6.21 are yellow, purple, red and silver respectively. Let's calculate inductance and the value limits of this coil according to its tolerance.

1.Colour (1.Number)	2. Color (2.Number)	3. Color (Multiplier)	Value (μH)	Tolerance (%)
4	7	00	4700	10

$$\% \pm 10 \text{ tolerance} = 4700 \cdot \frac{10}{100} = \frac{47000}{100} = 470$$

This means that this coil can have values between:
 $4700 - 470 = 4230\mu\text{H}$ and $4700 + 470 = 5170\mu\text{H}$

Numerical code method: This method is usually used for radial type coils. A three digit number is used for the inductance of coil. Tolerance is indicated as per cent (like %5, %10). Let's give an example:

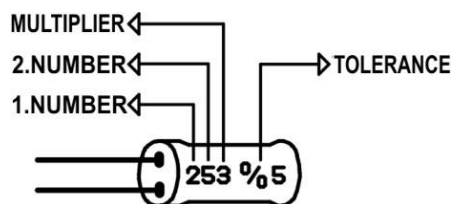


Figure 6.22

The first and second digits are numbers and the third digit indicates the multiplier. Let's calculate the inductance and value limits of coil according to its tolerance.

1.Number	2.Number	Multiplier	Value (μH)	Tolerance (%)
2	5	000	25000	5

$$\% \pm 5 \text{ tolerance} = 25000 \cdot \frac{5}{100} = \frac{125000}{100} = 1250$$

This means that this coil can have values between:
 $25000 - 1250 = 23750 \mu\text{H}$ and $25000 + 1250 = 26250 \mu\text{H}$

Besides their inductances, the current and the frequency is also important for coils. In electric circuits, usually, current is high and frequency is low. The wire of the coil must be thick enough for the high current. In electronic circuits, usually current is low and frequency is high. In these circuits, cores must be chosen appropriate for the working frequency.

Coils get heated because of the effect of current. There may be two things to happen as a result of degeneration of coils for any reason (heat, high current, etc..) First, is the break of the conductors of coil. In such a situation, ohmic resistance of the coil is indefinite. Secondly, there may be an electrical contact of coil conductors. In such a situation, ohmic resistance of coil is normal but its inductance is zero or very small.

6.10 MEASUREMENT OF COILS

Ohmic resistances of coils are measured by ohmmeter. It is sufficient to connect the probes of ohmmeter to the terminals of coil for this process. Measured ohmic resistance means that the coil conductors are not broken off. Coil measurement means the measure of coil's inductive reactance. Most commonly used device to measure coil inductance is "**LCR meter**". LCR is the abbreviation for coil, capacitor and resistor. LCR meters make a small AC current to pass through the coil while measuring. The direction of this current is not effective in measurement process. A mid-quality LCR meter is shown in figure 6.23

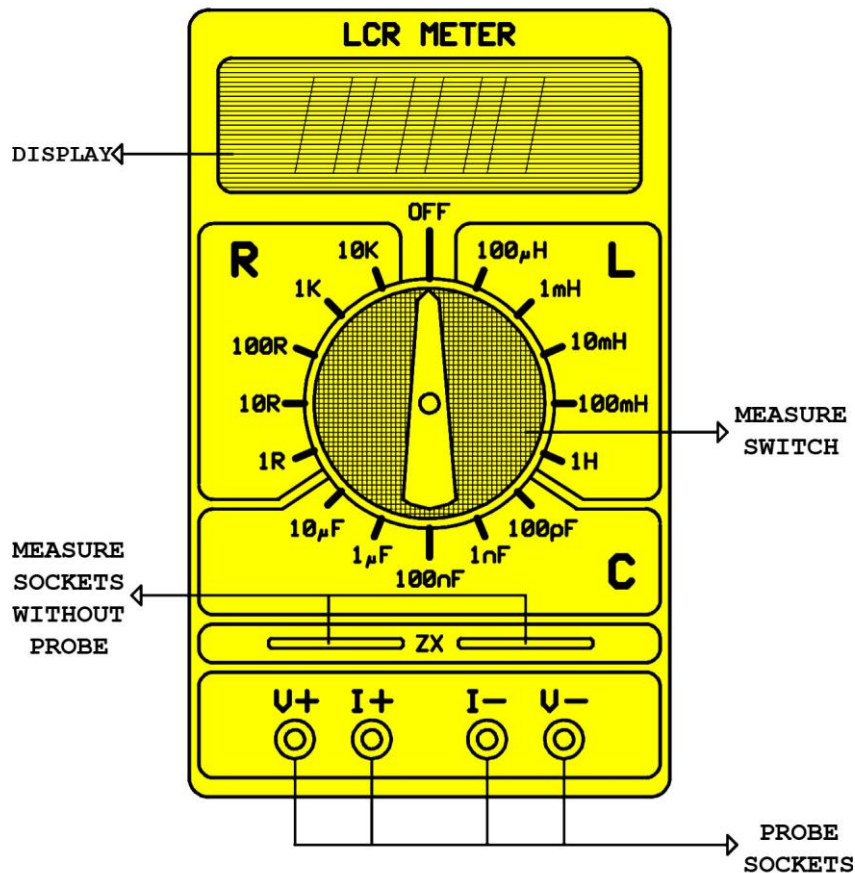


Figure 6.23

LCR meter is a device that measures delicate values and its usage is very easy. As seen in figure 6.23, measurement switch quadrant has three fields (**LCR**). There are multiple measure stages in every field. The devices that can measure a unit at multiple levels are called "**multimeter**". In order to measure coil inductance, the switch should be adjusted to lowest level (**100μH**) of "**L**" field.

Coil is connected to measurement sockets (without probe) "**zx**" from its terminals, like in figure 6.24

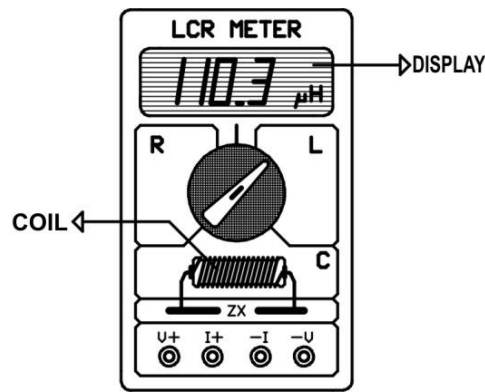


Figure 6.24

Measurement sockets without probe are in spring structure. These sockets clutch the connection pins of the coil and electrical contact is maintained. At that moment, coil inductance can be read on the display. If it can't be read then the inductance is higher than 100μH. So, the measurement switch should be leveled up gradually until the inductance is displayed.

All the coils (esp. Coils with lower inductance) should be measured by connecting to the sockets without probe. Yet, structures of some coils are not suitable for this. So, necessarily, probes will be used. Probes of LCR meters are specially designed to prevent the effects of probe cables to the measurement. There are two cables, two plugs and a crocodile (tong) in every probe. Measurement of a radial type coil with using probes is shown in figure 6.26.

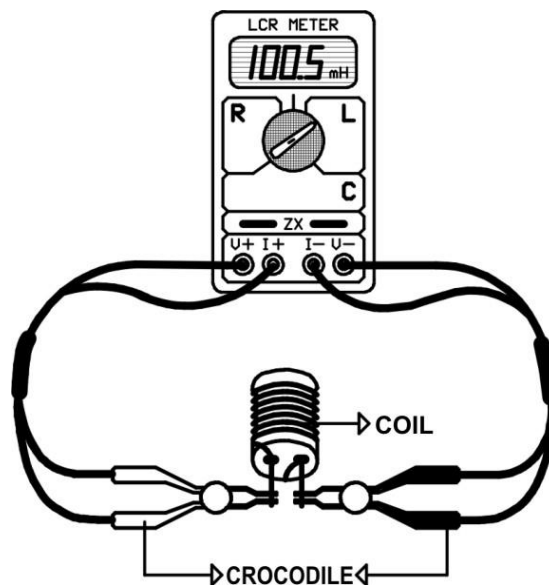


Figure 6.25

If the ohmic resistance of coil will be measured, the procedure will be just like the inductance measurement. It is enough to switch to field "R" to measure resistance.

6.11 COIL CONNECTIONS

If it is hard to provide a required coil in terms of coil value or current, multiple coils can be connected to circuit parallelly or serially. Inductance, ohmic resistance and alternating current resistance of coils respond to the current as resistances. Therefore, the mathematical processes in coil connections are the same as in resistance connections.

Serial connection: If there is not a coil at required magnitude of inductance available, multiple coils can be connected serially. Serial connection of two coils is shown in figure 6.26

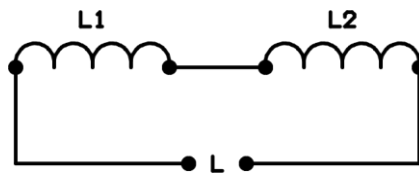


Figure 6.26

In serial connection, total inductance is the sum of all coil inductances.

$$L=L1+L2+.....+Ln$$

Maximum current that can pass through serially connected coils circuit is equal to the current value that can pass through the coil which has the lowest inductance.

Example:

Three coils with inductances $L1=100\text{mH}$, $L2= 250\text{mH}$ and $L3=1\text{H}$ are in serial connection. Find the total inductance.



Figure 6.27

Solution:

$$L1= 100\text{mH} = 0,1\text{H}$$

$$L2= 250\text{mH} =0,25\text{H}$$

$$L3= 1\text{H}$$

$$L =L1+L2+L3$$

$$L =0,1+0,25+1$$

$$L =1,35\text{H}$$

Parallel connection: If there is not a coil that is available for the required current to pass, multiple coils can be connected parallelly. Parallel connection of two coils is shown in figure 6.29

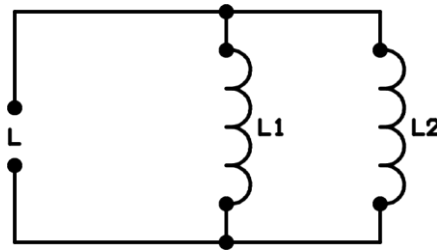


Figure 6.29

Total inductance in parallel;

$$\frac{1}{L} = \frac{1}{L1} + \frac{1}{L2} + \dots + \frac{1}{Ln}$$

The current passing through a parallel connected coils circuit is equal to the sum of current passing through all coils. Total inductance is lower than the lowest coil inductance in the circuit.

Example:

Three coils with inductances L1=6H, L2=6H and L3=3H are connected parallel. Calculate the total inductance.

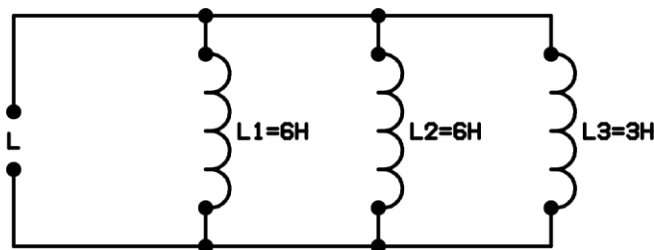


Figure 6.30

Solution:

$$\frac{1}{L} = \frac{1}{L1} + \frac{1}{L2} + \frac{1}{L3}$$

$$\frac{1}{L} = \frac{1}{6} + \frac{1}{6} + \frac{1}{3} = \frac{1}{6} + \frac{1}{6} + \frac{2}{6} = \frac{4}{6}$$

[2]

$$L = \frac{6}{4} = 1,5H$$

Mixed connection: If there is not a coil of required value in terms of current and induction, then, mixed connection of multiple coils can be carried out to fix the problem. Mixed connection has the properties of both parallel and serial connection. Mixed connection of three coils is shown in figure 6.32

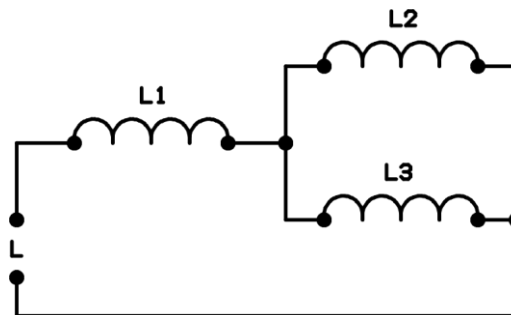


Figure 6.32

In figure 6.32, L2 and L3 coils are parallelly connected and L1 is serial to them. First, the parallel connected coils should be solved and the circuit will be serial. Then the solution will be carried out according to serial connection.

If we call L2, L3 connection as "LA":

$$L_A = \frac{L_2 \cdot L_3}{L_2 + L_3}$$

Total inductance of circuit will be:

$$L = L_1 + L_A$$

Example:

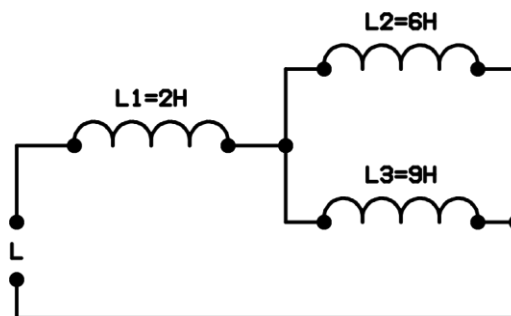


Figure 6.33

Find the total inductance of the circuit in figure 6.33

Solution:

If we call L2, L3 connection as "LA":

$$L_A = \frac{L_2 \cdot L_3}{L_2 + L_3} = \frac{6 \cdot 9}{6 + 9} = \frac{54}{15} = 3,6H$$

$$L = L_1 + L_A = 2 + 3,6 = 5,6H$$

CAPACITORS

7.1 INTRODUCTION

Capacitor is a passive element that can store direct current (**DC**) electrical energy. Capacitors are produced two types according to their usage in electrics and electronics circuits:

- 1- Constant Capacitors
- 2- Variable Capacitors

Despite the structures of constant and variable capacitors seem so differently, their working principle is the same.

7.2 CONSTANT CAPACITORS

Capacitors are made by putting an insulator between a pair of conductors. These conductors are called "**plates**", and the insulator between the plates is called "**dielectric**"

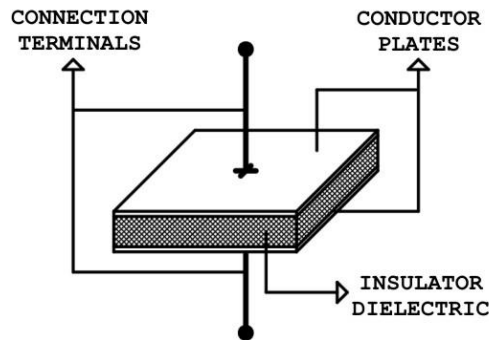


Figure 7.1

In figure 7.1 the structure of the capacitor is shown. In the conductors there are a lot of valance electrons. In conductors valance electrons can easily leave the nucleus of the atom. In insulators electrons are attached to their atoms with a big force. In ordinary situations the electrons that are in the plates are spinning around their atoms.

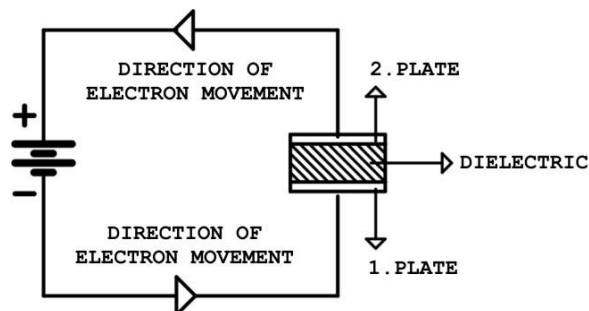


Figure 7.2

In figure 7.2 capacitor is attached to a direct current source. The electrons that are separated from the negative pole of the direct current source move towards the positive pole of the source. This situation goes on until the voltage difference between the two plates is equal to the direct current voltage. In the first plate there will be excess of electrons, and in the second plate there will be lack of electrons. The voltage difference between the two plates disrupts the orbit of the electrons of the dielectric material atoms and put it into a shape of elliptic.

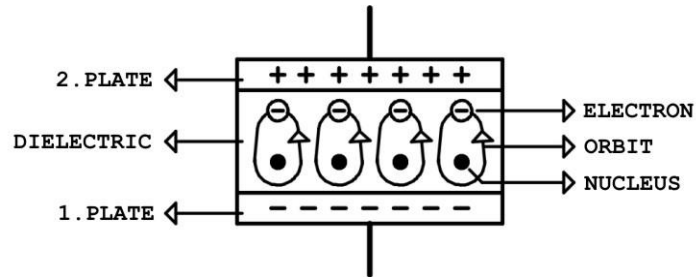


Figure 7.3

In figure 7.3 four atoms are shown. Actually, the number of atoms in a dielectric material is so many that is uncountable. At this moment if the direct current supply is taken out from the circuit the electric charge on the capacitor does not change. This situation is called the charging of the capacitor. A charged capacitor is a direct current supply.

If a capacitor is connected to a high-voltage supply the electrons in the dielectric break off the atoms they are attached. At this moment the nonconductiveness of the dielectric goes off and the electric charge disappears. A dielectric which exposed to this situation can not be recovered. If a dielectric of a capacitor breaks down capacitor can not be used again.

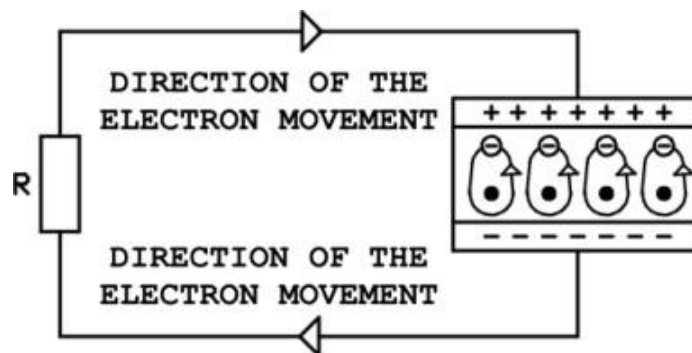


Figure 7.4

In figure 7.4 a resistance is connected to a charged capacitor. In this situation electrons that come from the plate that has excess of electrons move through the resistance to the plate that has low number of electrons. Electron flow will go on until the plates have the same electric charge. This situation is called discharging of a capacitor. A discharged capacitor have zero electric charge.

The electrons of dielectric material of a decharged capacitor have a normal circle orbit.

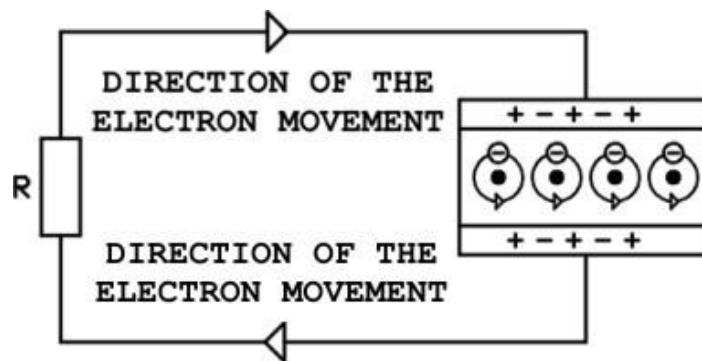


Figure 7.5

In figure 14-5 the charges of the plates of a capacitor and the structure of a atom in the dielectric is shown.

The electric energy storage capacity of a capacitor is directly proportional to the area of the plates and inversely proportional of the distance between the plates. The type of the dielectric material also effects the energy storage capacity. In DC circuits capacitors are used as a energy storage device whereas in the **AC/DC** converters they are used as filters.

In **AC** current circuits capacitors behaves like a conductor. Because of this property in alternating current they are usually used as coupling(**conductor**);and shuntling(**short circuit**) elements. The conductance of the capacitance is directly proportional to the frequency of the alternating current (**AC**) circuit.

The main unit of the capacitance is **farad**. Farad is shown by the letter **F**. The capacitance of a capacitor whose plates have a one coulomb electric charge and which has a voltage of one volt has 1 Farad capacitance. Farad is a big value. In electric circuits lower multiples of Farad are used.

In Figure 7.6 lower multiples of Farad and the relationship between them is shown.

MAIN UNIT	(F) FARAD	
LOWER MULTIPLES	(mF) MILIFARAD	$10^3 \text{ mF} = 1\text{F}$
	(μ F) MICRO FARAD	$10^6 \mu\text{F} = 1\text{F}$
	(nF) NANO FARAD	$10^9 \text{ nF} = 1\text{F}$
	(pF) PICO FARAD	$10^{12} \text{ pF} = 1\text{F}$

Figure 7.6

In capacitors metals with high conductors are used as plates. Aluminum is the mostly used material for capacitor manufacturing. This is because of aluminum is cheap and resistive to humidity. Dielectric material varies so much.

According to dielectric material capacitors can be categorized as follows:

- | | |
|------------|----------------|
| 1.AIR | 5.MIKA |
| 2.PAPER | 6.CERAMIC |
| 3.PLASTIC | 7.GLASS |
| 4.POLYSTER | 8.ELECTROLITIC |

In electronics capacitors behave differently according to their dielectric materials.

- 1.Paper-plastic-polyster capacitors
- 2.Ceramic-mika capacitors
- 3.Electrolitic capacitors

1.Paper-plastic-polyster capacitors:They are used in sound frequency (**20Hz-40KHz**) and radio frequency (**150 KHz-110MHz**) circuits. In paper dielectric circuits dielectric material is obtained by injecting parafin into the paper. They are capacitors without a pole. Their capacitances are usually under $1\mu\text{F}$ (**mikrofarad**)

2.Mika-ceramic capacitors:They are used in high frequency (**10^4MHz**) circuits. Their power loss is small. They are also capacitors without poles. Their capacitances are usually under $1\mu\text{F}$ (**mikrofarad**)

3.Electrolitic capacitors: They are usually used in sound frequency (**20Hz-40KHz**) and radio frequency (**150 KHz-110MHz**) circuits. Their capacitances are between $1\mu\text{F}$ and $10^4\mu\text{F}$.

Electrolitic capacitors have poles. When connecting to the circuit poles must be checked. If it is connected in the reverse direction it could harm the user and the environment.

In electrolitic capacitors aluminium or tantalum are used as plates. The capacitor with tantalum plates are called "**Tantal Capacitors**". Their power loss is very small.

Electrolitic capacitors are produced either taking out the nodes from the left or right (axial type) or taking out the nodes from the same direction (**radial type**)

7.3 ADJUSTABLE CAPACITORS

In radio and TV receiver and transmitter circuits adjustable capacitors are usually used for frequency adjusting. The structure of an adjustable capacitor is shown in figure 7.7.

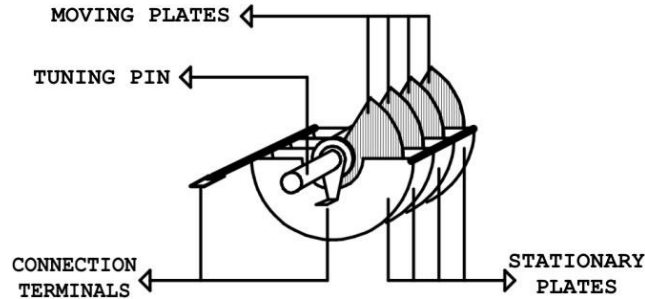


Figure 7.7

In adjustable capacitors a group of plates are used instead of each plate in the constant capacitor. These plates are called stationary and moving plates. Two group of plates are placed in such way that they can easily be crossed over each other. Two groups never contacts with each other electrically. Usually air or plastic is used as dielectric between the plates.

Adjustable capacitors are produced in two types according to their usage. These are "**trimmer**" and "**variable**" capacitors. Structure of the two capacitors are ver similar.

Trimmer Capacitors: They are designed to be mounted directly onto the circuit board and adjusted only when the circuit is built. It is adjusted by the help of a screwdriver. Trimmer capacitors are only available with very small capacitances, 0-60 pF.

Variable Capacitors: They can be adjusted when the circuit is working. They are suitable for lots of adjustments. Their capacitances are between 5pf-500pf. The control pin of the variable capacitor is put outside the device using button. An example of variable capacitor is the tuning capacitor of a radio.

In figure 6-8 symbols of the capacitors are shown:

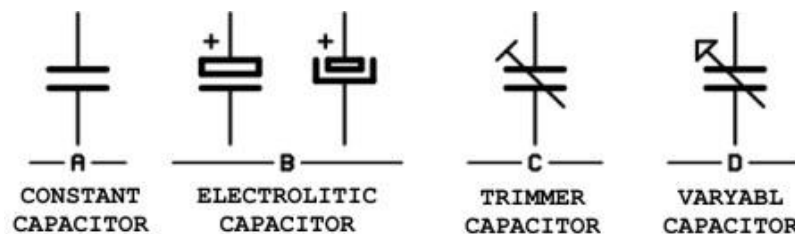


Figure 7.8

In Figure 7.9 the most used capacitors polyster, lential, elektrolitic, trimmer and variable capacitors are shown.



Figure 7.9

7.4 ENERGY STORED IN THE CAPACITORS

The energy of a charged capacitor is expressed in "**watt-seconds**" or by "**joules**". The stored energy in a capacitor is found by the formula;

$$W = \frac{1}{2} \cdot Q \cdot E$$

In the formulation;

W=stored energy (**Watt-Seconds or Joules**)

Q=Electrical Charge(**Coloumbs**)

E=voltage(**volt**).

Mathematically the charge (**Q**);

$$Q = C \cdot E.$$

In the formulation;

C= Capacitance (**Farad**)

E= Volatge (**Volt**)

If we put the charge expression in the energy formula;

$$W = \frac{1}{2} \cdot C \cdot E \cdot E = \frac{1}{2} \cdot C \cdot E^2$$

Example:

30VDC is applied to a capacitor of 1000 μ F. Find the stored energy in the capacitance.

Solution;

$$1000 \mu F = 1000 \cdot 10^{-6} F = 1 \cdot 10^{-3} F = 10^{-3} F$$

$$W = \frac{1}{2} \cdot C \cdot E^2$$

$$W = \frac{1}{2} \cdot 10^{-3} \cdot 30^2 = \frac{900}{2 \cdot 10^3} = \frac{900}{2000}$$

$$W = 0,45 \text{ jul}$$

7.5 INDICATION OF CAPACITANCE VALUE OF CAPACITORS

Usually the capacitance values of the capacitors are written on the capacitors by the producers. Earlier some capacitors were produced whose capacitance values are specified by colors like resistors. Some producers specifies the tolerance values of the capacitors by a letter written after the capacitance value.

The tolerance letters of the capacitors and the their mathematical meaning is shown below.

A- % 1	E- % 0,10
B- % 2	F- % 0,05
C- % 0,5	G - % 5
D- % 0,25	H- % 10

When buying capacitors capacitance value and the voltage must be specified. The maximum voltage value that a capacitor can work is written on it. If a voltage higher than maximum voltage is applied to capacitor it will blow up and it could harm the user and the environment. Because of this reason the operating voltage of the capacitor is so important.

In figure 7.10 three capacitors whose values are shown in different ways are seen.

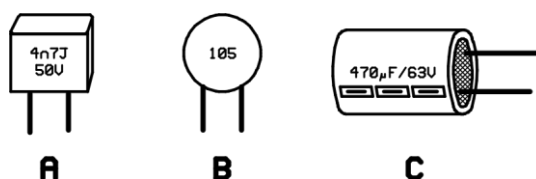


Figure 7.10

In figure 7.10A inside the numbers the unit and the tolerance values are shown. Capacitance of this capacitor is 4,7 nF, and the tolerance is %5. Maximum working voltage is 50 Volts. In figure 7.10B only three numbers are seen. This coding system is like the system coils. The unit of capacitance for this showing is pF (**picofarad**). The first and second numbers are also the first and second number of capacitance value. The third number is the factor. So, capacitance value is:

$$1\ 0\ 5 = 1\ 0\ 0000\text{pF} = 100\text{nF}.$$

In figure 7.10c it is clearly seen that the capacitance value is 470 µF and the maximum operating voltage is 63 Volts.

In figure 7.10B the working voltage and in Figure 7.10C tolerance value is not shown. In this situation these values should be learnt from the catalogue.

In the capacitors' catalogue especially in the electrolytic capacitors' catalogue the efficient operating temperatures are also specified.

7.6 MEASURING THE CAPACITORS

Measuring the capacitance means measuring the capacitance value of the capacitor. For measurement the LCR meter is brought to "C" position. The capacitor is connected to the sockets of the the LCR meter or using probe it is connected to the crocodile probes of the meter. Then the value can be read from the display.

If the capacitor is removed from a circuit recently it can be charged. In this situation capacitor should be discharged by connecting a 1K resistance to the capacitor's terminals. If there is high voltage in circuit that capacitor removed from ,capacitor can shock. Holding both of the terminals of the capacitor at the same time is very dangerous. If a charged capacitor is connected to a LCR meter the LCR meter breaks up.

In figure 7.11 measurement of a capacitor without probe and in figure 7.12 with probe is shown.

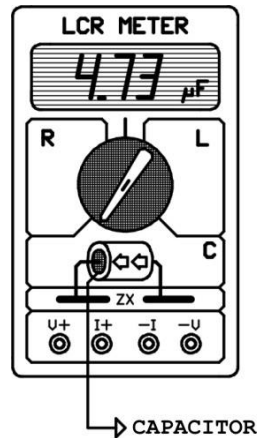


Figure 7.11

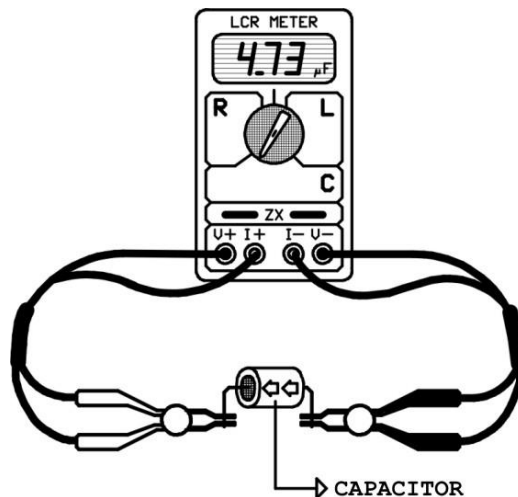


Figure 7.12

7.7 CONNECTIONS OF THE CAPACITOR

In electronic circuit applications sometimes the exact capacitance or voltage value can not be obtained. In these situations by connecting capacitors parallel, serial or mixed the desired value can be obtained. In capacitor connections the mathematical operations is inverse of the operations in coils and resistances.

Serial Connection: By connecting two or more capacitors serially a new capacitance that has a operating voltage bigger than the individual capacitors' voltages. In figure 7.13 serial connection of two capacitors are shown.

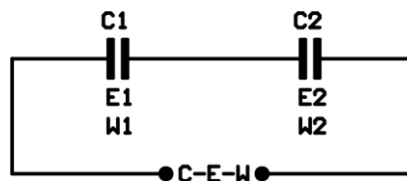


Figure 7.13

If the capacitors are connected serially their total capacitance decreases. By formulation;

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \dots + \frac{1}{C_n}$$

The operating voltage value of the new capacitor is the sum of the voltages of the three capacitors.

$$E = E_1 + E_2 + \dots + E_n.$$

The energy stored is:

$$W = W_1 + W_2 + \dots + W_n.$$

If the serial connected capacitors have poles, positive pole of a conductor is connected to the negative pole of an other capacitor. The new capacitor is also polar. In figure 7.14 serial connection of three polar capacitors are shown:

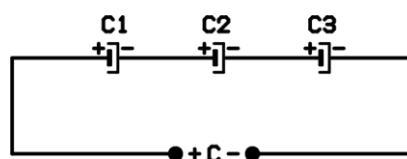


Figure 7.14

If two polar capacitors which have same capacitance are connected inversely serial a nonpolar capacitor is obtained. However the formed capacitor has big losses. In figure 7.15 this kind of connections are shown.

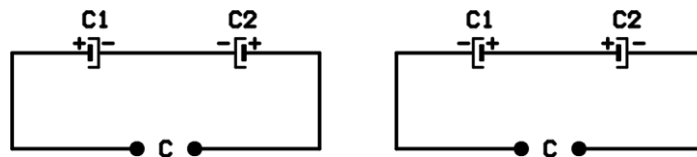


Figure 7.15

Nonpolar capacitor is also called "bipolar capacitor".

Solution:

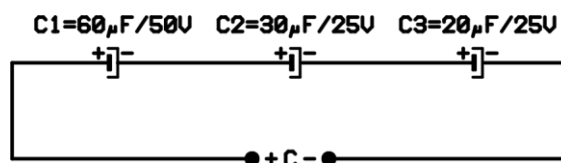


Figure 7.16

For the circuit in Figure 7.16;

A- Calculate the total capacitance.

B- Calculate the maximum work voltage for the new capacitance group.

Solution:

A- Total capacitance;

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} = \frac{1}{60} + \frac{1}{30} + \frac{1}{20} = \frac{2}{120} + \frac{4}{120} + \frac{6}{120} = \frac{12}{120}$$

$$\Rightarrow 12C = 120$$

$$C = \frac{120}{12} = 10\mu F .$$

B- The maximum work voltage for the capacitance group;

$$E = E_1 + E_2 + E_3$$

$$E = 50 + 25 + 25$$

$$E = 100 \text{ Volts.}$$

Parallel Connection : If a capacitance of value of a single capacitance is not enough, by connecting the capacitors parallel the desired value could be obtained. In figure 7.18 parallel connection of two capacitors are shown.

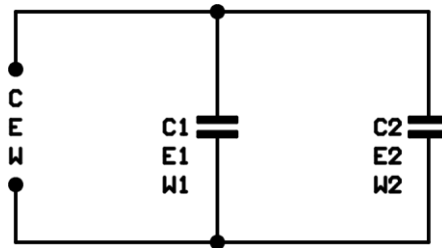


Figure 7.18

If the structure of the capacitance is remembered when the capacitors are connected parallel it can be seen that the area of the capacitance plates increases. Since the capacitance is directly proportional to the plates' area the total capacitance is equal to the sum of the capacitances. Mathematically;

$$C=C1+C2+.....+Cn.$$

The operating voltage of the new capacitance group is equal to the lowest voltage value of the capacitors' operating voltages.

The energy stored in the capacitors are same as with the serial connected capacitors.

$$W=W1+W2+.....+W3$$

If the parallel connected capacitors are polar all the positive poles are attached in one node and the negative poles are attached in the other node. If one capacitor is connected improperly dielectric can blow up. This could harm the user and the environment. In figure 7.19 parallel connected three capacitors are shown.

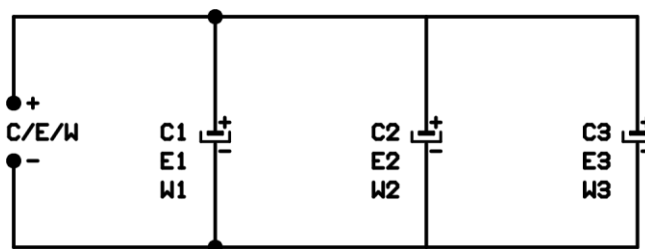


Figure 7.19

Example:

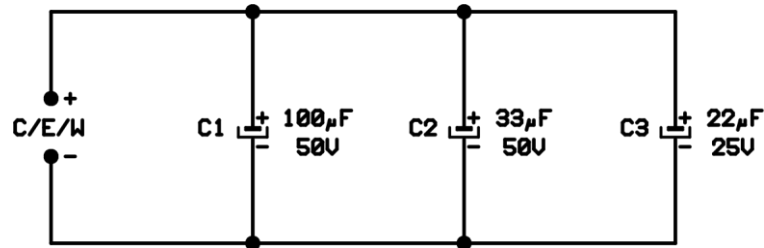


Figure 7.20

For the circuit in the Figure 7.20:

A- Calculate the total capacitance?

B- Calculate the maximum operating voltage for the new circuit.

Solution:

A- Total Capacitance;

$$C = C1 + C2 + C3$$

$$C = 100 + 33 + 22$$

$$C = 155 \mu\text{F}.$$

B- Since the maximum operating voltage is the minimum of the working voltages of capacitors;

$$E = 25 \text{ volts}.$$

Mixed Connection: If the desired capacitance could not be found in a circuit by mix connecting capacitors the desired value can be obtained. Mix connection is the combination of serial and parellel connections. In figure 7.22 the mix connection of three capacitors are shown.

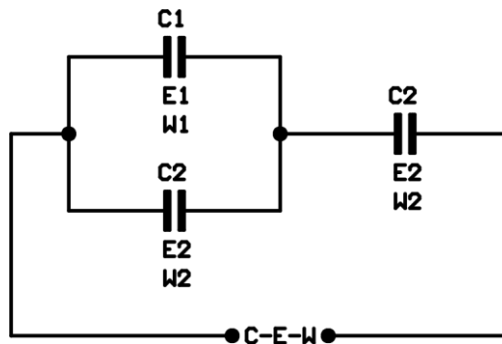


Figure 7.22

In figure 7.22 C1 and C2 capacitors are parellel to each other and C3 is serial to this group. For finding the total capacitance firstly the parellel capacitors are brought together and they form one capacitor. Then the capacitance is calculated as it is a serial connected capacitors.

Example:

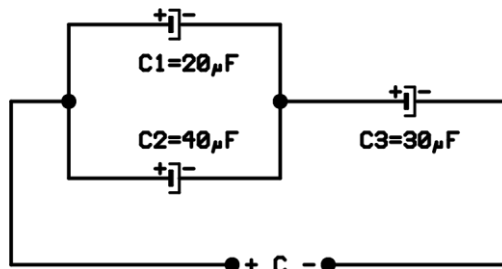


Figure 7.23

Calculate the total capacitance of the circuit shown in figure 7.23.

Solution:

Say the total capacitance of C1 and C3 is "**CA**".

$$CA = C1 + C2 = 20 + 40 = 60 \text{Mf}$$

$$C = \frac{CA.C3}{CA + C3} = \frac{60.30}{60 + 30} = \frac{1800}{90} = 20 \mu F$$