Module Title: Fundamental of Electrical Engineering (DC)

Module Code:	**UOMU024011**

Week 1

Introduction of Basic Electric Circuits & Components

Symbols and abbreviations, units, electric circuits, and its elements

1.1 SI Units and Common Prefixes.

1.2 Electrical Circuits, and its elements

Lecture (Week 1)

This chapter outlines the basics of Electrical Circuits:

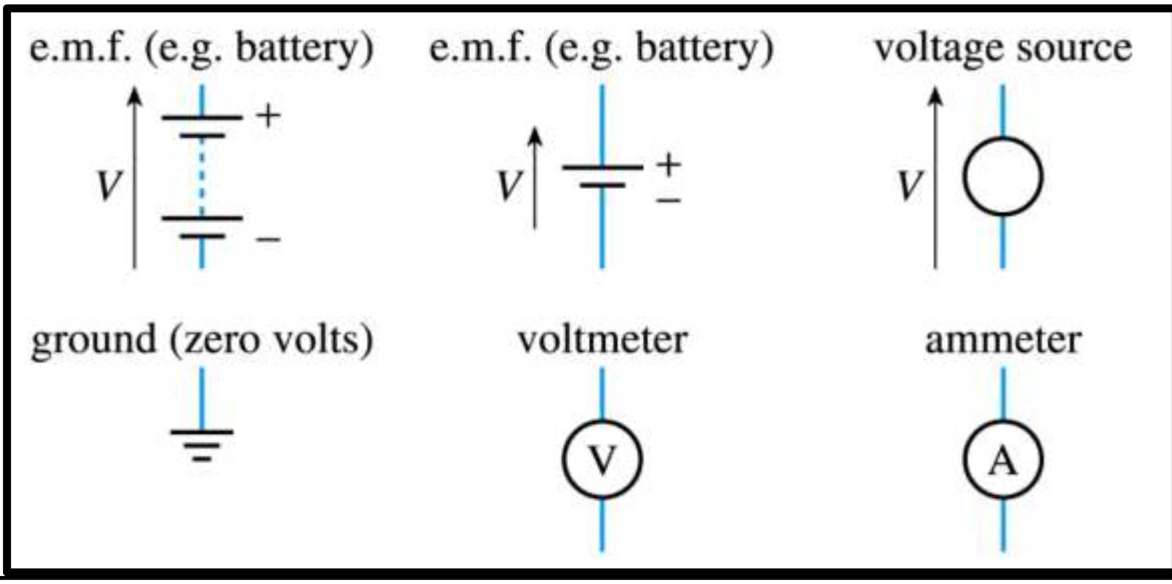
1.1 SI Units and Common Prefixes. / Symbols and abbreviations

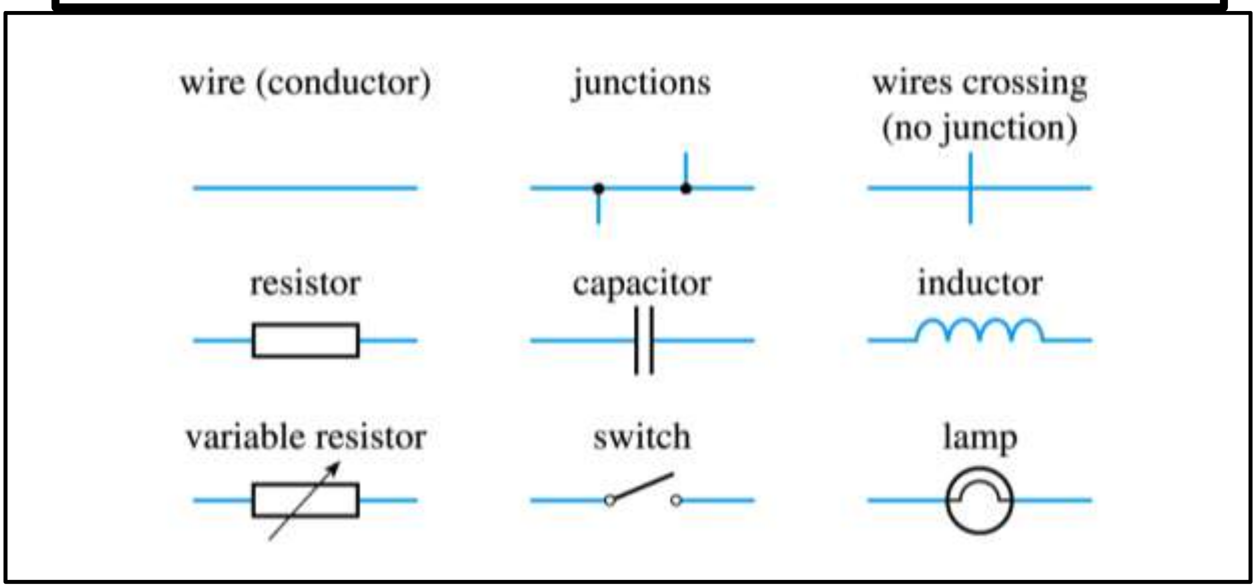
Quantity	Quantity symbol	Unit	Unit symbol
Capacitance	C	Farad	F
Charge	Q	Coulomb	C
Current	I	Ampere	A
Electromotive force	E	Volt	V
Frequency	f	Hertz	Hz
Inductance (self)	L	Henry	H
Period	T	Second	s
Potential difference	V	Volt	V
Power	P	Watt	W
Resistance	R	Ohm	Ω
Temperature	T	Kelvin	K
Time	t	Second	s

1.1.1 Common Prefixes/ SI units

Prefix	Name	Meaning (multiply by)
T	tera	10^{12}
G	giga	10^{9}
M	mega	10^{6}
k	kilo	10^{3}
m	milli	10^{-3}
μ	micro	10^{-6}
n	nano	10^{-9}
p	pico	10^{-12}

1.1.2 Circuit Symbols


e.m.f. (e.g. battery)
e.m.f. (e.g. battery)
voltage source
V
+
−
ground (zero volts)
voltmeter
ammeter
V
A


wire (conductor)
junctions
wires crossing (no junction)
resistor
capacitor
inductor
variable resistor
switch
lamp

Week 2

The Direct–Current Network

1.2 Electrical Circuits and its elements.

1.2.1 Direct Currents.

1.2.2 Resistors, Capacitors and Inductors.

1.2.3 Electric charge: An amount of electrical energy can be positive or negative.

1.2.4 Electric current: A flow of electrical charge, often a flow of electrons.

Conventional current is in the opposite direction to a flow of electrons.

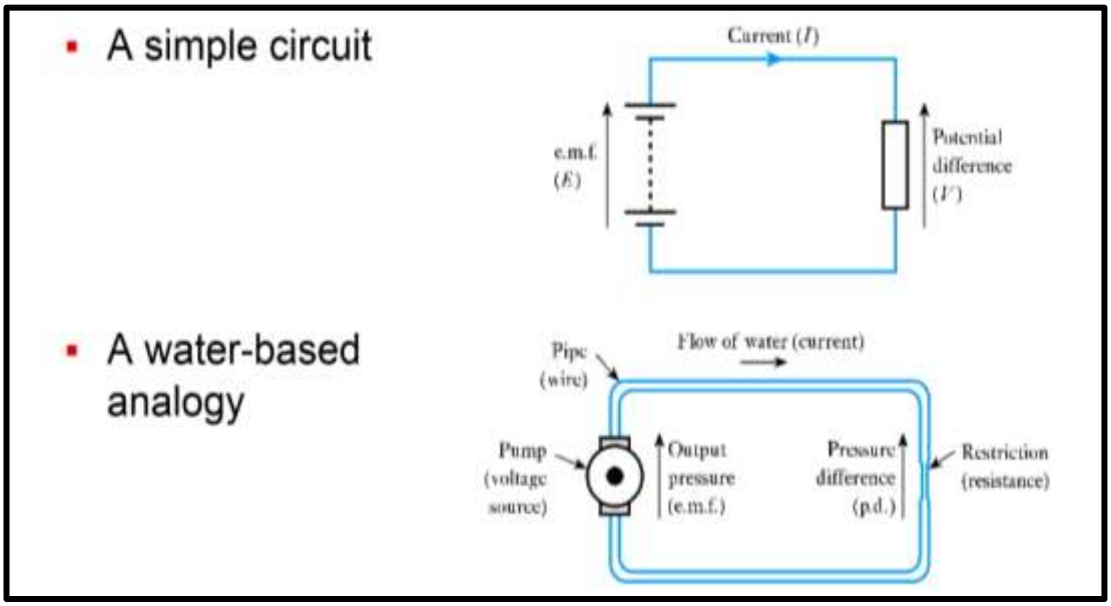
Current flow in a circuit a sustained current needs a complete circuit.

1.2.5 Electromotive force (E.M.F) and potential difference:

The stimulus that causes a current to flow is an e.m.f. This represents the energy introduced into the circuit by a battery or generator.

This results in an electric potential at each point in the circuit between any two points in the circuit there may exist a potential difference both e.m.f. and potential difference are measured in volts.

1.2.3 Simple Electrical Circuit:



1.2.4 Voltage Reference Points

- All potentials within a circuit must be measured with respect to some other point Figure 1.a
- We often measure voltages with respect to a zero-volt reference called the ground or earth. Figure 1.b

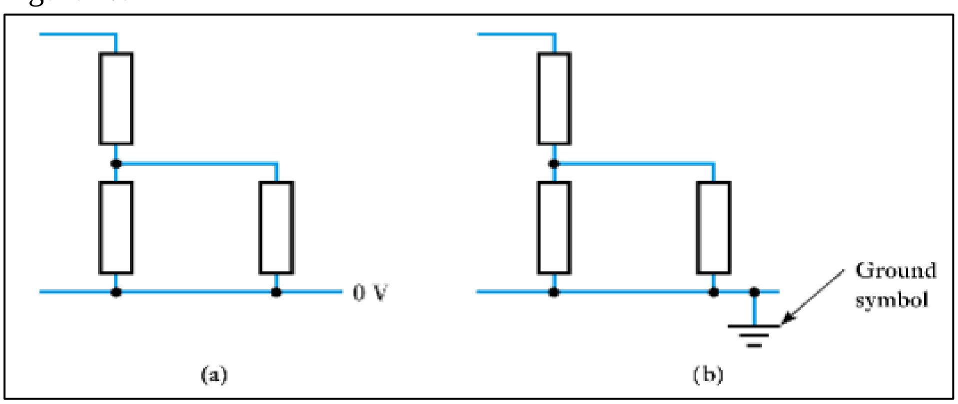


Figure 1, a, b

1.3 Direct Current

Currents in electrical circuits may be constant in DC circuits.

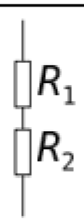
In this semester course will concerned only DC circuits.

In DC circuits the current flowing in a conductor always flows in the same direction this is direct current (DC).

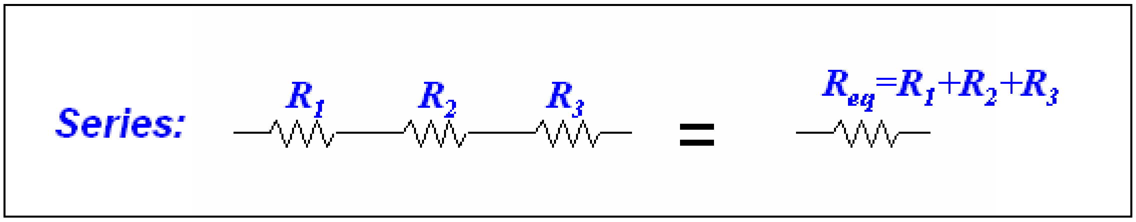
1.4 Resistors, Capacitors and Inductors.

- **Resistors** provide resistance
  - they oppose the flow of electricity
  - measured in Ohms (Ω)
- **Capacitors** provide capacitance
  - they store energy in an electric field
  - measured in Farads (F)
- **Inductors** provide inductance
  - they store energy in a magnetic field
  - measured in Henry (H)

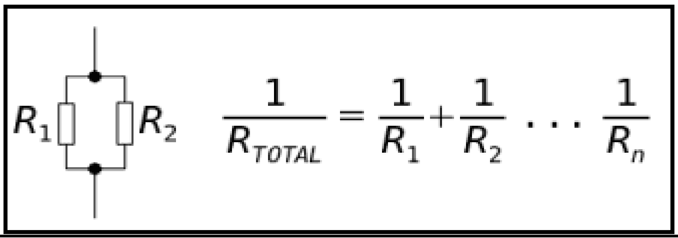
1. **Resistance in series:**

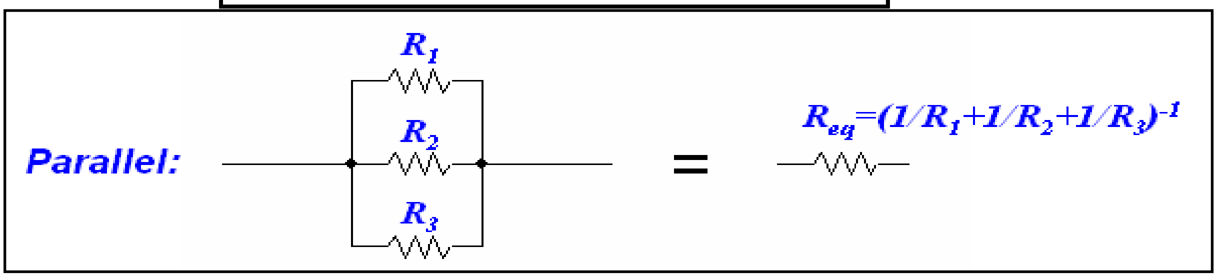


$$R_{TOTAL} = R_1 + R_2 \; . \; . \; . \; R_n$$



2. **Resistance in parallel:**



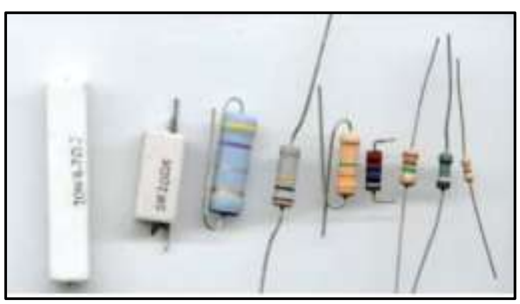


<u>3. Types of Resistors</u> :

Now that the basics have been covered its time to take a more detailed look at the various electronic components, the different types, and their specific uses. As before, we start with the resistor.

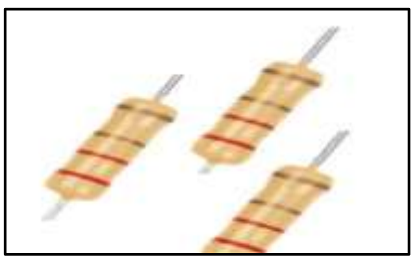
These fall into two major categories:

1. Fixed resistors: The most widely used. There are many types of fixed resistor for use in different circumstances.

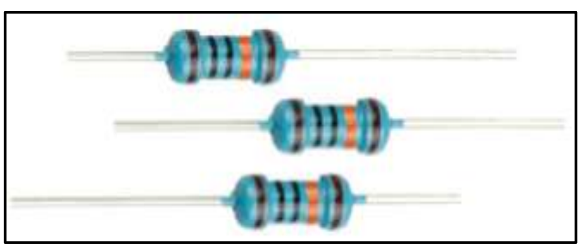


2. Variable resistors – these consist of a fixed resistor element and a slider for tapping off a variable resistance.

3. Carbon film – this resistor type is formed by depositing carbon onto a ceramic former; the resistance value being set by cutting a helix or spiral into the carbon film.

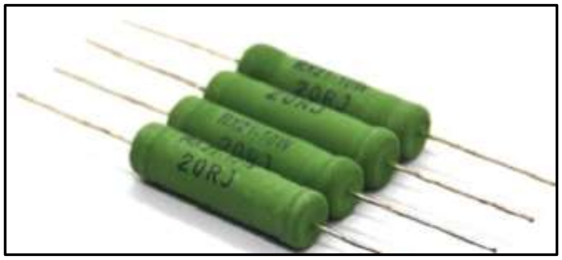


4. Metal film – instead of a carbon film, this resistor type uses a metal film deposited on ceramic rod.

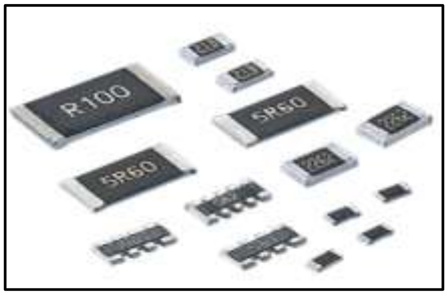


5. Metal oxide film – very similar to the metal film resistor, but uses a metal oxide film (such as tin oxide) deposited on a ceramic rod.

6. Wirewound – generally used for high-power applications, these resistors are made using lengths of wire, called resistance wire, of which the exact resistance per length is known. The wire is wound round a former, and the resistor covered with a protective enamel coating.



7. Thin film – uses thin film technology and is used for manufacturing billions of the tiny surface mount types of resistor (SMT) in use today.



Week 3

Capacitors and inductors

3. Capacitors

3.1 Capacitance parameter

- A capacitor *consists of two metallic surfaces* or *conducting surfaces* separated by a *dielectric medium*.
- It is a *circuit element* which is capable of *storing electrical energy* in its *electric field*.
- *Capacitance* is its capacity to *store electrical energy*.
- *Capacitance* is the *proportionality constant relating the charge on the conducting plates to the potential.*

Charge on the capacitor **Q**= **C V**

Where '**C**` is the capacitance in farads, if '**Q**' is charge in coulombs and '**V**' is the potential difference across the capacitor in volts.

The current flowing in the circuit is rate of flow of charge:

Where : $i = \frac{dq}{dt} = C\frac{dv}{dt}$ $\therefore \boldsymbol{i = C\frac{dv}{dt}}$

The capacitance of a capacitor depends on the dielectric medium & the physical dimensions. For a parallel plate capacitor, the capacitance:

$$\mathbf{C = \frac{€A}{D} = €_0 €r\frac{A}{D}}$$

A : is the surface area of plates D: is the separation between plates

€ : is the absolute permeability of medium

€₀ : is the absolute permeability of free space

€ᵣ : is the relative permeability of medium

$$i = \frac{dq}{dt} = C\frac{dv}{dt}$$

$$\frac{dv}{dt} = \frac{i}{c}$$

$$V = \frac{1}{c}\int i\,dt$$

The power absorbed by the capacitor $P = vi = vc\,\frac{dv}{dt}$

Energy stored in the capacitor $W = \int_0^t P\,dt = \int_0^t VC\,\frac{dv}{dt}dt$

$$= C\int_0^t v\,dv = \frac{1}{2}\,cv^2 \text{ Joules}$$

This energy is stored in the electric field set up by the voltage across capacitor.

3.2 Capacitors in Series and Parallel

1. Derive expressions for total capacitance in series and in parallel.
2. Identify series and parallel parts in the combination of connection of capacitors.
3. Calculate the effective capacitance in series and parallel given individual capacitances.
4. Several capacitors may be connected together in a variety of applications.

There are two simple and common types of connections, called series and parallel, for which we can easily calculate the total capacitance. Certain more complicated connections can also be related to combinations of series and parallel.

3.2.1 Capacitance in Series

Figure (1a) shows a series connection of three capacitors with a voltage applied.

As for any capacitor, the capacitance of the combination is related to charge and voltage by: **C= QV**

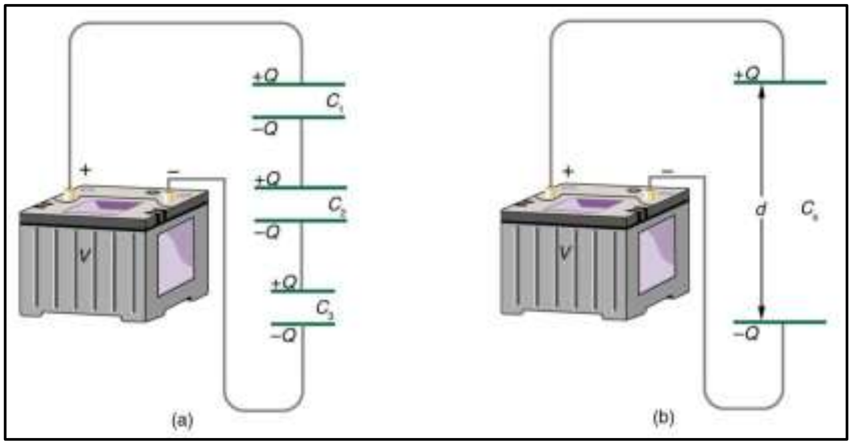


Figure 1a ,b

Figure (1a) that opposite charges of magnitude **Q** flow to either side of the originally uncharged combination of capacitors when the voltage **V** is applied.

Conservation of charge requires that equal-magnitude charges be created on the plates of the individual capacitors, since charge is only being separated in these originally neutral devices.

The end result is that the combination resembles a single capacitor with an effective plate separation greater than that of the individual capacitors.

capacitors alone. (See Figure 1b.) Larger plate separation means smaller capacitance. It is a general feature of series connections of capacitors that the total capacitance is less than any of the individual capacitances.

Capacitance in series voltage (V) and charge (Q)

Let $\mathbf{C_1}$ $\mathbf{C_2}$ $\mathbf{C_3}$ be the three capacitances connected in series and let $\mathbf{V_1}$ $\mathbf{V_2}$ $\mathbf{V_3}$ be the potential difference p.ds across the three capacitors. Let **V** be the applied voltage across the combination and **C**. see figure 2 .

The combined or equivalent capacitance. For a series circuit, charge on all capacitors is same but potential difference (p.d) across each is different.

$$V=V_1+V_2+V_3$$

$$\frac{Q}{C} = \frac{Q}{C1} + \frac{Q}{C2} + \frac{Q}{C3}$$

$$\frac{1}{C} = \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}$$

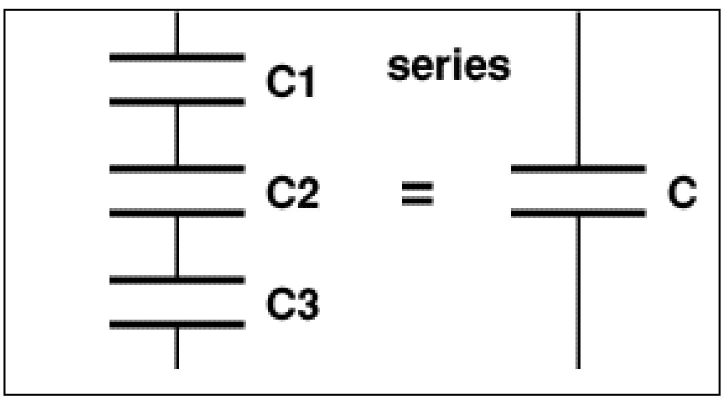


Figure 2 Three capacitances connected in series

Example 3.1.

What is the series capacitance?

Find the total capacitance for three capacitors connected in series, given their individual capacitances are: 11.0 µF, 15.0 µF, and 18.0 µF.

Strategy

With the given information, the total capacitance can be found using the equation for capacitance in series.

Solution:

Entering the given capacitances into the expression:

$$\frac{1}{C\ total} = \frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}$$

$$\frac{1}{C\ total} = 1/\ 11.000\mu F + 1/\ 15.000\mu F + 18.000\mu F$$

C total = 0.909 µF + 0.0666 µF + 0.0555 µF

C total = 1.033 µF

3.2 .2 Capacitance in parallel:

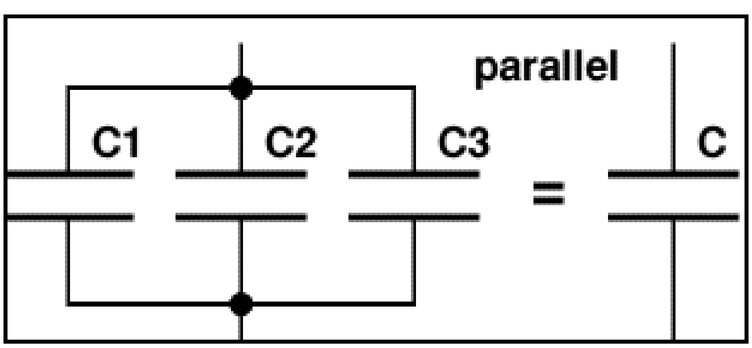


Figure 3 Capacitance in parallel

Figure 3 a,b shows a parallel connection of three capacitors with a voltage applied.

Here the total capacitance is easier to find than in the series case.

To find the equivalent total capacitance **Cp**, we first note that the voltage across each capacitor

is **V**, the same as that of the source, since they are connected directly to it through a conductor. (Conductors are equipotential, and so the voltage across the capacitors is the same as that across the voltage source.) Thus the capacitors have the same charges on them as they would have if connected individually to the voltage source.

The total charge **Q** is the sum of the individual charges:

$$Q = Q1 + Q2 + Q3.$$

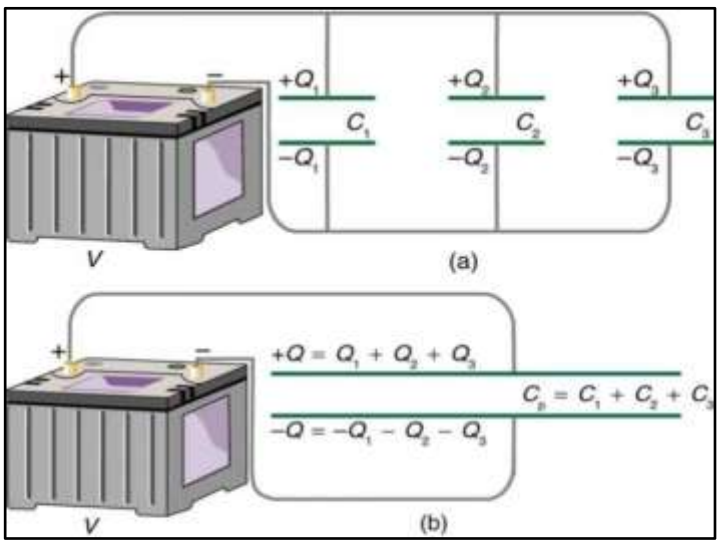


Figure 3 a, b

Figure 3 (a) Capacitors in parallel. Each is connected directly to the voltage source just as if it were all alone, and so the total capacitance in parallel is just the sum of the individual capacitances.

Figure 3 (b) The equivalent capacitor has a larger plate area and can therefore hold more charge than the individual capacitors.

Using the relationship **Q = CV**, we see that the total charge is **Q = CpV**, and the individual charges are

Q1 = C1V,

Q2 = C2V, and

Q3 = C3V.

Entering these into the previous equation gives.

CpV = C1V + C2V + C3V.

Canceling V from the equation, we obtain the equation for the total capacitance in parallel

Cp: Cp = C1 + C2 + C3 + ….

Total capacitance in parallel is simply the sum of the individual capacitances. (Again the "…" indicates the expression is valid for any number of capacitors connected in parallel.) So, for example, if the capacitors in previous Example 3.1 were connected in parallel, their capacitance would be.

Cp = 11. µF + 15.0 µF + 18.0 µF = 44.0 µF.

The equivalent capacitor for a parallel connection has an effectively larger plate area and, thus, a larger capacitance, as illustrated in Figure 3b.

3.2.3 More complicated connections of capacitors:

can sometimes be combinations of series and parallel. (See Figure 4.) To find the total capacitance of such combinations, we identify series and parallel parts, compute their capacitances, and then find the total.

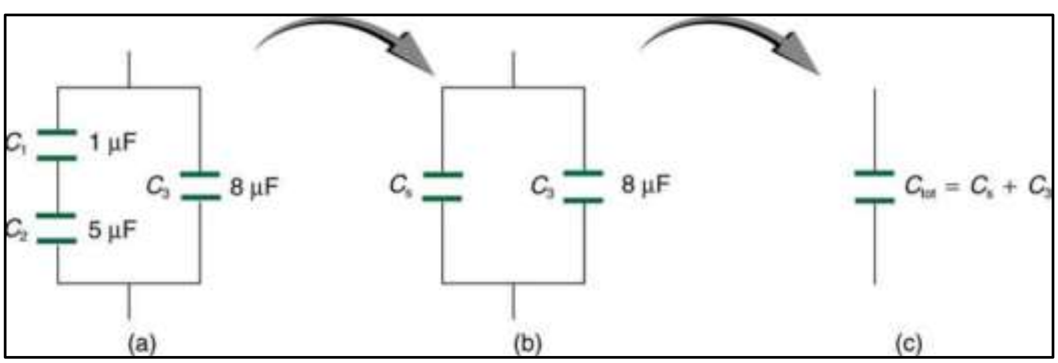


Figure 4, a,b,c

Figure 4. (a) This circuit contains both series and parallel connections of capacitors.

See Example 4 for the calculation of the overall capacitance of the circuit.

(b) **C1** and **C2** are in series; their equivalent capacitance $\mathbf{C_{Total}}$ is less than either of them.

(c) Note that $\mathbf{C_{TotalP}}$ in parallel with **C3**. The total capacitance is,

thus, the sum of $\mathbf{C_{SUM}}$ and **C3**.

Example 3. A MIXTURE OF SERIES AND PARALLEL CAPACITANCE

Find the total capacitance of the combination of capacitors shown in Figure 4.

Assume the capacitances in Figure 4 are known to three decimal places (**C1** = 1.000 µF, **C2** = 5.000 µF, and **C3** = 8.000 µF), and round your answer to three decimal places.

Solution:

Since **C1** and C2 are in series, their total capacitance is given by:

$$\mathbf{1/C_{TotalS} = 1/C1 + 1/C2}$$

Entering their values into the equation gives.

$$\mathbf{1/C_{TotalS} = 1/C1 + 1/C2 = 1/1.000\mu F + 1/5.000\mu F = 1.200\mu F}$$

Inverting gives $\mathbf{C_{TotalS} = 0.833\ \mu F.}$

This equivalent series capacitance is in parallel with the third capacitor C3; thus, the total is the Sum:

$$\mathbf{C_{EqvTotal} = C_{TotalS} + C3 = 0.833\mu F + 8.000\mu F = 8.833\mu F}$$

PROBLEMS & EXERCISES: (Home Work)

Q1: Find the total capacitance of the combination of capacitors in Figure 5.

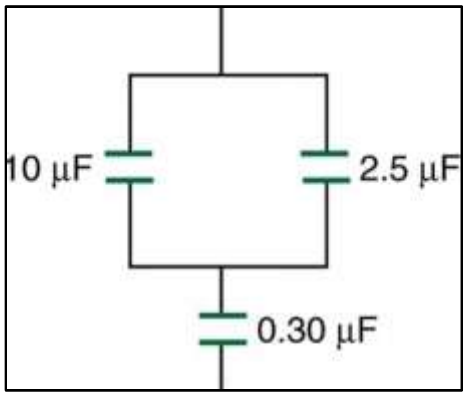


Figure 5 A combination of series and parallel connections of capacitors

Q2. Suppose you want a capacitor bank with a total capacitance of 0.750 μF and you possess numerous 1.50 μF capacitors. What is the smallest number you could hook together to achieve your goal, and how would you connect them?

Q3. What total capacitances can you make by connecting a 5.00 μF and an 8.00 μF capacitor together?

Q4. Find the total capacitance of the combination of capacitors shown in Figure 6.

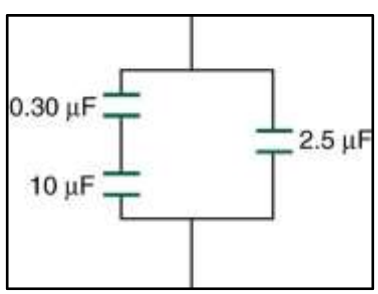


Figure 6

Q5. Find the total capacitance of the combination of capacitors shown in Figure 7.

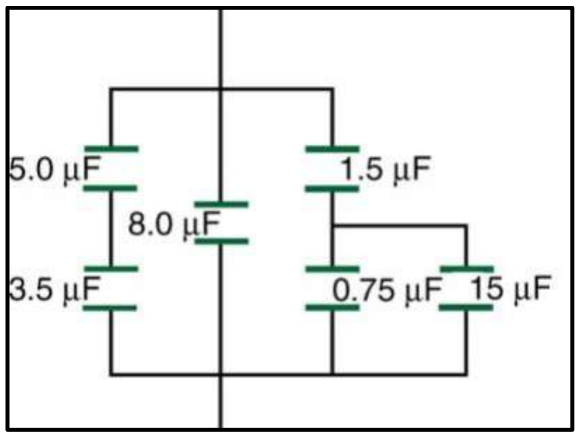


Figure 7

SELECTED SOLUTIONS TO PROBLEMS & EXERCISES

Q1. 0.293 µF

Q3. 3.08 µF in series combination, 13.0 µF in parallel combination

Q4. 2.79 µF

Conclusions:

1. *The current in a capacitor is zero, if the voltage across it is constant, that means the capacitor acts as an open circuit to DC.*

2. *The capacitor can store a finite amount of energy, even if the current through it is zero.*

Week 3 continue

4. Inductors.

4.1 Inductance

Inductance is the property of a material by virtue of which it:

- *opposes any change of magnitude and direction of electric current passing through conductor*.
- A wire of certain length, when twisted into a coil becomes a basic conductor.
- A change in the magnitude of the current changes the electromagnetic field.

Notes:

1. Increase in current expands the field & decrease in current reduces it.
2. A change in current produces change in the electromagnetic field.
3. This induces a voltage across the coil according to Faradays laws of Electromagnetic Induction.

Induced Voltage $\mathbf{V = L\,\frac{di}{dt}}$

V = Voltage across inductor in volts

I = Current through inductor in amps

$$\mathbf{di = \frac{1}{L}\,v\,dt}$$

Integrating both sides,

$$\int_0^t di = \frac{1}{L}\int_0^t v\,dt$$

Power absorbed by the inductor: $\mathbf{P = Vi = Li\,\frac{di}{dt}}$

Energy stored by the inductor:

$$W=\int_0^t P\,dt = \int_0^t Li\,\frac{di}{dt}\,dt = \frac{Li^2}{2}$$

$$W = \frac{Li^2}{2}$$

Conclusions

1) **V = L $\frac{di}{dt}$**

The ***induced voltage*** across an inductor is **zero** if the current through it is constant.

That means an **inductor acts as short circuit** to DC.

2) The inductor can store finite amount of energy, even if the voltage across the inductor is zero.
3) A pure inductor never dissipates energy, it only stores it. Hence it is also called as a non–dissipative passive element. However, physical inductor dissipate power due to internal resistance.

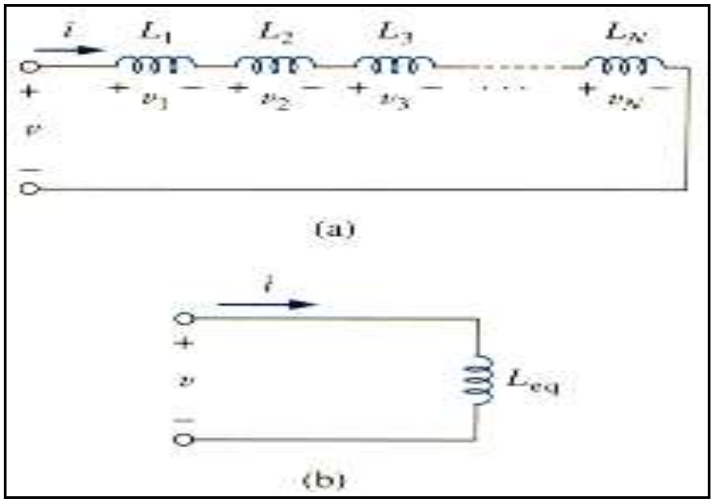
Example # 1
The current in a 2H inductor raises at a rate of 2A/sec.
Find the voltage across the inductor & the energy stored in the magnetic field at after 2sec.

V = L $\frac{di}{dt}$

= 2X2 = 4V

W = $\frac{1}{2}$ Li^2 = $\frac{1}{2}$ X 2 X (4)^2 = 16 J

4.2 Inductance in series:



$$V(t) = V_1\ (t) + V_2\ (t)$$

$$= L_1 \frac{di}{dt} + L_2 \frac{di}{dt}$$

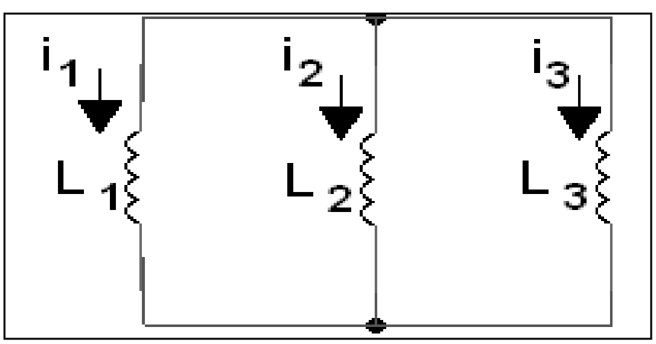
$$= (L_1 + L_2)\frac{di}{dt} = L_{eq}\frac{di}{dt}$$

$$\therefore L_{eq} = L_1 + L_2$$

In `*n*` inductances are in series, then the equivalent inductance.

$$L_{eq} = L_1 + L_2 + \ldots\ldots\ldots\ldots + L_n$$

4.3 Inductances in parallel



i(t) = i_1(t) + i_2(t)

$$= \frac{1}{L_1}\int Vdt + \frac{1}{L_2}\int Vdt = \left(\frac{1}{L_1} + \frac{1}{L_2}\right)\int Vdt$$

$$= \frac{1}{L_{eq}}\int Vdt$$

$$\therefore \frac{1}{L_{eq}} = \left(\frac{1}{L_1} + \frac{1}{L_2}\right)$$

In `$n$` Inductances are connected in parallel, then

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

Appendix I

Important formulas

V-I Relation of circuit elements

Circuit elements	Voltage(V)	Current(A)	Power(W)
Resistor R (Ohms Ω)	V=RI	I=$\frac{V}{R}$	P =i^2R
Inductor L (Henry H)	V=L$\frac{di}{dt}$	I =$\frac{1}{L}\int vdt + i_o$	P =Li $\frac{di}{dt}$
Capacitor C (Farad F)	I=$\frac{1}{C}\int idt + v_0$ where v_0 is the initial voltage across capacitor	I =C $\frac{dv}{dt}$	P =CV $\frac{dv}{dt}$

References:

1. **Floyd, Thomas L., 2013, Principles of Electric Circuits, 9th Edition, Pearson.**
2. **Fundamental of electric circuits. C.K Alexander, and M.N.O Sadiku. Mc Graw Hill Education**
3. **Horowitz, P., 2015, The Art of Electronics, 3rd Edition, Cambridge University Press.**