ISTANBUL COMMERCE UNIVERSITY

Electrical-Electronics Engineering
EEE202 Electro-technic Laboratory

Theory

Part 3

Contents

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1 COILS

1.1 Coils in DC

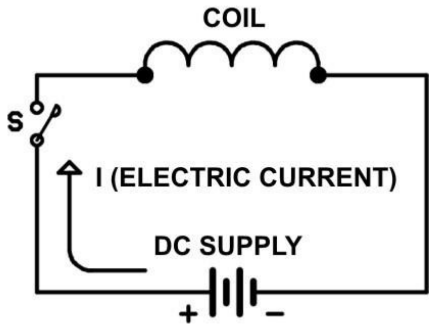

Figure 1: Electric circuit consisting of DC supply, coil, and switch

In Figure 1, 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 EMF. Its poles are opposite to the supply, this is why it is called "counter EMF". Figure 2 is shown as an observation of the events after the switch is closed until the current reaches steady state.

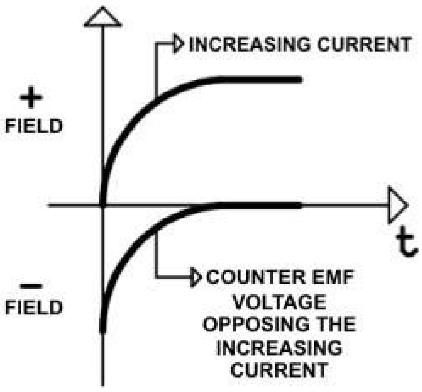

Figure 2: Observation of the events after the switch is closed

After current reaches steady 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 a minimum. Numerically, the ohmic resistances of coils are under 300 R. So, the 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 3.

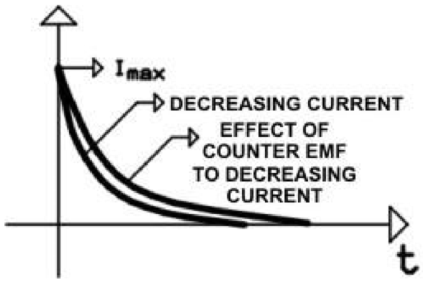

Figure 3: Support of counter EMF

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

The resistance of coils to the Alternating Current (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 are directly proportional to the frequency. Coils in AC are used in transformers, engines, contractors, electromagnets, etc..

Resistance and the ability to store energy depend on the coil. 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. " The inductance is high in high-frequency circuits. Because of this, the lower multipliers are mostly used in electronics. Lower multipliers and their mathematical conversion can be seen in Figure 4.

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

Figure 4: Lower multipliers and their mathematical conversion

Generally, coils with high inductance are used in electrics and coils with low inductance are used in electronics. In lower frequencies (up to 20kHz) 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 to their conductivities. There exist frame and air between the coil and its kernel. In this case, conductivity is a ratio of the magnitude of force vector between poles of a magnet when there are material and air. It is also called as permeability. It is shown with the letter "μ" (mui). "μ" (mui) is a relatively small value. Metals have low resistivity.

Non-metal materials with high permeability are developed through experiments. For example; Ferro-ferrite (Fe_30_4), copper-Ferro-ferrite ($CuFe_20_4$), lead-Ferro-Ferrite ($PbFe_20_4$) and iron combinations have resistivity nearly $10^(8)R$ and their magnetic permeabilities are between 100-200. These cores are called "ferrous" cores. Ferrite is a non-metal with high conductivity. Ferrite cores have conductivities between 10 and 200 mhos.

In high-frequency circuits (higher than 20 KHz), silicium iron combination is not used since they have higher loss than ferrite core coils.

In high frequency or a certain frequency band circuits, adjustable core coils are used. In this kind of coils, the core is screwed into 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 inductance of the coil.

Coils with different cores have different symbols. These symbols are shown in Figure 5

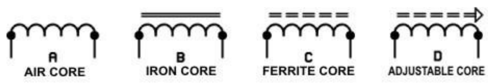

Figure 5: Different cores and their symbols

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

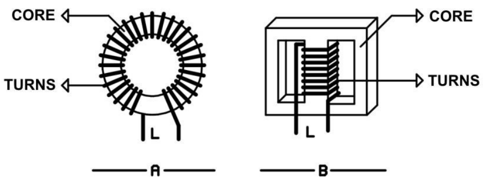

Figure 6: Toroid coils

The coil in Figure 6 is called "toroid coil". Toid coils are used in SMPS (Switch Mode Power Supply) circuits. The coil in figure 6.19B is called "transformer 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 the cylinder. Very small sized axial and radial coils are produced in order to be used in circuits printed on surfaces.
Axial, radial, toroid and transformer type coils can be seen in Figure 7;

Figure 7: Types of coils

1.2 Representation of Coil Inductances

Inductance of coils are indicated in two ways, 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:

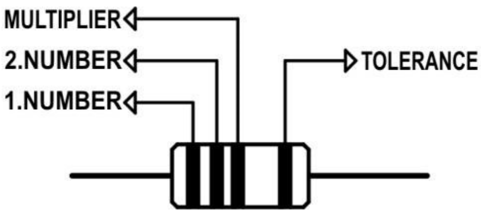

Figure 8: Color coding of a coil

The colors of the coil in Figure 8 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**

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

This means that this coil can have values between:

$$4700 - 470 = 4230\mu H\ and\ 4700 + 470 = 5170\mu H$$

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

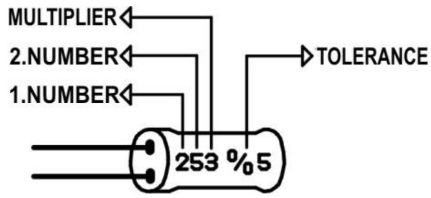

Figure 9: Example of numerical code method

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

1. Number	2. Number	Multiplier	Value	Tolerance
2	5	000	25000	5

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

This means that this coil can have values between:

$$25000 - 1250 = 23750\mu H\ and\ 25000 + 1250 = 26250\mu H$$

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 to handle high current. In electronic circuits, usually current is low and frequency is high. In these circuits, cores must be chosen appropriately for the working frequency. Coils get heated because of the current. There may occur two defects as a result of degeneration of coils for any reason (heat, high current, etc..). Firstly, conductors of the coil can be broken. In such a situation, the ohmic resistance of the coil is indefinite. Secondly, there may be electrical contact between conductors of coil. In such a situation, the ohmic resistance of the coil is normal but its inductance becomes zero or very small.

1.3 Measurement of Coils

Ohmic resistances of coils are measured by an ohmmeter. It is sufficient to connect the probes of ohmmeter to the terminals of the coil for this process. Measured ohmic resistance means that the coil conductors are not broken off. Coil measurement means the measure of the coil's inductive reactance. Most commonly used the 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 the measurement process. A mid-quality LCR meter is shown in following Figure 10.

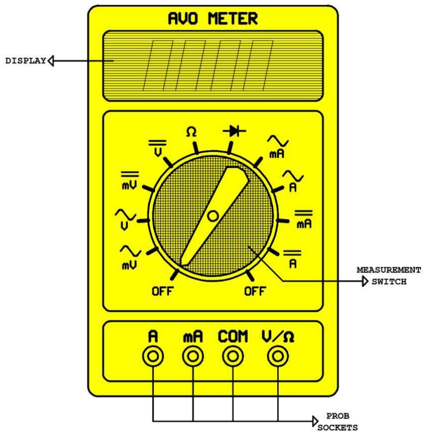

Figure 10: LCR meter

LCR meter is a device that measures delicate values. As seen in Figure 10, 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 the lowest level (100 μH) of "L" field. Coil is connected to measurement sockets (without probe) "zx" from its terminals, like in Figure 11.

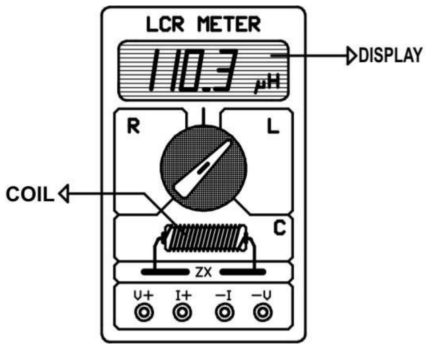

Figure 11: LCR meter format

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 100mikroH. 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 in every probe. Measurement of a radial type coil with using probes is shown in Figure 12.

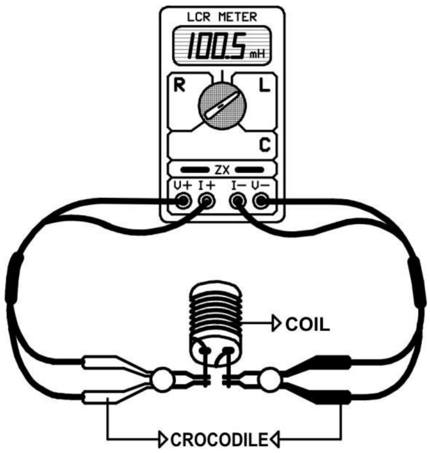

Figure 12: Measuring inductance value with LCR meter

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

1.4 Connection Types of Coils

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. Series connection of two coils is shown in Figure 13.

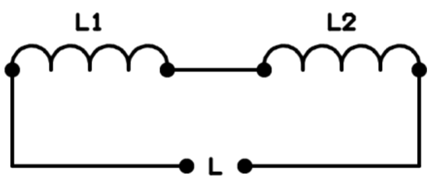

Figure 13: Inductance connection in series

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

$$L_{eq} = L_1 + L_2 + ... + L_n$$

Example : Three coils with inductances L1=100mH, L2= 250mH and L3=1H are in serial connection. Find the total inductance for given Figure 14.

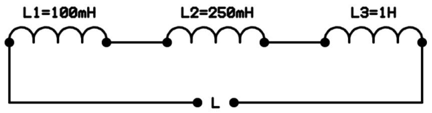

Figure 14: Example for coils in serial connection

Solution:

$$\begin{aligned} L_1 100mH &= 0.1H \\ L_2 = 250mH &= 0.25H \\ L_3 &= 1H \\ L_{eq} &= L_1 + L_2 + L_3 \\ L_{eq} &= 0,1 + 0,25 + 1 \\ L_{eq} &= 1,35 \end{aligned}$$

- **Parallel Connection:** If there is not a coil that is available for the required current to pass, multiple coils can be connected in parallel. Parallel connection of two coils is shown in Figure 15.

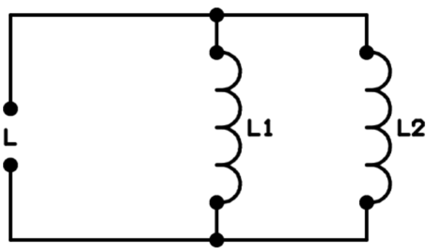

Figure 15: Coils in parallel connection

Total inductance in parallel connection can be calculated by following process;

$$\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} + ... + \frac{1}{L_n}$$

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 $L_1 = 6H$, $L_2 = 6H$ and $L_3 = 3H$ are connected parallel. Calculate the total inductance in given Figure 16.

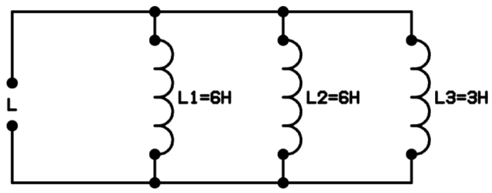

Figure 16: Example for coils in parallel connection

Solution:

$$\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}$$
$$\frac{1}{L_{eq}} = \frac{1}{6} + \frac{1}{6} + \frac{1}{3}$$
$$\frac{1}{L_{eq}} = \frac{4}{6}$$
$$L = \frac{6}{4} = 1,5H$$

- **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 17.

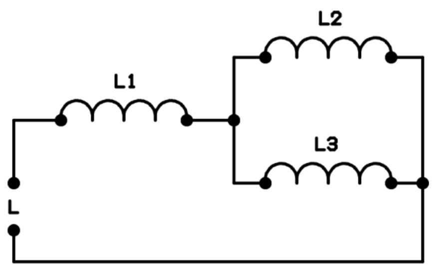

Figure 17: Example for coils in parallel connection

In 17, L_2 and L_3 coils are parallelly connected and L_1 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 L_2, L_3 connection as "L_A" ;

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

Total inductance of the circuit will be:

$$L_{eq} = L_1 + L_A$$

Example: Find the total inductance of the circuit in Figure 18.

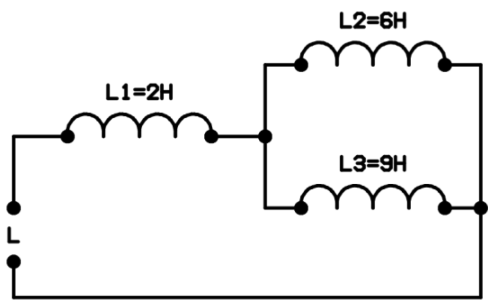

Figure 18: Example for coils in parallel connection

Solution:

If we call L_2, L_3 connection as "L_A":

$$L_A = \frac{L_2 \times L_3}{L_2 + L_3} = 3,6H$$
$$L_{eq} = L_1 + L_A = 2 + 3,6 = 5,6H$$

2 CAPACITORS

2.1 Introduction

A capacitor is a passive two-terminal electronic component that stores electrical energy in an electric field. The effect of a capacitor is known as capacitance. Capacitors are produced two types according to their usage in electrics and electronics circuits:

- Constant Capacitors
- Variable Capacitors

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

2.2 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**.

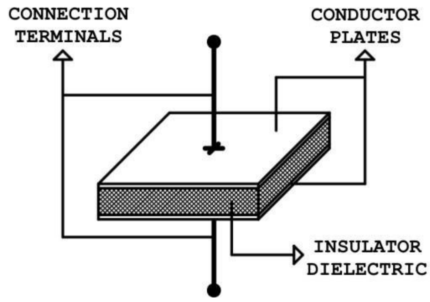

Figure 19: Structure of a capacitor

In Figure 19, the structure of the capacitor is shown. In the conductors, there are a lot of valance electrons and they can easily leave the atom. In insulators electrons are attached to their atoms with a big force.

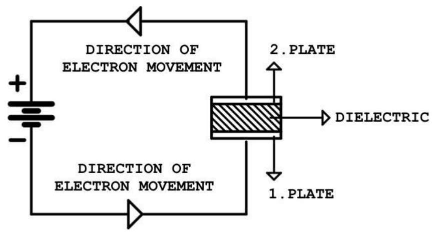

Figure 20: Electron flow in a capacitor

In Figure 20 is attached to a direct current source. The electrons that are seperated 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 two plates is equal to the voltage of dc source. 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 effects the dielectric material atoms making its electrons rotate in an elliptical shapet orbit.

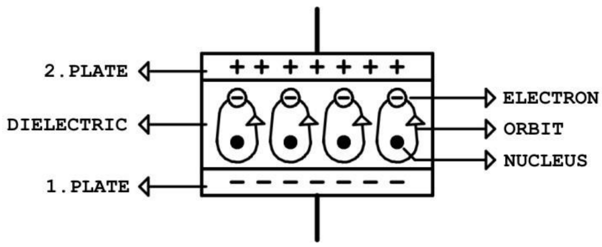

Figure 21: Structure of a capacitor

In Figure 21 a resistance is connected to a charged capacitor. In this situation electrons that come from the plate that has lots 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. When a capacitor is discharged, it has zero electric charge.The electrons of dielectric material of a discharged capacitor have a normal circle orbit.

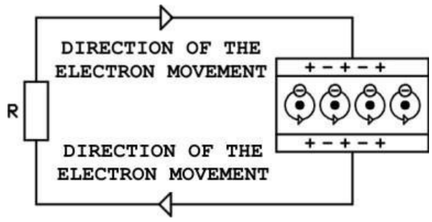

Figure 22: Electron flow of a dielectric material

In Figure 22 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 capacitor 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. Generally in electric circuits, capacitors that has lower capacitance are used. In Figure 23 lower capacitance values (Farad) and the relationship between them is shown.

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

Figure 23: Farad unit equivalents

In capacitors, metals that have high conductivities are used as plates. The most used material for capactior manufacturing is Aluminum because Aluminum is cheap and moisture-proof. According to dielectric material capacitors can be catogerized as follows:

1. AIR
2. PAPER
3. PLASTIC
4. POLYSTER
5. MIKA
6. CERAMIC

7. GLASS
8. ELECTROLYTIC

In electronics, capacitors behave differently according to their dielectric materials.

1. **Paper-Plastic-Polyster Capacitors:**
2. **Mika-Ceramic Capacitors:**
3. **Electrolytic Capacitors:**

Paper-Plastic-Polyster Capacitors They are used in sound frequency (20 Hz - 40 kHz) and radio frequency (150 kHz - 110 MHz) circuits. In paper dielectric circuits, dielectric material is obtained by injecting Parafin into the paper. They are called capacitor without a pole. Their capacitances are usually under 1 mikrofarad.

Mika-Ceramic Capacitors They are used in high frequency (10^4 MHz) circuits. Their power loss is small. They are also called capacitor without poles. Their capacitances are usually under 1 mikrofarad.

Electrolytic Capacitors They are usually used in sound frequency (20 Hz - 40 kHz) and radio frequency (150 kHz - 110 MHz) circuits. Their capacitances are between 1 mikrofarad and 104 mikrofarad. Electrolytic capacitors have poles. When connecting to the circuit, poles of the capacitor must be checked. If it is connected in the reverse direction it could harm the user and the circuitry. In Electrolytic capacitors, Aluminum or Tantalium are used as plates. The capacitor with Tantalium plates are called Tantal Capacitors. Their power loss is very small. Electrolytic 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).

2.3 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 24.

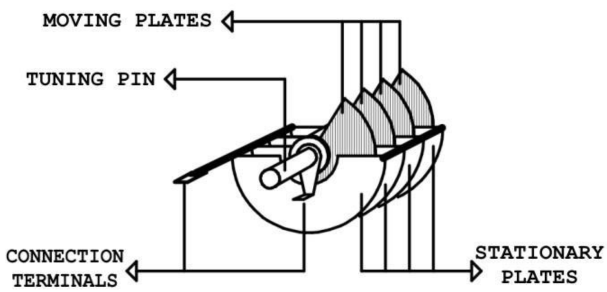

Figure 24: Structure of a adjustable capacitor

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 a way that they can easily crossed over each other. Two groups never contact 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 very 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 pikofarad.

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

In Figure25 symbols of the capacitors are shown;

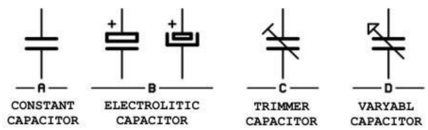

Figure 25: Different types of capacitors

In Figure 25 the most used capacitors polyster, lentil, electrolytic, trimmer and variable capacitors are shown.

Figure 26: Different types of capacitors II

2.4 Stored Energy in Capacitors

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

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

where W is stored energy in the capacitor (Watt-Seconds or Joules), Q is the electrical charge (Coulombs), E is the applied voltage across capacitor (Volt).

Mathematically, the charge (Q);

$$Q = C \times E$$

In the formulation, C is the capacitance, E is the voltage. If we put the charge expression in the energy formula;

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

Example: 30V DC is applied across to the capacitor which is 1000 mikroF. Find the stored energy in the capacitance.

$$1000\mu F = 1000 \times 10^{-6} = 10^{-3} F$$
$$W = \frac{1}{2} \times C \times E^2$$
$$W = \frac{1}{2} \times 10^{-3} \times 30^2$$
$$W = 0,45 Joules$$

2.5 Indication Of Capacitance Value Of Capacitors

Usually the capacitance values of the capacitors are written on the capacitors by the manufacturer. Earlier times some capacitors were produced whose capacitance values are specified by colors like resistors. Some manufacturers specifies the tolerance values of the capacitors by a letter written after the capacitance value. The tolerance letters of the capacitors and their mathematical equivalent is given below.

$$\begin{array}{ll} A - \%1 & E - \%0,10 \\ B - \%2 & F - \%0,05 \\ C - \%0,5 & G - \%5 \\ D - \%0,25 & H - \%10 \end{array}$$

When purchasing a capacitor, capacitance value and the voltage value that it can hold must be specified. The maximum voltage value that a capacitor can work is usually written on it. If a voltage value is higher than the maximum voltage value of a capacitor it will blow up and it could harm the user and the circuit. Because of this reason the operating voltage of the capacitor is so important.In Figure 27 three capacitors whose values are shown in different ways are seen.

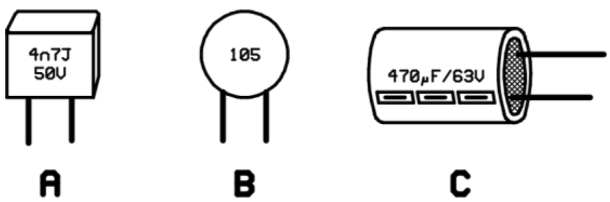

Figure 27: Tolerance values of capacitors

In Figure 27-A, the unit and the tolerance value of the capacitor is shown on it. Capacitance of this capacitor is 4,7 nF, and the tolerance is %5. Maximum working voltage is 50 Volts. In Figure 27-B only three numbers are seen. The unit of capacitance for this showing is pikofarad. The first and second numbers corresponds to the first and second number of the capacitance value. The third number is the scaling factor. So, the capacitance value is:

$$1 \quad 0 \quad 5 \equiv 1 \quad 0 \quad 10^5 pF = 100nF$$

In Figure 27-C it is clearly seen that the capacitance value is 470 mikrofarad and the maximum operating voltage is 63 Volts. In Figure 27-B the working voltage and in Figure 27-C tolerance value is not shown. In this situation these values should be learnt from the datasheet of capacitor which is provided by manufacturer. In the capacitors' datasheet, especially in the electrolytic capacitors' datasheet the efficient operating temperatures are also specified.

2.6 Measuring The Capacitors

In order to measure the capacitance value, LCR meter is used in **C** position. The capacitance 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 capacitance value can be read on the display. If the capacitor is removed from a circuit recently it might not be discharged after taking off from the circuit. 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 28 measurement of a capacitor without probe and in Figure 29 with probe is shown.

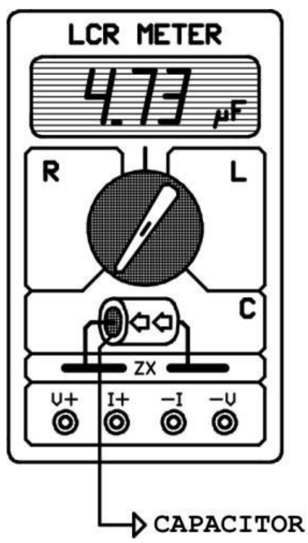

Figure 28: LRC meter C mode

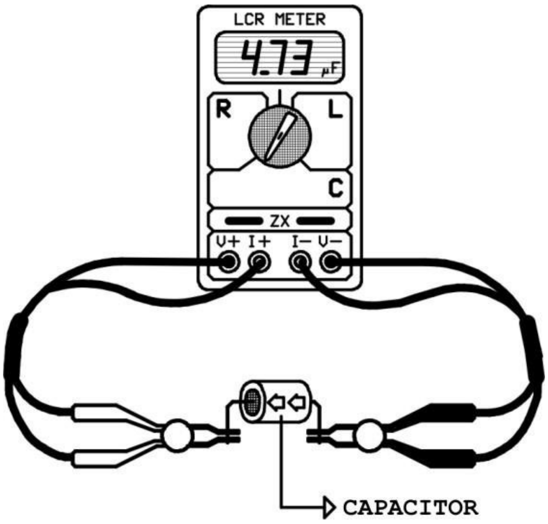

Figure 29: Measuring capacitor with LRC meter

2.7 Connections of the Capacitors

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 mathemetical 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 indivudial capacitors voltages. In Figure 30 serial connection of two capacitors are shown.If the capacitors are connected serially their total capacitance decreases. By formulation;

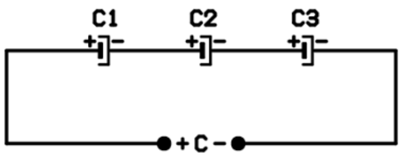

Figure 30: Measuring capacitor with LCR meter

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

$$E_{eq} = E_1 + E_2 + ... + E_n$$

The energy stored is ;

$$W_{eq} = W_1 + W_2 + ... + W_n$$

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 31 serial connection of three polar capacitors are shown:

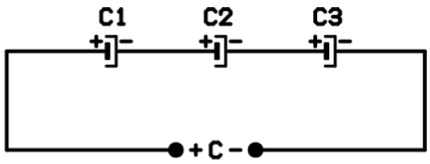

Figure 31: Serial capacitors with different polarities

If two polar capacitors which have same capacitance are connected inversely serial a non-polar capacitor is obtained. However, the resulting capacitor will lose a lot of capacitance value. In 32 this kind of connections are shown.

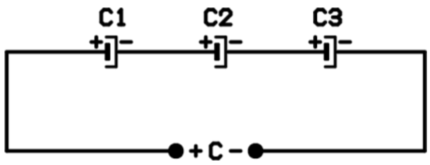

Figure 32: Serial capacitors with same capacitances

Non-polar capacitor is also called **bipolar capacitor**.

Example: For the circuit in 33;

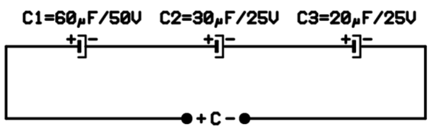

Figure 33: Serial connection of capacitors

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

Solution:

A- Total capacitance;

$$\frac{1}{L_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$
$$C = 10\mu F$$

B- The maximum work voltage for the capacitance group;

$$E = E_1 + E_2 + E_3$$
$$E = 100V$$

- **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 34 parallel connection of two capacitors are shown.

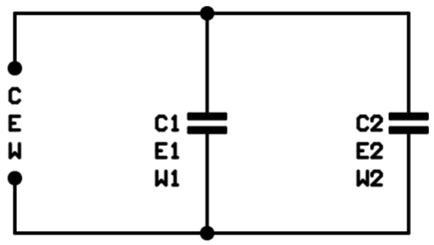

Figure 34: Parallel capacitor connection

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 tha capacitances. Mathematical notation is;

$$C_{eq} = C_1 + C_2 + ... + C_n$$

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.

$$W_{eq} = W_1 + W_2 + ... + W_n$$

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, the capacitor can blow up. This could harm the user and the circuit. In Figure 35 parallel connected capacitors are shown.

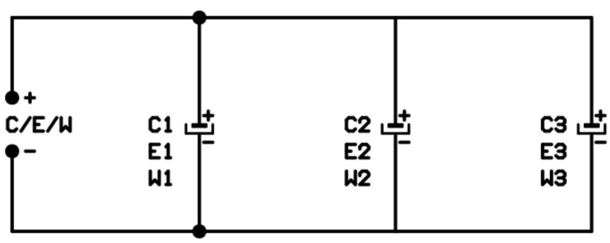

Figure 35: Parallel capacitor connection without poles

Example: For the circuit given in the Figure 36,

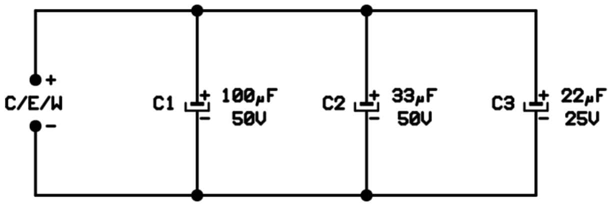

Figure 36: Parallel capacitor example

A- Calculate the total capacitance, **B-** Calculate the maximum operating voltage for the new circuit.

Solution:

A- Total Capacitance;

$$Ceq = C_1 + C_2 + C_3$$
$$C = 155\mu F$$

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

$$E = 25V$$

- **Mixed Connection:**If the desired capacitance could not be found in a circuit by mix connected capacitors the desired value can be obtained. Mix connection is the combination of serial and parallel connections. In Figure 37 the mix connection of capacitors are shown;

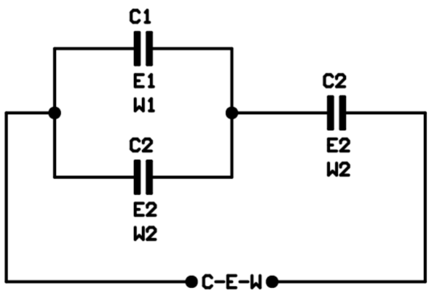

Figure 37: Mixed connection of capacitors

In Figure 37 C_1 and C_2 capacitors are in parallel to each other and C_3 is serial to this group. For finding the total capacitance, first the parallel capacitors are brought together and they become form one capacitor. Then the capacitance is calculated as it is a serial connected capacitors.

Example: Calculate the total capacitance of the circuit shown in Figure 38.

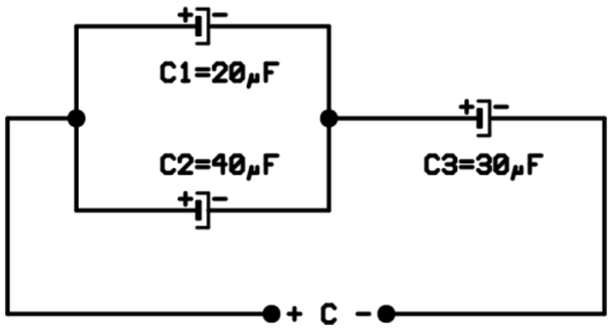

Figure 38: Example for mixed connection of capacitors

Solution:

Let's say the total capacitance of C_1 and C_2 is C_A.

$$C_A = C_1 + C_2 = 60\ \mu F$$
$$C_{eq} = \frac{C_A \times C_3}{C_A + C_3} = \frac{1800}{90} = 20\ \mu F$$