

SEMESTER - I

BASIC ELECTRONICS

UNIT - I : PASSIVE COMPONENTS AND CIRCUIT
FUNDAMENTALS



BY

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LECTURER IN PHYSICS

SEMESTER - I

COURSE 6: BASIC ELECTRONICS

Theory

Credits: 3

3 hrs/week

COURSE OBJECTIVES

This course aims to introduce undergraduate physics students to the fundamental principles of electronics. It covers passive components, semiconductor physics, diode and transistor operation, DC power supplies, and the basics of digital logic. The goal is to build a solid foundation in circuit analysis and electronic devices for students with minimal prior background.

LEARNING OUTCOMES:

By the end of the course, students will be able to:

1. Identify and explain the function and types of resistors, capacitors, and inductors.
2. Understand the basic concepts of semiconductors and diode characteristics.
3. Analyze simple transistor circuits and their applications.
4. Describe the functioning of rectifiers, filters, and voltage regulators.
5. Perform basic binary arithmetic and construct simple digital logic circuits.

UNIT I: PASSIVE COMPONENTS AND CIRCUIT FUNDAMENTALS (9 hrs)

Resistors: Types (carbon, wire-wound, metal film), color coding, tolerance, power ratings
- Capacitors: Types (ceramic, electrolytic, film), applications, charge/discharge behavior -
Inductors: Basic structure and applications - Series and parallel combinations: Equivalent resistance/capacitance/inductance - Basic laws: Ohm's Law, Kirchoff's Voltage and Current Laws (KVL, KCL) with simple applications

UNIT II: SEMICONDUCTOR PHYSICS AND DIODES (9 hrs)

Intrinsic vs extrinsic semiconductors - Doping, energy band diagrams, charge carriers - PN junction diode: Construction, working, forward/reverse biasing, I-V characteristics - Special diodes: Zener diode, LED, photodiode, solar cell – construction, characteristics and uses

UNIT III: TRANSISTORS AND THEIR OPERATION (9 hrs)

BJT: Structure, current components, working of NPN/PNP - Configurations: CB, CE, CC – input/output characteristics - Applications: Transistor as switch and amplifier (qualitative understanding)

UNIT IV: POWER SUPPLIES AND REGULATION (9 hrs)

Need for DC power supply: Block diagram - Rectifiers: Half-wave, full-wave, bridge with waveforms - Filter circuits: RC, LC, and π filters – working principle - Voltage regulation: Zener diode regulation, IC regulators (brief intro)

UNIT V: INTRODUCTION TO DIGITAL ELECTRONICS

(9 hrs)

Analog vs Digital signals - Number systems: Binary, decimal, hexadecimal – conversions, binary arithmetic - Logic gates: AND, OR, NOT – symbols, truth tables, simple logic circuits, Universal gates (NAND, NOR) – brief introduction

Textbooks / References:

1. V.K. Mehta & Rohit Mehta – *Principles of Electronics*, S. Chand
2. R.S. Sedha – *A Textbook of Applied Electronics*, S. Chand
3. D. Chattopadhyay & P.C. Rakshit – *Electronics: Fundamental Concepts*, New Central
4. Malvino & Leach – *Digital Principles and Applications*, McGraw-Hill
5. A.K. Maini – *Digital Electronics*, Wiley India

Student Activities

1. **Component Hunt**
 - Task: Identify and collect physical samples of resistors, capacitors, diodes, and transistors from old circuit boards.
 - Outcome: Visual and tactile understanding of component shapes, labels, and ratings.
2. **Poster Presentation**
 - Topic examples: “Types of Diodes and Their Applications” or “Power Supply Block Diagram.”
 - Outcome: Encourages concise technical communication and peer learning.
3. **Group Demonstration**
 - Task: Simulate or build a basic rectifier or transistor switch circuit using breadboard or simulation software.
 - Outcome: Team collaboration and hands-on understanding.
4. **Number System Puzzle or Quiz**
 - Task: Convert between binary, decimal, and hexadecimal; perform binary addition/subtraction.
 - Outcome: Reinforces digital electronics basics through gamified learning.
5. **Mini Project (Optional)**
 - Task: Build a simple LED flasher or night lamp circuit using transistors and passive components.
 - Outcome: Design thinking and real-world application.
6. **Circuit Debugging Challenge**
 - Task: Find and correct errors in a faulty circuit diagram provided by the teacher.
 - Outcome: Improves analytical and practical troubleshooting skills.
7. **Logic Gate Simulation**
 - Task: Use a free simulator (like Falstad, Tinkercad, or Logic.ly) to create logic circuits.
 - Outcome: Concept reinforcement through virtual labs.

SEMESTER - I
COURSE 6: BASIC ELECTRONICS

Practical

Credits: 1

4 hrs/week

COURSE OBJECTIVE:

To develop practical skills in handling basic electronic components and circuits by constructing, testing, and analyzing simple electronic systems such as rectifiers, filters, diode/transistor configurations, and digital logic gates using fundamental measurement tools.

Learning Outcomes

After successful completion of the lab course, students will be able to:

1. Measure and verify the behavior of passive components in circuits.
2. Construct and test diode and transistor-based circuits.
3. Analyze rectifier output and filter performance using basic instruments.
4. Build and verify logic gate circuits using ICs or trainer kits.
5. Practice circuit debugging, use of multimeters, and interpretation of waveforms using a CRO.

Minimum of 6 experiments to be done and recorded

Experiments (Practical List)

1. **Verification of Ohm's Law** using resistive networks (series and parallel combinations).
2. Series and Parallel Combination of Capacitors and Inductors
3. **Capacitor charging and discharging curves** using RC circuits and a stopwatch/multimeter.
4. **V-I characteristics of a PN junction diode** (forward and reverse bias)
5. Temperature Dependence of Resistance (Using Thermistor).
6. **Zener diode characteristics** and voltage regulation behavior.
7. **Study of LED and photodiode characteristics** under different light conditions.
8. **BJT transistor as a switch**: ON/OFF control of an LED.
9. **Construction of half-wave and full-wave rectifiers** and measurement of output voltage.
10. **Design and analysis of simple π -filtered power supply** circuits.
11. **Verification of logic gates (AND, OR, NOT, NAND, NOR)** using digital ICs or simulation.

Passive Components

Chapter 1

1.0 INTRODUCTION :

Each circuit is the combination of electrical and (or) electronic components designed to perform specific task. Hence, *components* are treated as the basic building blocks that are combined using some *circuits* to yield the *system*. These components are broadly classified into *two* major groups : (i) Passive components and (ii) active components.

(i) Passive components : The components/elements which do not generate power by themselves, but instead dissipates, stores and/or releases it are called *passive components*.

Ex : Resistors, inductors, capacitors etc.

Generally, passive components do not require bias voltage or trigger voltage for their proper operation. The behaviour of passive components is linear.

(ii) Active components : The components/elements which generate power (voltage or current) by themselves are called *active components*.

Ex : Energy sources (voltage or current sources), diodes, transistors, thyristors etc.

Active components require bias voltage or trigger voltage for their proper operation. The behaviour of active components is not linear.

In this chapter, we discuss the principles, types, functions, applications and faults of main passive components namely resistors, inductors and capacitors. We begin our discussion with resistors.

1.1 RESISTORS :

Resistor is one of the basic passive components found in almost all electronic circuits. The property exhibited by a resistor is known as *electrical resistance* or simply *resistance*.

(A.P)

[Oct./Nov. 2018]

Resistance :

Resistance may be defined as the opposition to the flow of charge carriers (current). It is represented by the letter R and its unit is ohm (Ω). Its circuit symbol is $\overset{R}{\sim}$ (US resistor symbol) or \boxed{R} (European resistor symbol).

The resistance (R) of a resistor is defined mathematically as the ratio of applied voltage (V) to the current (I) flowing through it.

$$\text{i.e., } R = \frac{V}{I}$$

If V is in volts and I in amperes, then the resistance R will be in ohms. Thus

$$1 \text{ ohm } (\Omega) = \frac{1 \text{ volt (V)}}{1 \text{ ampere (A)}}$$

Hence a resistor is said to have a resistance of 1 ohm, if a constant current of one ampere flows through it for an applied voltage of one volt.

The instrument that measures resistance is known as an *ohmmeter*. Now-a-days multimeter is used for the measurement of resistance. Good conductors have low resistance and insulators have high resistance. Where as semiconductors have medium resistance.

The reciprocal of resistance (R) is conductance G ($G = \frac{1}{R}$) and its unit is mho (\mathcal{O}). A sample of different kinds of resistors are shown in Fig. 1.1.

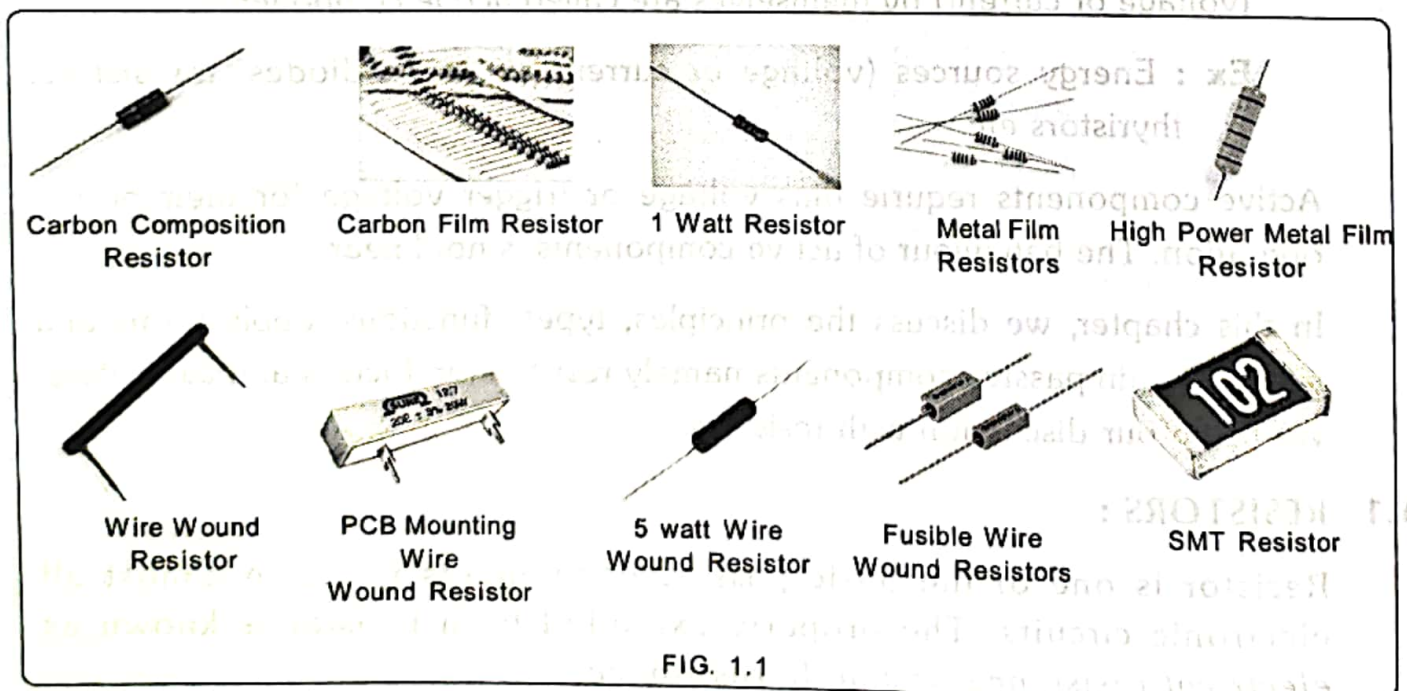


FIG. 1.1

(A.P)

Features of Resistors :

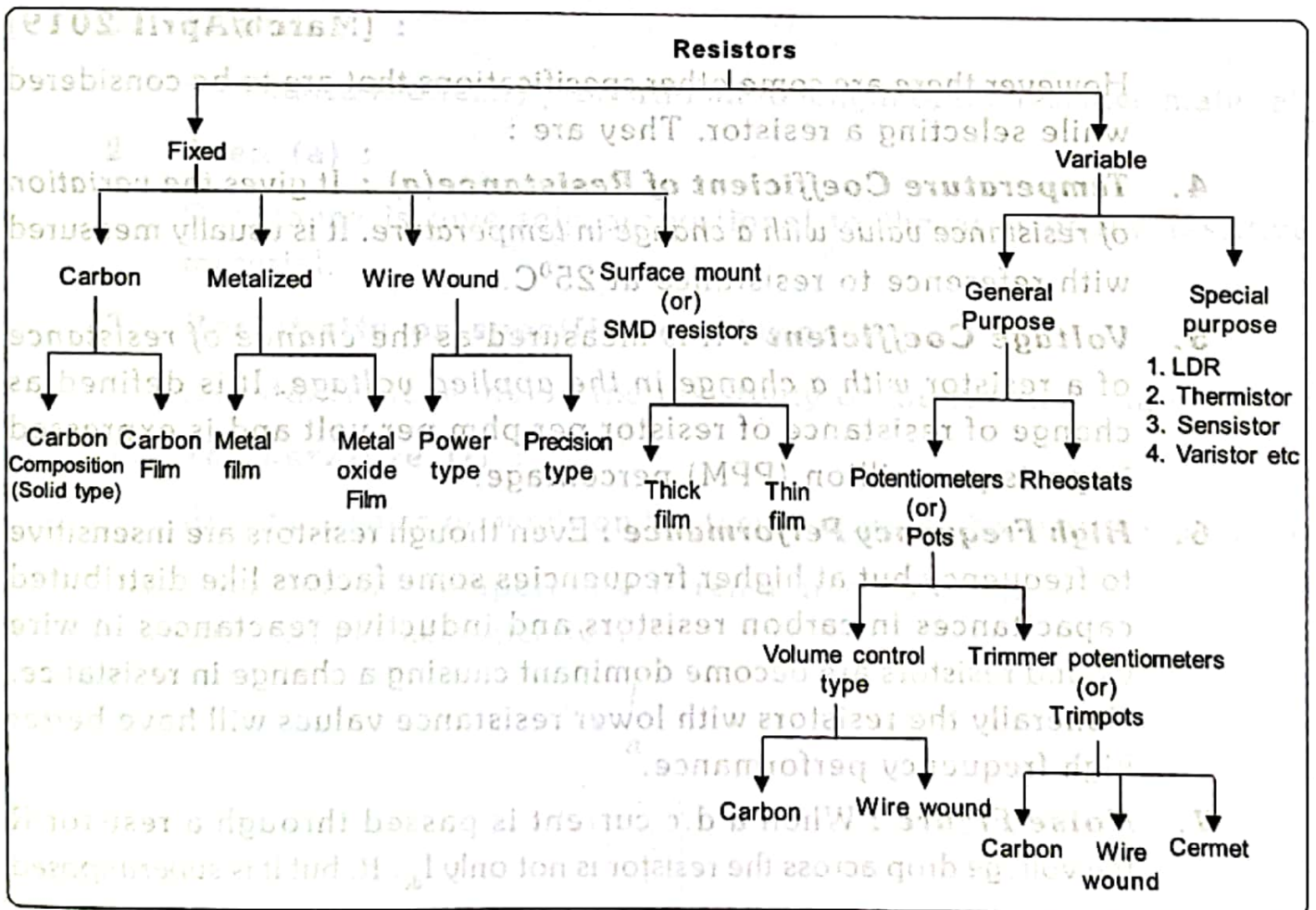
1. These are two terminal, passive, bilateral components.
2. The effect of resistance is same for both d.c and a.c (over a limited frequency range)

Some of the common uses of resistors are :

1. Used to limit current.
2. Used to establish proper values of circuit voltages due to IR drops.
3. Used as load.
4. Used in biasing circuits.
5. Used in filter circuits etc.

1.2 CLASSIFICATION OR TYPES OF RESISTORS : [March/April 2018]

Resistors are broadly classified into two types namely *fixed resistors* and *variable resistors*. These two types are further classified into different categories as :



(A.P)

1.3 SPECIFICATIONS OF RESISTORS :

All resistors will have **three** main specifications that are to be considered. They are 1. Resistance value 2. Tolerance 3. Power rating

1. **Resistance Value** : It gives the *value of resistor R* in ohms. It's value is either printed or colour coded over the body depending upon the type of resistor. In general, resistors from 1Ω to many $M\Omega$ are available.
2. **Tolerance** : It gives the *variation of resistance value from the indicated value*. It is generally expressed in percentage. It's typical values are ranging from $\pm 1\%$ to $\pm 20\%$. Resistors with low tolerance values are preferred. [March/April 2019]
3. **Power Rating** : It is very important specification. Because it determines the *maximum current that a resistor can withstand without being destroyed*. It is expressed in watts. The resistors with power ratings ranging from 0.1 watt to hundreds of watts are available. The power rating depends on the size of the resistor. The larger the surface area of a resistor, the more power it can dissipate. [March/April 2019]

However there are some other specifications that are to be considered while selecting a resistor. They are :

4. **Temperature Coefficient of Resistance(a)** : It gives the *variation of resistance value with a change in temperature*. It is usually measured with reference to resistance at 25°C .
5. **Voltage Coefficient** : It is measured as the *change of resistance of a resistor with a change in the applied voltage*. It is defined as change of resistance of resistor per phm per volt and is expressed in parts per million (PPM) percentage.
6. **High Frequency Performance** : Even though resistors are insensitive to frequency but at higher frequencies some factors like distributed capacitances in carbon resistors and inductive reactances in wire wound resistors are become dominant causing a change in resistance. Generally the resistors with lower resistance values will have better high frequency performance.
7. **Noise Figure** : When a d.c current is passed through a resistor R the voltage drop across the resistor is not only $I_{dc} \cdot R$, but it is superimposed

1.6 RESISTORS COLOUR CODING :

Necessity of Colour Coding : Resistors are made in different sizes and shapes. Some resistors like wire wound resistors are large enough in size to have their value printed on the body. However there are some resistors like carbon resistors that are too small in size to have numbers printed on them. Therefore colour coding is used for small size resistors to indicate its resistance value.

Colour coding is the process in which colour bands are used to indicate numerical values. The use of bands or stripes is the most common system for colour coding carbon and metal oxide resistors which indicate their resistance value and tolerance. Two methods of colour coding are in common use. They are : (i) 4 colour bands method (ii) 5 colour bands method.

(i) 4 colour band resistor :

This method involves 4 colour bands to represent the value of a resistor and its tolerance. The colour coding for carbon resistors with axial leads is shown in Fig. 1.2.

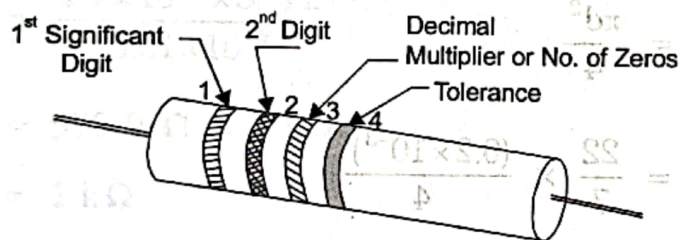


FIG. 1.2: 4 COLOUR BAND RESISTOR

The colour bands are read from left to right from the end which has the bands closest to it as shown in Fig. 1.2. The first band indicates the first *significant digit* and second band indicates second *digit* while the third band indicates *decimal multiplier* or *number of zeros followed by first two digits*. The fourth band indicates the tolerance—the amount by which the actual resistance value R can be different from the indicated value. Absence of fourth band means the tolerance is $\pm 20\%$. Table 1.1 gives the colour code for 4 colour band resistors.

(ii) 5 colour band resistor :

Resistors with high precision i.e with tolerance as low as $\pm 0.05\%$ have an extra band to indicate a third digit. The colour coding for a film resistor with axial leads is shown in Fig. 1.3.

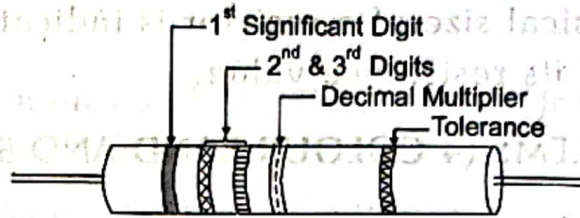


FIG. 1.3 : 5 COLOUR BAND RESISTOR

The colour bands are read from left to right from the end which has the bands closest to it as shown in Fig. 1.3. The first band indicates *first significant digit*; second, third bands indicate the second and third digits, the fourth band indicates the decimal multiplier and the fifth band indicates the tolerance. Table 1.1 also gives the colour code for 5 colour band resistors.

Resistors below 10Ω will have a third band of gold or silver which have 0.1 or 0.01 multiplier as shown in Table 1.1.

Table 1.1 Colour Code

Colour	Digit	Multiplier	Tolerance
Black	0	$10^0 = 1$	
Brown	1	$10^1 = 10$	$\pm 1\%$
Red	2	10^2	$\pm 2\%$
Orange	3	10^3	$\pm 3\%$
Yellow	4	10^4	$\pm 4\%$
Green	5	10^5	$\pm 0.5\%$
Blue	6	10^6	$\pm 0.25\%$
Violet	7	10^7	$\pm 0.1\%$
Gray	8	10^8	$\pm 0.05\%$
White	9	10^9	
Gold	-	10^{-1} or 0.1	$\pm 5\%$
Silver	-	10^{-2} or 0.01	$\pm 10\%$
No colour	-	-	$\pm 20\%$
Pink colour	-	-	High stability

From the table it can be noted that the darkest colours indicate lowest numbers and lighter colours indicate highest numbers.

Note : The physical size of a resistor is indicative of the power it can dissipate, not of its resistance value.

1.7 EXAMPLE PROBLEMS (4 COLOUR BAND AND 5 COLOUR BAND RESISTORS) :

Example 1.4 ●

Find the resistance values with tolerances of the following resistors with 4 colour band sequence of

- (i) Brown, Black, Red, Gold
 (ii) Red, Red, Red, Gold [March/April 2018]
 (iii) Brown, Black, Gold, Silver

Solution :

S. No.	I digit	II digit	Multiplier	Tolerance	Resistance value with Tolerance
(i)	1	0	100	$\pm 5\%$	$1K\Omega \pm 5\%$
(ii)	2	2	100	$\pm 5\%$	$2.2K\Omega \pm 5\%$
(iii)	1	0	0.1	$\pm 10\%$	$1\Omega \pm 10\%$

Example 1.5 ●

Give the colour coding for the following 4 colour band resistors with resistance values of :

- (i) $1M\Omega \pm 10\%$ (ii) $8.2K\Omega \pm 5\%$
 (iii) $68\Omega \pm 20\%$ (iv) $2.7\Omega \pm 10\%$

Solution :

S. No.	Colour bands			
	I	II	III	IV
(i)	Brown	Black	Green	Silver
(ii)	Grey	Red	Red	Gold
(iii)	Blue	Grey	Black	No colour
(iv)	Red	Voilet	Gold	Silver

1.24 CHOKES :

A choke is an inductor used to block higher-frequency AC in a circuit, while passing lower frequency or d.c. Chokes are divided into two board classes (i) AF Chokes (ii) RF Chokes

Audio frequency chokes (AFC) : Designed to block audio (20Hz - 20kHz) and power line frequency (50Hz) while allowing DC to pass.

Radio frequency chokes (RFC) : Designed to block radio frequencies (>500kHz) while allowing audio and DC to pass.

[**Note :** The name choke comes from blocking-"choking"-high frequencies while passing low frequencies. It is a functional name ; the name "choke" is used if an inductor is used for blocking or decoupling higher frequencies, but is simply called an "inductor" if used in electronic filter or tuned circuits].

1.24.1 Applications of AF and RF Chokes : [March/April 2019]

Applications of AF Chokes : AF chokes are used in

1. Power supplies.
2. Switching power supplies.
3. Radio & T.V. transmitters.
4. Radio & T.V receivers.
5. Audio & power transformers.
6. Magnets & relays.

Applications of RF Chokes : RF chokes are used in

1. Radio & T.V recivers.
2. Digital computers.
3. Tuning circuits.
4. Wave shaping circuits.

1.25 CAPACITORS :

Apart from resistors and inductors capacitor is another basic passive component commonly used in electronic circuits. A capacitor essentially consists of two conducting surfaces separated by an insulating medium called dielectric. Capacitors are designed to have the ability to store electric charge and release it whenever desired. Capacitor opposes the instantaneous changes of voltage in the circuit in which it is connected.

1.26 CLASSIFICATION OF CAPACITORS :

Capacitors are classified in to different types based on various factors as given below :

1. According to the Type of Dielectric Used :

Ex : Mica, Paper, Ceramic, Air, Electrolytic Capacitors etc.

2. According to the Physical Construction :

(i) **Fixed Capacitors** : Whose capacitance value cannot be varied mechanically or by any other external means.

Ex : Mica, Paper, Ceramic, Electrolytic capacitors.

(ii) **Variable capacitors** : Whose capacitance value can be varied mechanically quite frequently or less frequently.

Ex : Tuning capacitors, and Trimming capacitors.

3. According to the Polarization :

(i) **Polarized** : Used in d.c applications

Ex : Aluminium, Tantalum Electrolytic Capacitors (majority)

(ii) **Non polarized** : Used in a.c applications.

Ex : Aluminium, Tantalum Electrolytic Capacitors

4. According to Voltage Rating :

(i) **Low voltage capacitors** ($< 50V$)

Ex : Ceramic, Electrolytic capacitors etc

(ii) **High voltage capacitors** ($> 100V$)

Ex : Mica, Glass, Ceramic capacitors etc.

1.27 SPECIFICATIONS OF CAPACITORS :

Following are the few important specifications of capacitors.

- 1. Capacitance Value** : It gives the value of a capacitor C in Farads. It's value is either printed or colour coded over the body of the capacitor. Practical capacitors are available from one pico farad to one Farad.
- 2. Tolerance** : It gives the variation of capacitance value from the indicated value. Tolerance rating is expressed as plus or minus value either in Pico Farads ($\pm PF$) for low value capacitors (i.e., $< 100PF$) or as a percentage ($\pm\%$) for higher value capacitors ($>100PF$).

The most common tolerance variation for capacitors is 5% or 10% but some plastic capacitors are rated as low as $\pm 1\%$.

3. **Working voltage** : It defines the maximum continuous voltage either DC or AC that can be applied to the capacitor without failure during its working life. Generally the working voltage printed on to the side of a capacitors body refers to it's DC working voltage. Working voltage mainly depends upon the dielectric strength of the material used in capacitor.
4. **Temperature coefficient** : It gives the maximum change in capacitance value over a specified temperature range. It is generally expressed linearly as part per million per degree centigrade (PPM/ $^{\circ}\text{C}$) or as a percent change over a particular range of temperature.
5. **Leakage resistance/current** : Reciprocal terms that denote leakage property of a capacitor. It is in the order of micro amperes (μA). As the dielectric used inside the capacitor wont be a perfect insulator, these leakage current occurs in the dielectric.
6. **Dielectric absorption** : The dielectric absorption of a capacitor is the inability of a capacitor to completely discharge to zero. Low dielectric absorption values is desired one.
7. **Power factor** : It gives the fraction of input power dissipated as heat loss in the capacitor. The quality of a capacitor in terms of minimum loss is often indicated by its power factor. The lower the numerical value of the power factor (P.F) the better is the quality (Q) of the capacitor
i.e., $\text{P.F} = \frac{1}{Q}$.
8. **Stability** : Stability is usually expressed in terms of the long or short-term percentage variation of capacitance which occurs under specified physical and electrical operating conditions.

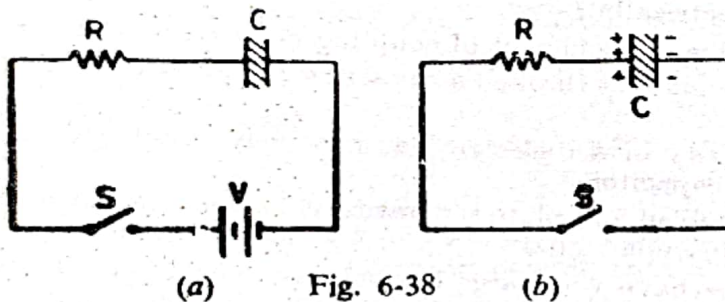
1.28 FACTORS AFFECTING THE CAPACITANCE OF A CAPACITOR :

Consider a parallel plate capacitor with uniform dielectric medium as shown in Fig. 1.14.

3. If the pointer does not go to low-resistance side of the scale (i.e. if capacitor shows no charging action) but just goes straight to infinity, the capacitor is open.
4. If the meter pointer first moves quickly towards the low-resistance side of the scale (showing capacitor charging) and then slowly goes to infinity, it shows a good capacitor which is supposed to have very large (almost infinite) resistance.

6-52. CHARGING OF A CAPACITOR

As shown in Fig. 6-38 (a), when S is closed, the capacitor starts getting charged from the battery. The capacitor, however, requires a certain amount of time to get fully charged to the battery voltage V . The time taken depends on its capacitance (C) and the resistance (R) in the charging circuit.



The time required for the charge to attain 63.2% of its final value is called *time-constant* (T) of the circuit. Its value = CR and is in seconds if C is in farads and R in ohms.

A total time equal to 5 time constants ($= 5T = 5CR$) is required for the capacitor to be considered fully charged as shown in Fig. 6-39.

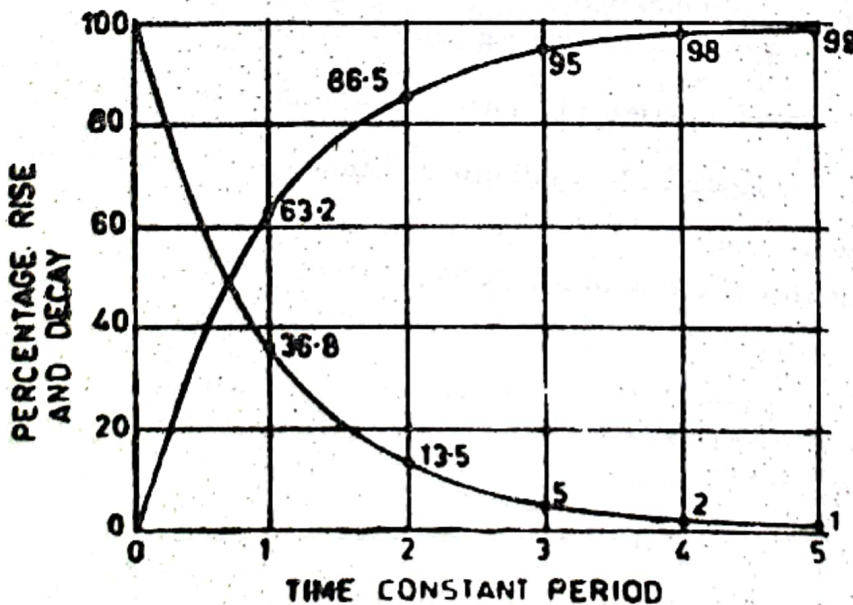


Fig. 6-39

In Fig. 6-38 (b), the fully-charged capacitor can be discharged through R by closing S . In one time-constant, the charge decreases

to 36.8% of its fully-charged value. Again, in 5 time-constants, the capacitor is considered fully discharged.

The increase and decrease of charge across the capacitor can be found from the Universal Time Constant Chart of Fig. 6-39. It also represents rise and decay of charging and discharging current of the capacitor respectively.

Example 6-10. A 50- μ F capacitor is charged through a 40-K resistor to a potential difference of 400 V. Calculate

1. time constant of the circuit
2. value of full charge
3. charge acquired in one time-constant
4. energy stored in the fully-charged capacitor

Solution.

1. $T = CR = 50 \times 10^{-6} \times 40 \times 10^3 = 2$ seconds
2. full charge, $Q = CV = 50 \times 10^{-6} \times 400 = 0.02$ C
3. charge acquired by the capacitor in one time-constant i.e. in 2 seconds

$$= 63.2\% \text{ of full charge}$$

$$= 0.632 \times 0.02 = 0.0126 \text{ C}$$

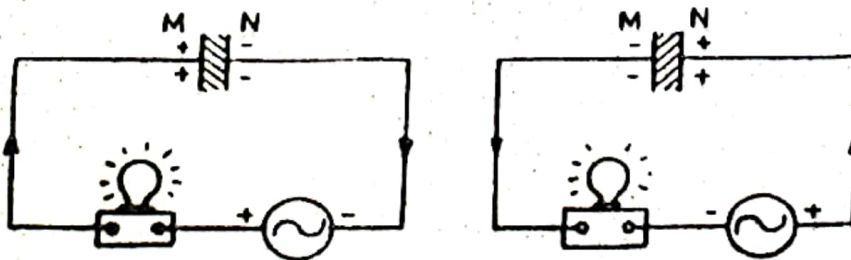
$$(iv) \text{ energy stored} = \frac{1}{2} CV^2$$

$$= \frac{1}{2} \times (50 \times 10^{-6}) \times 400^2$$

$$= 2 \text{ joules.}$$

6-53. CAPACITOR CONNECTED ACROSS AN AC SOURCE

Suppose a capacitor is connected across an ac voltage supply as shown in Fig. 6-40. It is found that the capacitor is charged first in one direction during the positive half-cycle of the applied voltage [Fig. 6-40 (a)] and then in the opposite direction during the negative half-cycle [Fig. 6-40 (b)]. Since, it is an alternating voltage, the capacitor keeps getting charged and discharged continuously. If a lamp is included in the circuit, it will continue to glow. The reason is as follows :



(a) Fig. 6-40

(b)

During the positive half-cycle of the applied voltage, charging current flows from plate N to M through the external circuit con-

Another point worth remembering is : not to touch the ohmmeter leads. There is no danger of electric shock but body resistance of about 50 K acting in parallel with the resistance being measured will lower the ohmmeter reading.

6-19. INDUCTOR

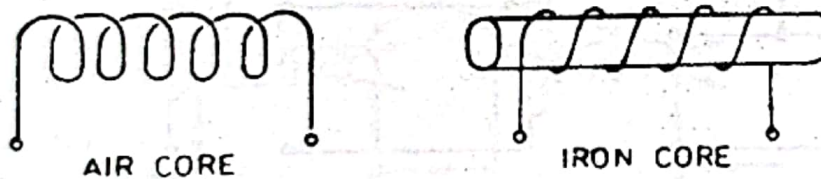
It is another basic component commonly used in electronic circuits. It is nothing else but a coil wound on a core or former of some suitable material.

(a) Air-core Inductor

It consists of number of turns of wire wound on a former made of ordinary cardboard [Fig. 6-13 (a)]. Since there is nothing but air inside of the coil, an air-core inductor has the least inductance for a given number of turns and core length.

(b) Iron-core Inductor

It is that inductor in which a coil of wire is wound over a solid or laminated iron core [Fig. 6-13 (b)]. Putting iron inside an inductor has the effect of increasing its inductance as many times as the relative permeability (μ_r) of iron. In order to avoid eddy current loss, iron core is laminated *i.e.* it is made up of thin iron laminations pressed together but insulated from each other. Sometimes, such an inductor is also called a choke.



(a)

Fig. 6-13

(b)

The iron core has been found to work more efficiently particularly at low frequencies if it is in the form of a closed core *i.e.* if the core not only goes through the centre of the coil but also surrounds it on its two sides as shown in Fig. 6-14.

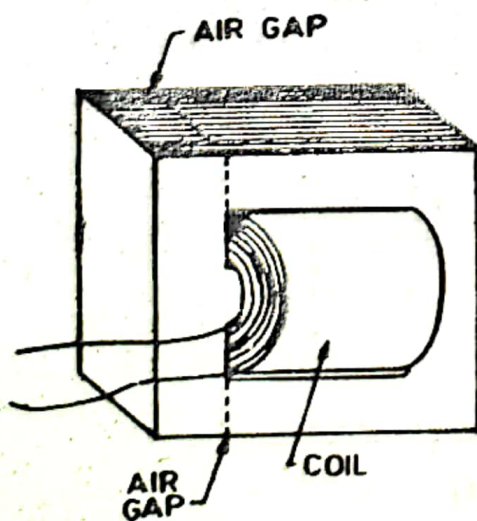


Fig. 6-14

(c) Ferrite-core Inductor

In this case, coil of wire is wound on a solid core made of highly ferromagnetic substance called ferrite. Ferrite is a solid material consisting of fine particles of iron powder embedded in an insulating binder. A ferrite core has minimum eddy current loss.

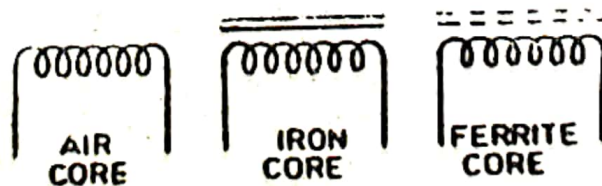


Fig. 6-15

The symbols for different types of inductors discussed above are shown in Fig. 6-15.

6-20. COMPARISON OF DIFFERENT CORES

In air-core coils, there are no core losses even at high frequencies but their inductances are limited to low values in the μH or mH range.

In iron-core coils, losses are minimal at low *i.e.* audio frequencies but become considerable at high frequencies even when iron core is laminated. They possess comparatively much larger inductance as compared to air-core coils.

Ferrite-core coils have high inductance value with minimum eddy current and hysteresis losses even at very high frequencies. The built-in antennas used in transistor radios have ferrite core.

6-21. INDUCTANCE OF AN INDUCTOR

It is found that whenever current through an inductor changes (*i.e.* increases or decreases), a counter emf is induced in it which tends to oppose this change. This property of the coil due to which it opposes any change of current through it is called inductance (L). Its unit is henry (H). The inductance of a coil is given by

$$L = \frac{\mu_0 \mu_r A N^2}{l} \text{ henrys}$$

It is seen that L varies

1. directly as relative permeability of the core material
2. directly as core cross-sectional area
3. directly as square of the number of turns of the coil
4. inversely as core length

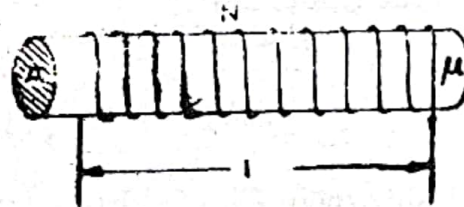


Fig. 6-16

6-22. ANOTHER DEFINITION OF INDUCTANCE

Suppose current through an inductor is changed at the rate of di/dt because of which a counter emf of ' e ' is induced in it. Then, it is found that

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

or
$$L = \frac{e}{di/dt}$$

If $di/dt = 1 \text{ A/s}$ and $e = 1\text{V}$, then $L = 1 \text{ H}$

Hence, a coil has an inductance of one henry if an emf of one volt is induced in it when current through it changes at the rate of 1 A/s .

The radio-frequency (RF) coil for the radio broadcast band 550-1650 kHz has an inductance of about $250 \mu\text{H}$ whereas iron-

where L_1 = inductance of the first coil
 L_2 = inductance of the second coil
 M = mutual inductance between the two coils

When magnetic flux produced by one coil does not link with the other coil, then $k = 0$. If all the flux produced by one coil links with the other, $k = 1$. Air-core coils wound on the same former have k value of 0.05 to 0.3. Coils on iron core have k almost equal to unity.

6-25. VARIABLE INDUCTORS

The inductance of a coil can be varied by the three different methods shown in Fig. 6-18.

1. by using a tapped coil as shown in Fig. 6-18 (a). Here, either more or fewer turns of the coil can be used by connection to one of the taps on the coil.
2. by using a slider contact to vary the number of turn used as in Fig. 6-18 (b).

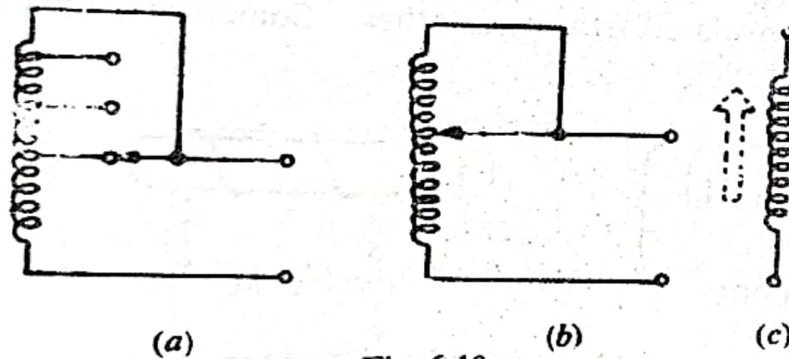


Fig. 6-18

These methods are used for large coils. It will be noted that the unused turns have been short-circuited to prevent the tapped coil from acting as an autotransformer otherwise the stepped up voltage could cause arcing across the turns.

3. Fig. 6-18 (c) shows the symbol for a coil with a ferrite slug which can be screwed in or out of the coil to vary its inductance.

6-26. INDUCTORS IN SERIES OR PARALLEL WITHOUT M

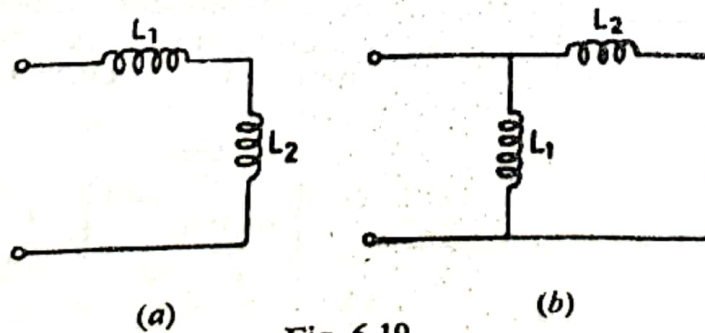


Fig. 6-19

We will assume that the different coils connected in series or parallel have no mutual inductance M .

(a) Series Combination

$$\text{Here, } L = L_1 + L_2$$

—Fig. 6-19 (a)

$$\text{In general, } L = L_1 + L_2 + L_3 + \dots$$

(b) Parallel Combination

$$\text{Here, } L = L_1 \parallel L_2 = \frac{L_1 L_2}{L_1 + L_2}$$

—Fig. 6-19 (b)

$$\text{In general, } \frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \dots$$

6-27. SERIES COMBINATION WITH M

In this case, value of total inductance will depend upon

1. amount of mutual inductance present and
2. whether the combination is series-aiding or series-opposing.

In series-aiding, the direction of the common current through the two coils is such that their magnetic fields are in the same direction *i.e.* they aid each other as shown in Fig 6-20 (a). In series-opposing, the direction of current flow is such that the two fields oppose each other as shown in Fig. 6-20 (b).

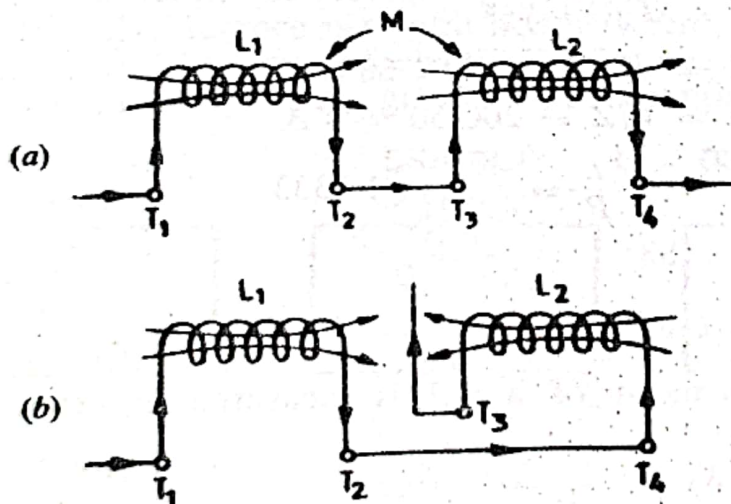


Fig. 6-20

For the circuit of Fig. 6-20 (a)

$$L_a = L_1 + L_2 + 2M$$

For the circuit of Fig. 6-20 (b)

$$L_o = L_1 + L_2 - 2M$$

Incidentally, it can be deduced from the above two equations that

$$M = \frac{L_a - L_o}{4}$$

Example 6-1. Two coils each having an inductance of $250 \mu\text{H}$ have combined inductance of $550 \mu\text{H}$ when connected series-aiding and $450 \mu\text{H}$ when connected series-opposing. Calculate

- (i) their mutual inductance and
(ii) coefficient of coupling.

$$\text{Solution. (i) } M = \frac{L_1 - L_0}{4} = \frac{550 - 450}{4} = 25 \mu\text{H}$$

$$\text{(ii) } k = \frac{M}{\sqrt{L_1 L_2}} = \frac{25}{\sqrt{250 \times 250}} = 0.1$$

6-28. STRAY INDUCTANCE

It is the unwanted inductance inherently present in the connecting leads and wire-wound resistors.

For example, a connecting wire 10 cm long and 1 mm in diameter has an inductance of about $0.1 \mu\text{H}$. It is negligible at low frequencies but can be troublesome at MHz frequency range. That is why connecting leads are kept very short in high-frequency circuits.

Since ordinary wire-wound resistors have considerable stray inductance, non-inductive wire-wound resistors are used instead. These are wound in such a way that adjacent turns have currents in the opposite direction so that opposing magnetic fields cancel out the inductance.

6-29. ENERGY STORED IN A MAGNETIC FIELD

When current passes through an inductor, magnetic flux is produced for which energy is supplied by the voltage source. This energy is safely stored in the field itself and is recoverable. The amount of energy stored is

$$E = \frac{1}{2} L I^2 \text{ joules}$$

where L is inductance in henrys and I is the steady current in amperes.

6-30 D C RESISTANCE OF A COIL

It is the ohmic resistance of the wire used in making the coil. This resistance will depend on the thickness of the wire and its length *i. e.* total number of turns. For radio-frequency coils with inductance values upto several mH requiring 10 to 100 turns of fine wire, the dc resistance is from 1 to 20Ω approximately.

6-31 TROUBLES IN COILS

The most common trouble is an 'open' in the winding. An ohmmeter connected across the coil will read infinity for the open circuit. As usual, while checking its resistance, the coil should be disconnected from the external circuit to eliminate any parallel paths which could affect the resistance reading.

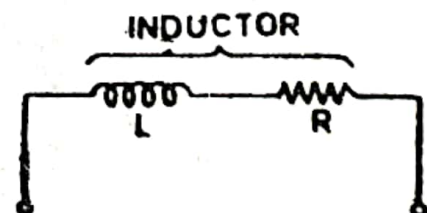


Fig. 6-21

In the case of printed-circuit boards (PCB) made of plastic, a rim of solder around the edge serves as the chassis ground as shown in Fig 2-5. When a voltage source is connected between points *A* and *B*, its one end is grounded through *B* and the other is connected to the resistors R_1 and R_2 .

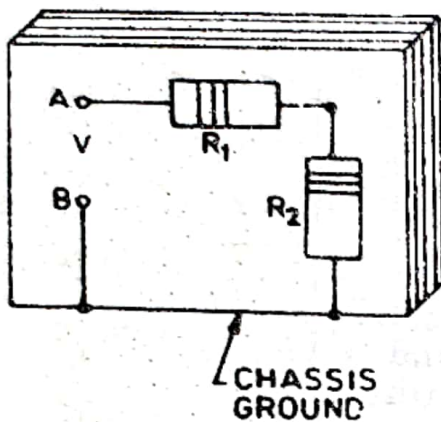


Fig. 2-5

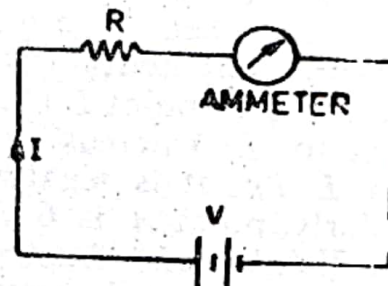


Fig. 2-6

2-3. OHM'S LAW

In circuits energised by dc voltage sources, there exists a definite relationship between the current (I) that flows through a resistance (R) and the voltage (V) applied across the resistance (Fig. 2-6). This relationship is called Ohm's law and may be expressed by the equation

$$I = \frac{V}{R}$$

where

I = current in amperes

V = applied voltage in volts

R = resistance in ohms

It is seen from the above formula that current is

1. directly proportional to applied voltage and
2. inversely proportional to resistance.

2-4. FORMULA VARIATIONS OF OHM'S LAW

The three formula variations of Ohm's law are as under :—

1. $I = V/R$

— for finding current

2. $R = V/I$

— for finding resistance

3. $V = I/R$

— for finding voltage

These formulae are an important aid to the understanding of circuit behaviour. They enable us to determine the value of any of the three quantities involved if the values of the other two are known. It makes it possible to design electronic circuits and to determine the values of various components mathematically thereby avoiding unnecessary measurements or experimentation and wastage of time.

KIRCHHOFF'S LAWS

4

4-1. GENERAL

We come across many circuits in which various components are neither in series nor in parallel nor in series-parallel. One example is a circuit with two or more batteries connected in its different branches. Another is an unbalanced bridge circuit. Here, rules of series and parallel circuits are inapplicable. Such circuits can be easily solved with the help of Kirchhoff's laws which are two in number :

1. Kirchhoff's Current Law (KCL)
2. Kirchhoff's Voltage Law (KVL)

4-2. KIRCHHOFF'S CURRENT LAW

It states that in any network of conductors, the algebraic sum of currents meeting at a point (or junction) is zero.

Put in another way, it simply means that the total current leaving a junction is equal to the total current entering that junction.

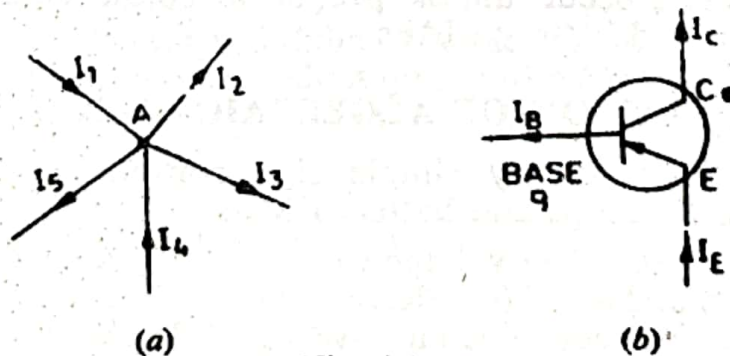


Fig. 4-1

Explanation

Consider the case of five currents meeting at junction A of the network shown in Fig. 4-1 (a). Let us adopt the following sign convention for determining the algebraic sign of different currents.

All currents *entering* the junction would be taken as **positive** whereas those **leaving** it would be taken as **negative**.

According to the above convention, I_1 and I_4 would be taken as positive whereas I_2 , I_3 and I_5 would be taken as negative. Using KCL, we have

$$I_1 + (-I_2) + (-I_3) + I_4 + (-I_5) = 0$$

or
$$I_1 - I_2 - I_3 + I_4 - I_5 = 0$$

$$\therefore \Sigma I = 0 \quad \text{---at a junction}$$

Also, transposing the negative terms to the right-hand side, we get

$$I_1 + I_4 = I_2 + I_3 + I_5$$

incoming currents = outgoing currents

or
$$I_{in} = I_{out} \quad \text{---at a junction}$$

Similarly, in Fig. 4-1 (b), I_E is the emitter current directed *towards* the base. The two currents *i.e.* base current I_B and collector current I_C are directed *away* from the base. Hence, according to KCL

$$I_E + (-I_B) + (-I_C) = 0$$

or
$$I_E - I_B - I_C = 0$$

or
$$I_E = I_B + I_C$$

4-3. KIRCHHOFF'S VOLTAGE LAW

It states that the algebraic sum of all IR drops and EMFs in any closed loop (or mesh) of a network is zero.

or
$$\Sigma IR + \Sigma \text{EMF} = 0 \quad \text{---round a loop}$$

While applying the above two laws for circuit calculations, plenty of errors can occur unless proper algebraic signs are given both to IR drops and battery EMFs.

4-4. DETERMINATION OF ALGEBRAIC SIGN

We will follow a very simple sign convention which would apply equally to IR drops and battery EMFs.

A *rise* (or increase) in voltage would be considered *positive* and given a +ve sign and a *fall* (or decrease) in voltage would be considered negative and hence given a -ve sign. Let us see how we will apply this convention (i) firstly, to battery EMFs or voltage sources and (ii) secondly, to IR drops across various branch resistors.

(i) Battery EMF

While going round a loop (in a direction of our own choice) if we go from the -ve terminal of a battery to its +ve terminal, there is a *rise* in potential, hence this EMF should be given +ve sign. If, on the other hand, we go from its +ve terminal to its -ve terminal, there is *fall* in potential, hence this battery EMF should be given -ve sign.

It is important to note that algebraic sign of battery EMF is independent of the direction of current flow (whether clockwise or anticlockwise) through the branch in which the battery is connected.

(ii) IR drops on resistors

If we go through a resistor in the *same* direction as its current, then there is a *fall or decrease* in potential for the simple reason that current always flows from a higher to a lower potential. Hence, this IR drop should be taken *-ve*. However, if we go around the loop in a direction *opposite* to that of the current, *i.e.* if we go upstream, there is a *rise in voltage*. Hence, this IR drop should be taken as *positive*.

It is clear from above that algebraic sign of IR drop across a resistor depends on the direction of current through that resistor.

Consider the closed loop ABCDA of Fig. 4-2. Starting from point A if we go around this mesh in clockwise direction,* then different EMFs and IR drops will have following values and signs :

$I_1 R_1$ is	-ve	(fall in potential)
$I_2 R_2$ is	+ve	(rise ..)
E_2 is	-ve	(fall ..)
$I_3 R_3$ is	-ve	(fall ..)
E_1 is	+ve	(rise ..)
$I_4 R_4$ is	-ve	(fall ..)

Hence, according to KVL,

$$-I_1 R_1 + I_2 R_2 - E_2 - I_3 R_3 + E_1 - I_4 R_4 = 0$$

or
$$-I_1 R_1 + I_2 R_2 - I_3 R_3 - I_4 R_4 = E_2 - E_1$$

or
$$I_1 R_1 - I_2 R_2 + I_3 R_3 + I_4 R_4 = E_1 - E_2$$

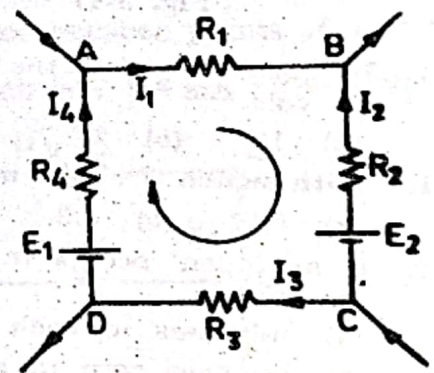


Fig. 4-2

4-5. ASSUMED DIRECTION OF CURRENT FLOW

In applying Kirchhoff's laws to electrical or electronic networks, one is often faced with the tricky question of assuming proper direction of current flow through different branches of the network. However, the matter is quite simple because one is at full liberty to choose either clockwise or anticlockwise direction. If the assumed direction of current does not happen to be the actual direction, then on solving the question, this current would be found to have minus sign. If the answer is positive, then assumed direction is the correct direction of current flow.

Example 4-1. Using Kirchhoff's laws, calculate the branch currents in the network of Fig. 4-3.

* We could as well choose to go along anticlockwise direction.

Solution. As shown in the figure, we have taken currents I_1 and I_2 as originating from the positive terminals of the batteries. However, it is not always essential to do so because a stronger battery can drive current into one with lower e.m.f. i.e. it can charge it. We will consider the following two closed loops:

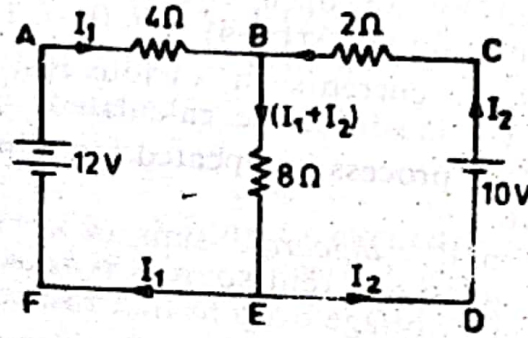


Fig. 4-3

(i) Loop ABEFA

Starting from point A and going clockwise round the loop, we have

$$-4 I_1 - 8(I_1 + I_2) + 12 = 0$$

or

$$3 I_1 + 2 I_2 = 3$$

... (i)

(ii) Loop BCDEB

Starting from point B and again going clockwise round the loop, we get

$$+2 I_2 - 10 + 8(I_1 + I_2) = 0$$

or

$$4 I_1 + 5 I_2 = 5$$

... (ii)

Multiplying Eq. (i) by 5 and Eq. (ii) by 2 and subtracting one from the other, we get

$$15 I_1 - 8 I_1 = 15 - 10$$

or

$$7 I_1 = 5 \quad \therefore I_1 = 5/7 \text{ A}$$

Substituting this value either in Eq. (i) or (ii), say, Eq. (i), we have

$$3 \times (5/7) + 2 I_2 = 3 \quad \text{or} \quad I_2 = 3/7 \text{ A}$$

Since these have come out to be positive, it means that their assumed directions are the actual directions.

Current through branch $BE = I_1 + I_2$

$$= \frac{5}{7} + \frac{3}{7} = 1 \frac{1}{7} \text{ A}$$

Example 4-2. In the grounded-emitter transistor amplifier circuit of Fig. 4-4, calculate the base current I_B and collector current I_C .

Solution. We will consider two loops: base-current loop ADBEGA and collector-current loop ACBEGA.

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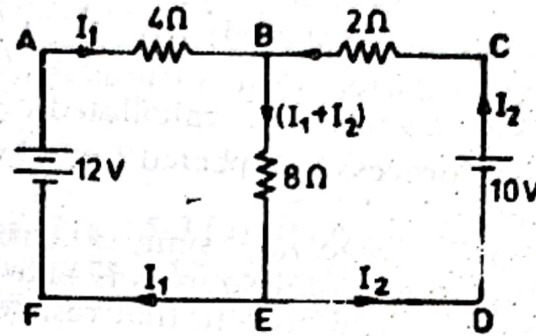


Fig. 4-3

(i) Loop ABEFA

Starting from point A and going clockwise round the loop, we have

$$-4 I_1 - 8(I_1 + I_2) + 12 = 0$$

or $3 I_1 + 2 I_2 = 3 \quad \dots(i)$

(ii) Loop BCDEB

Starting from point B and again going clockwise round the loop, we get

$$+2 I_2 - 10 + 8 (I_1 + I_2) = 0$$

or $4 I_1 + 5 I_2 = 5 \quad \dots(ii)$

Multiplying Eq. (i) by 5 and Eq. (ii) by 2 and subtracting one from the other, we get

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3-20. ANALYSING SERIES-PARALLEL CIRCUITS

In most of the situations, it is helpful to reduce the given circuit to an equivalent series circuit. This can be done by first handling the parallel part of the circuit and then reducing it to an equivalent single resistance as shown in Fig. 3-26 (c).

First step is to find equivalent resistance of R_2 and R_3 which is

$$\begin{aligned} &= R_2 \parallel R_3 \\ &= \frac{R_2 \times R_3}{R_2 + R_3} \\ &= \frac{3 \times 6}{6 + 3} = 2 \Omega \end{aligned}$$

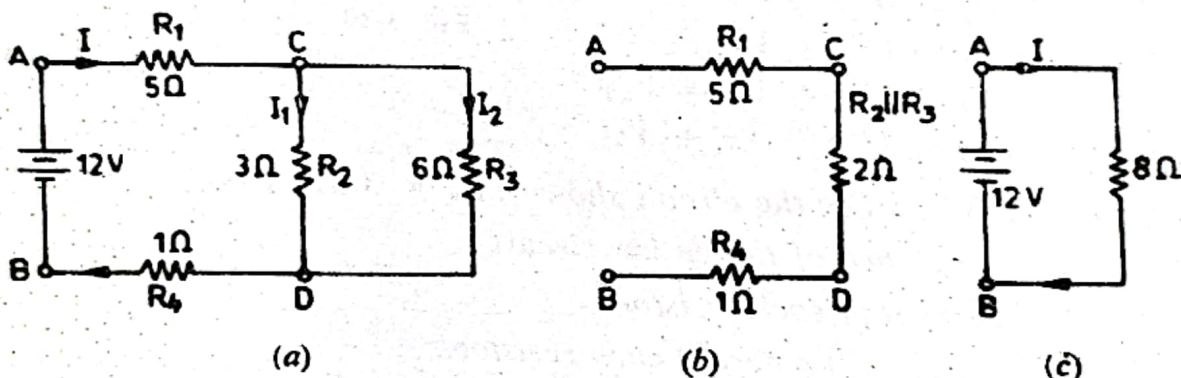


Fig. 3-26

The circuit becomes as shown in Fig. 3-26 (b).

Second step is to find total resistance by addition.

$$R = 5 + 2 + 1 = 8 \Omega$$

Third step is to calculate total current supplied by the battery by using Ohm's law.

$$I = 12/8 = 1.5 \text{ A}$$

The branch currents I_1 and I_2 and various voltage drops can be found as under :

$$I_1 = I \frac{R_3}{R_2 + R_3} = 1.5 \times \frac{6}{9} = 1 \text{ A}$$

$$I_2 = I \frac{R_2}{R_2 + R_3} = 1.5 \times \frac{3}{9} = 0.5 \text{ A}$$

(or $I_2 = I - I_1 = 1.5 - 1.0 = 0.5 \text{ A}$)

Drop across 5- Ω resistor = $1.5 \times 5 = 7.5 \text{ V}$

Drop across $R_2 = 3 \times 1 = 3 \text{ V}$

Drop across $R_3 = 6 \times 0.5 = 3 \text{ V}$

It should be noted that the above two 3-V drops are not two different voltages but actually the one and the same voltage of 3 V across points C and D is driving both currents I_1 and I_2 .

Drop across $R_1 = 1.5 \times 1 = 1.5 \text{ V}$

Sum of various drops $= 7.5 + 3 + 1.5 = 12 \text{ V}$

This sum equals the battery voltage as it, in fact, should.

3-21. 'OPENS' IN SERIES-PARALLEL CIRCUITS

As indicated earlier, an 'open' has the effect of introducing infinite resistance in the branch or leg of the circuit, where it occurs. The effect of an 'open' would be explained with the help of Fig. 3-27.

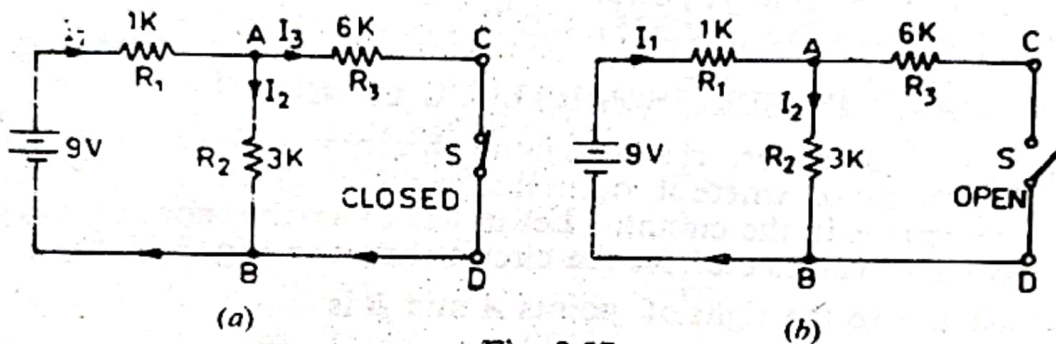


Fig. 3-27

Let us calculate the values of currents and voltages in the circuit of Fig. 3-27 (a) when it is working normally with switch S closed. Since R_2 and R_3 are in parallel, their combined resistance is $R_2 \parallel R_3 = 6 \times 3 / (6 + 3) = 2 \text{ K}$. This is in series with R_1 . Hence, total resistance of the series-parallel circuit becomes $= 1 + 2 = 3 \text{ K}$.

$$\therefore I_1 = 9 / 3 \text{ K} = 3 \text{ mA}$$

Branch currents can be found by using the relation given in Art 3-16.

$$I_2 = 3 \times \frac{6}{9} = 2 \text{ mA}$$

$$I_3 = 3 \times \frac{3}{9} = 1 \text{ mA}$$

Drop across $R_1 = 3 \times 1 = 3 \text{ V}$

Drop across $R_2 = 2 \times 3 = 6 \text{ V}$

(same is the drop across R_3)

Of course, total voltage drop is equal to the battery voltage.

Now, let us consider the effect of opening the switch as in Fig 3-27 (b). First thing to note is that because of 'open' in path CD , R_3 cannot be considered in parallel with R_2 . In fact, now R_1 and R_2 become in series with the battery. Treated as a voltage divider,

$$\begin{aligned} \text{drop across } R_1 &= 9 \times \frac{R_1}{R_1 + R_2} \\ &= 9 \times \frac{1}{4} = 2.25 \text{ V} \end{aligned}$$

Hence, combined capacitance is less than the *smallest* individual value.

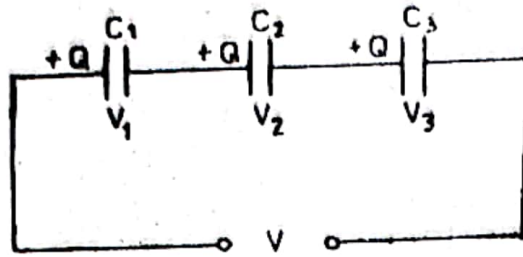


Fig. 6-33

Following points about series combination of capacitors should be noted :

1. charge on each capacitor is the *same* irrespective of its capacitance
2. p.d. across each capacitor is *different* being inversely proportional to its capacitance
3. sum of voltages across the capacitors equals the applied voltage

As seen from Fig. 6-33,

$$V = V_1 + V_2 + V_3$$

4. combined capacitance is given by the reciprocal formula.

In Fig 6-33,
$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

or

$$C = \frac{1}{1/C_1 + 1/C_2 + 1/C_3}$$

Capacitors are used in series to provide a higher voltage breakdown rating for the combination. For example, combined voltage rating of three equal 200-V capacitors becomes 600 V when connected in series (even though overall capacitance is reduced).

6-46. TWO CAPACITORS IN SERIES

As seen from Fig. 6-34

1.
$$C = \frac{C_1 C_2}{C_1 + C_2}$$
2.
$$V_1 = V \frac{C_2}{C_1 + C_2}$$
3.
$$V_2 = V \frac{C_1}{C_1 + C_2}$$

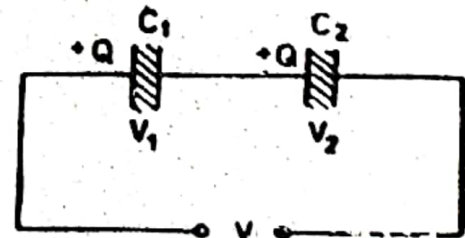


Fig. 6-34

6-47. CAPACITORS IN PARALLEL

Connecting capacitors in parallel is equivalent to *adding their plate areas*. Hence, combined capacitance equals the sum of individual capacitances.

Following facts about parallel combination of capacitors (Fig. 6-35) should be noted :

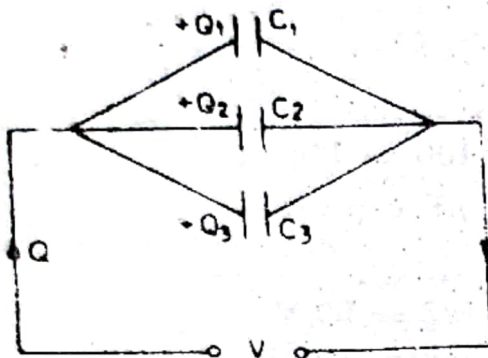


Fig. 6-35

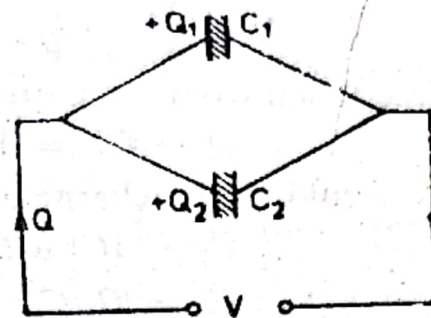


Fig. 6-36

1. charge across each capacitor is different, being directly proportional to its capacitance

$$\therefore Q = CV$$

2. p.d. across each capacitor is the same i.e. the applied voltage V .
3. the sum of the individual charges is equal to the total charge supplied by the power source

$$Q = Q_1 + Q_2 + Q_3$$

4. combined capacitance is equal to the sum of individual capacitances

$$C = C_1 + C_2 + C_3$$

6-48. TWO CAPACITORS IN PARALLEL

Consider the case when only two unequal capacitors are connected in parallel as shown in Fig. 6-36. In this case.

1. since V is the same across both capacitors

$$\therefore V = \frac{Q_1}{C_1} = \frac{Q_2}{C_2}$$

$$\therefore \frac{Q_1}{C_1} = \frac{Q_2}{C_2} \text{ or } \frac{Q_1}{Q_2} = \frac{C_1}{C_2}$$

2. the two capacitor charges can be expressed in terms of the total charge Q taken from the power source.

$$Q_1 = Q \frac{C_1}{C_1 + C_2}$$

$$Q_2 = Q \frac{C_2}{C_1 + C_2}$$

6-49. ENERGY STORED IN A CAPACITOR

Energy is required to charge a capacitor and is supplied by the charging agency *i.e.* a battery or any other voltage source. This energy is stored in the electric field set up in the dielectric medium. On discharging the capacitor, the field collapses and the stored energy is released.

$$\text{Stored energy} = \frac{1}{2} C.V^2 \text{ joules}$$

This stored energy is the reason why a charged capacitor can produce an electric shock when you touch its two leads. Stored energy of more than 1 joule can be dangerous with a capacitor charged to a voltage high enough (> 90 V) to produce electric shock.

Example 6-6. A multiplate capacitor is made up of ten plates $4 \text{ cm} \times 5 \text{ cm}$ separated by mica sheets having thickness of 1 mm and a relative permittivity of ϵ_r . Find its capacitance.

$$\text{Solution} \quad C = \frac{(n-1) \epsilon_0 \epsilon_r A}{d}$$

Here, $n = 10$, $\epsilon_r = 6$, $A = 4 \times 5 = 20 \text{ cm}^2 = 2 \times 10^{-3} \text{ m}^2$

$d = 1 \text{ mm} = 10^{-3} \text{ m}$, $\epsilon_0 = 8.854 \times 10^{-12} \text{ F/m}$

$$C = \frac{(10-1) \times 8.854 \times 10^{-12} \times 6 \times 2 \times 10^{-3}}{10^{-3}}$$

$$= 956 \times 10^{-12} \text{ F}$$

$$= 956 \text{ pF}$$

Example 6-7. Two capacitors of $4 \mu\text{F}$ and $12 \mu\text{F}$ capacitance and each of working-voltage rating of 24 V are connected in series across a 24-V battery. Calculate

1. charge across each
2. voltage across each
3. combined voltage rating

Solution.

$$1. \quad C = \frac{C_1 C_2}{C_1 + C_2} = \frac{4 \times 12}{4 + 12} = 3 \mu\text{C}$$

$$Q = CV = 3 \times 24 = 72 \mu\text{C}$$

Each of the two series-connected capacitor will have the same charge.

$$2. \quad V_1 = V \frac{C_2}{C_1 + C_2}$$

$$= 24 \times \frac{12}{16} = 18 \text{ V}$$