Q.2a. Define the following:

(i) Flux density **(ii) Magnetic flux**
(iii) Magnetic field intensity **(iv) Permeability**

Flux Density (B)

In any elemental area across flux, it is convenient to work in terms of flux density B as Wb/m².

We can write Eq. (7.1) as

$$F = B \cdot (i_2 l) \quad (7.2\text{ a})$$

(2)

where the flux, density B is defined as

$$B = \mu\left(\frac{i_1}{2\pi r}\right), \frac{\text{N}}{\text{Am}}$$

In terms of flux, units of B are Wb/m², generally called *tesla* (T).

Magnetic Field Intensity (H) or Magnetizing Force

It is convenient to work in terms of a quantity that is independent of the medium. We define from Eq. (7.2) the magnetic field intensity as

$$H = \frac{i_1}{2\pi r} = \frac{B}{\mu} \text{ A/m} \quad (7.3)$$

It is indeed the consitive force i_1 spread over the length of the flux path (2)

The current i_1 in one conductor many comprise of

$$i_1 = Ni \quad (7.4)$$

where there are N conductors each carrying current i.

As current always flows in a closed path, N conductors indeed are N turns. So we write

$$N i = \textit{ampere-turns} \text{ (AT)} \quad (7.5)$$

The ampere-turns in magnetic circuits are referred to as *magnetomotive force.*

$$\mathcal{F} = mmf = Ni \text{ AT} \quad (7.6)$$

Permeability It is the property of the medium which determines the flux density for a given magnetizing force; it is indeed a constant of proportionality. Thus

$$B = \mu H \; ; \; \mu = \text{permeability} \tag{7.7}$$

In *free space*

$$B = \mu_0 H$$

where $\mu_0 = 4\pi \times 10^{-7}$ Wb/Am, permeability of free space (7.8)

We can express

$$\mu = \mu_0 \mu_r$$

where

$$\mu_r = \frac{\mu}{\mu_0}, \text{ the } \textit{relative permeability} \text{ of the medium} \tag{7.9}$$

Magnetic materials, iron, steel and certain alloys, by virtue of their inherent property induce much larger flux density. These magnetic materials have

$$\mu_r = 4000 - 10000$$

Of course, non-magnetic materials have

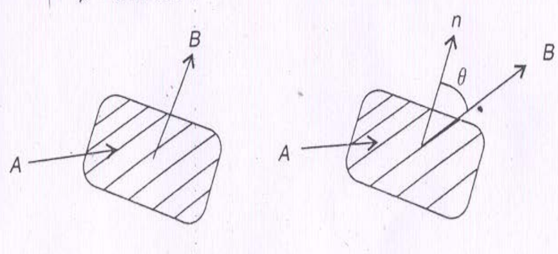
$$\mu_r = 1$$

Magnetic Flux For uniform flux density, normal to area A of Fig. 7.3 (a), the flux passing through the area is

$$\phi = B A \tag{7.10}$$

If the flux makes an angle θ with respect to the surface normal as in Fig. 7.3 (b), then

$$\phi = B A \cos \theta \tag{7.11}$$



(a) (b)

Fig. 7.3

b. **Draw and explain magnetization characteristic of magnetic materials.**

2b

7.4 MAGNETIC MATERIALS AND B–H RELATIONSHIP (MAGNETIZATION CHARACTERISTIC)

Magnetic materials are characterized by high permeability and nonlinear *B–H* relationship (magnetization characteristic) which exhibits *saturation* and *hysteresis*. This type of behaviour is explained by the domain theory of magnetization for which a suitable book on material science may be consulted.

Magnetic materials are classified as *ferromagnetic* and *ferrimagnetic*. Iron and its various alloys are ferromagnetic. Hard ferromagnetic materials include permanent magnetic materials such as alnicos, chrome steels, certain copper–nickel alloys and several other alloys. Ferrimagnetic materials consist of mixed oxides of iron and other metals. The oxide mixture is 'sintered', i.e. heated to a steady temperature of 1300°C which is maintained for several hours. The resulting material known as *ferrite* is chemically homogeneous and extremely hard. It has typically maximum flux density of 0.3–0.5 T, as compared to 2.18 T for pure iron.

Magnetization Characteristic

The *B–H* relationship for cyclic *H* is the *hysteresis loop* exhibited in Fig. 7.13 where the tip of the loop corresponds to the maximum *H* of the cyclic variation. Three hysteresis loops are indicated in this figure. The portions of the loops for decreasing *H* lie above the portions for increasing *H*, which is the hysteresis lag typical of ferro- and ferrimagnetic materials. The dotted curve passing through tips of the hysteresis loops is the *normal magnetization curve* or *B–H curve* of the material. A typical magnetization curve is provided in Fig. 7.14. It is initially nonlinear with a nearly linear portion in the middle and exhibits saturation for high values of *H*. For extremely high values of *H* it possesses a slope corresponding to that of free space ($\mu_r = 1$). It is this *B–H* curve which is used in magnetic circuit calculations and hysteresis effects, where necessary, are accounted for empirically. In fact the *B–H* curve is appreciably affected by heat treatment and mechanical handling. High degree of precision need therefore not be attempted in these calculations.

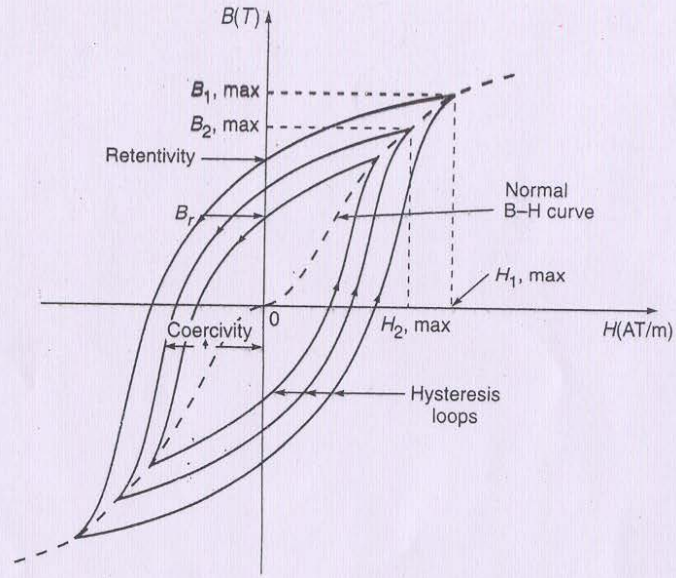


Fig. 7.13 Hysteresis loop and magnetization (*B–H*) Curve

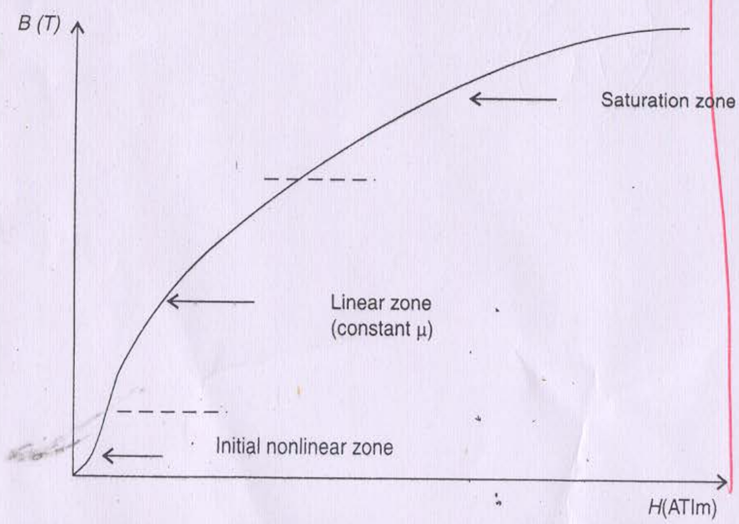


Fig. 7.14 Typical normal magnetization curve of ferromagnetic material

In a *B-H* curve the value of the flux density at H=0 is known as the *residual flux density* B_r. The value of H to reduce B_r to zero is called the *coercive force* H_c. The maximum possible value of B_r corresponding to deep saturation is know is as *retentivity* and the maximum value of H_0 is the *coercivity.* All these value are indicated in Fig. 7.13.

Q.3a. Find Thevenin's equivalent of the circuit shown in Fig.3 across the terminals a, b and calculate current in load resistance $R = \frac{10}{3}\Omega$**.**

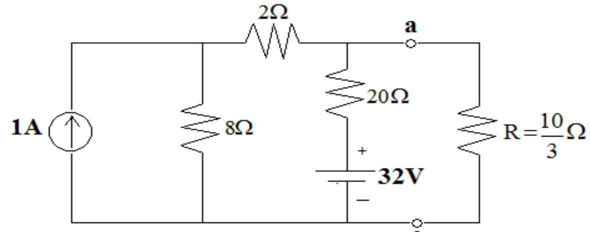
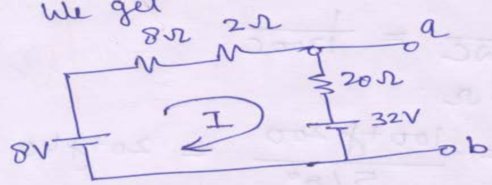


Fig.3

(3a) 1. Remove resistance R.
2. Replace current source into voltage source
We get



$30I = 8 - 32 = -24$

$I = -\frac{24}{30}$

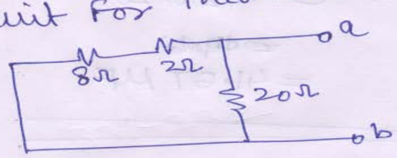
$V_{th} = V_{ab} = 32 + V_{20\Omega}$

$= 32 - \frac{24}{30} \times 20 = 32 - 16$

$= 16$ Volt

(4)

Circuit For Thevenin's equivalent Resistance is

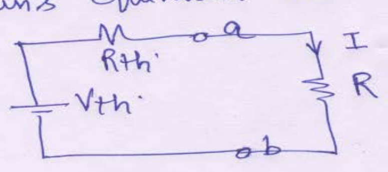


$R_{th} = R_{ab} = 20 \| 10$

$= \frac{200}{30} = \frac{20}{3}\ \Omega$

(2)

Thevenin's equivalent circuit is



$I = \frac{V_{th}}{R_{th} + R}$

$I = \frac{16}{\frac{20}{3} + \frac{10}{3}}$

$= \frac{16 \times 3}{30}$

$= 1.6$ A

(2)

b. For the circuit shown in Fig.4, if $I = 5\angle 0^\circ$, find C for $V = (100 + j200)$ Volt and $\omega = 1.2KHz$

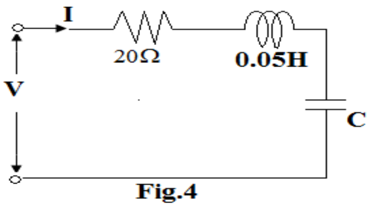


Fig.4

(3b) $\omega = 1.2\,KHz$

$X_L = \omega L = 1200 \times 0.05 = 60\Omega$

$X_C = \frac{1}{\omega C} = \frac{1}{1200C}$ (2)

$R = 20\Omega$

$Z = \frac{V}{I} = \frac{100 + j200}{5\angle 0^\circ} = 20 + j40$ (2)

here $Z = 20 + j60 - jX_C$

so $20 + j60 - jX_C = 20 + j40$ (2)

$X_C = 20 = \frac{1}{1200C}$

So $C = \frac{1}{1200 \times 20}$

$= 41.67\,\mu F$ (2)

Q.4a. Derive EMF equation of DC Machines.

4a

EMF Equation

Full-pitch armature coils are assumed. Let

$$\Phi = \text{flux/pole}$$

Imagine the coil in Fig. 10.2(a) to lie in the interpolar region linking all the flux of one pole. Thus its flux linkages are

$$\lambda_1 = N_c \Phi$$

where N_c is the number of coil turns. As the coil moves through one pole pitch, its flux linkages change to

$$\lambda_2 = -N_c \Phi \text{ (it now links the flux of opposite polarity)}$$

During this movement, change of flux linkages of the coil is

$$\Delta\lambda = -2N_c\Phi \quad (10.3)$$

For a P-pole machine, the time of travel through one pole pitch is

$$\Delta t = \frac{2\pi}{P\omega_m} \text{ s} \quad (10.4)$$

where ω_m is the armature speed in mechanical rad/s. Hence the average coil emf induced is

$$E_c = -\frac{\Delta\lambda}{\Delta t} = \Phi\omega_m N_c P \quad (10.5)$$

Let C_p = coils/parallel path

Then the armature emf is

$$E_a = \frac{\Phi\omega_m (C_p N_c) P}{\pi}$$

DC Machines

But $C_p N_c = \frac{Z}{2A}$ = turns/parallel path

where Z is the total number of armature conductors. Hence

$$E_a = \frac{\Phi\omega_m Z}{2\pi}\left(\frac{P}{A}\right) = K_a \Phi \omega_m \quad (10.6)$$

where $K_a = \frac{ZP}{2\pi A}$ = machine constant

Equation (10.6) can also be written as

$$E_a = \frac{\Phi n Z}{60}\left(\frac{P}{A}\right) = \frac{2\pi}{60} K_a \Phi n \quad (10.7)$$

where n is the armature speed in rpm.

(4)

(4)

b. A 600 V dc shunt motor drives a 60 kW load at 900 RPM. The shunt field resistance is 100Ω and armature resistance is 0.16Ω. If motor efficiency at this load is 85%. Determine speed at no

load and speed regulation.

10.26 A 600V dc shunt motor drives a 60 kW load at 900 rpm. The shunt field resistance is 100 W and armature resistance is 0.16 W. If the motor efficiency at this load is 85%, determine (a) the speed at no-load and speed regulation (b) the rotational loss.

Solution

(a)

$$P_{out} = 60\text{ kW}, \eta = 0.85$$

$$P_{in} = \frac{60}{0.85} = 70.59\text{ kW}$$

$$I_L = \frac{70\times10^3}{600} = 117.65\text{ A}$$

$$I_f = \frac{600}{100} = 6\text{ A}$$

Then $I_a = 117.65 - 6 = 111.65$ A

$$E_a = 600 - 111.65 \times 0.16 = 582.14\text{ A}$$

$$n = 900\text{ rpm}$$

No load

$$E_a \approx V = 600\text{ V}$$

$$n \propto E_a$$

$$n_o = 900 \times \frac{600}{582.14} = 927.6$$

$$\text{speed regulation} = \frac{927.6 - 900}{900} \times 100 = 3.1\%$$

Q.5 a. For an ideal transformer, derive the voltage equation and obtain the transformation ratio.

Voltages and *emfs*

As the primary and secondary circuits are linked through the mutual flux, we begin with flux which is expressed as

$$\phi = \phi_{max} \sin \omega t; \quad \omega = 2\pi f \text{ rad/s} \tag{8.1}$$

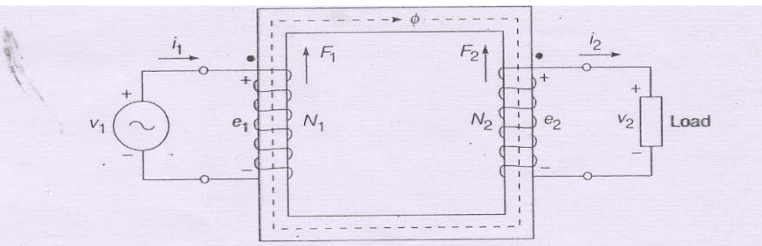


Fig. 8.5 Ideal transformer (*IT*)

The *emf* induced in primary winding balances the applied voltage as per KVL. Thus

$$v_1 = e_1 = N_1 \frac{d\phi}{dt} = \omega N_1 \phi_{max} \cos \omega t \tag{8.2}$$

The secondary induces *emf* which equals the load voltage and is similarly given by

$$v_2 = e_2 = \omega N_2 \phi_{max} \cos \omega t \tag{8.3}$$

In terms of *rms* values

$$V_1 = E_1 = \sqrt{2}\,\pi f N_1 \phi_{max} \tag{8.4}$$

and

$$V_1 = E_2 = \sqrt{2}\,\pi f N_2 \phi_{max} \tag{8.5}$$

We find that the voltage and *emf*s are in phase and the flux lags by 90° (sin ωt lags cos ωt by 90°)

Transformation Ratio

It is found from the above equations that the voltage transformation ratio of *rms* values is

$$\frac{V_1}{V_2} = \frac{E_1}{E_2} = \frac{N_1}{N_2} = a \text{ (turn ratio)} \tag{8.6}$$

Also, in terms of phasors we have

$$\frac{\bar{V}_1}{\bar{V}_2} = \frac{\bar{E}_1}{\bar{E}_2} = a \text{ (turn ratio)} \tag{8.7}$$

as the voltages are in phase.

It is seen from these equations that in an ideal transformer, the voltages are in direct ratio of turns with no change in phase angle.

The maximum value of the flux is found from Eqs (8.4) and (8.5) to be

$$\phi_{max} = \frac{E_1}{\sqrt{2}\pi f N_1} = \frac{E_2}{\sqrt{2}\pi f N_2}; \quad \sqrt{2}\pi = 4.44 \tag{8.8}$$

It is seen that ϕ_{max} is determined by the applied voltage and its frequency and is independent of current. This is a general result and, as we shall see in later chapter, applies also to *ac* machines.

b. What is rotating magnetic field? Explain working of 3 phase induction motor.

5b

Marks (3)

4.1. INTRODUCTION

A rotating magnetic field is that field which is constant in magnitude but whose axis of direction rotates in space as field system of a dc machine. With a stationary field system the magnetic field is stationary in space, but if the field system is rotated at a certain speed, its magnetic field will rotate with it at the same speed.

The magnetic field produced by single phase alternating current is an *alternating magnetic field*, the field acting along a fixed axis, varying in magnitude periodically and changing its

5.4. PRINCIPLE OF OPERATION

In a direct current motor, current is drawn from the supply and conducted into the armature conductors through the brushes and commutator. When the armature conductors carry current in the magnetic field established by the field, a force is exerted on the conductors which tends to move them at right angles to the field.

Though in an induction motor, there is no electrical connection to the rotor, but currents are induced in the rotor circuit, and therefore, the same condition exists as in the dc motors i.e., the rotor conductors carry current in the stator magnetic field and thereby have a force exerted upon them tending to move them at right angles to the field.

When the stator or primary winding of a 3-phase induction motor is connected to a 3-phase ac supply, a rotating magnetic field is established which rotates at synchronous speed. The direction of revolution of this field will depend upon the phase sequence of the primary currents and, therefore, will depend upon the order of connection of the primary terminals to the supply. The direction of rotation of the field can be reversed by interchanging the connection to the supply of any two leads of a 3-phase induction motor. (Refer Art. 4.4). The number of magnetic poles of the revolving field will be the same as the number of poles for which each phase of the primary or stator winding is wound. The speed at which the field produced by the primary currents will revolve is called the *synchronous speed* of the motor and is given by an expression, $N_s = \frac{120f}{P}$ where f is supply frequency and P is the number of poles on stator.

(5) Marks

As the rotating magnetic field produced by the primary currents sweeps across the rotor conductors, an emf is induced in these conductor just as an emf is induced in the secondary winding of a transformer by the flux set up by the primary current. Since the rotor winding is either directly shorted or closed through some external resistance, the emf induced in the secondary by the revolving field causes a current to flow in the rotor conductors.

The setting up of the torque for causing the rotor to rotate is explained below:

A section of an induction motor stator and rotor, with the magnetic field assumed to be rotating in a clockwise direction and with the rotor stationary, as at starting, is shown

Q.6a. Explain P-N junction with forward bias.

4.2.2 *PN*-Junction with Forward Bias

Suppose we connect a battery to the *PN*-junction diode such that the positive terminal of the battery is connected to the *P*-side and the negative terminal to the *N*-side, as shown in Fig. 4.3. In this condition the *PN*-junction is said to be *forward-biased.*

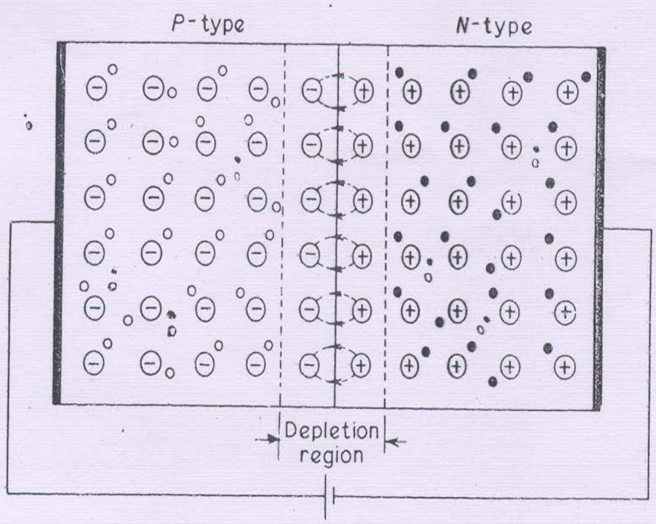


Fig. 4.3 *PN*-junction showing forward bias

When the *PN*-junction is forward-biased, the holes are repelled from the positive terminal of the battery and are compelled to move towards the junction. The electrons are repelled from the negative terminal of the battery and drift towards the junction. Because of their acquired energy, some of the holes and the free electrons penetrate the depletion region. This reduces the potential barrier. The width of the depletion region reduces and so does the barrier height. As a result of this, more majority carriers diffuse across the junction. These carriers recombine and cause movement of charge carriers in the space-charge region.

For each recombination of free electron and hole that occurs, an electron from the negative terminal of the battery enters the *N*-type material. It then drifts towards the junction. Similarly, in the *P*-type material near the

*In a semiconductor, all the charge carriers do not have same kinetic energy. Some have very high energy, whereas some have very low energy. The average energy depends upon the temperature of the sample.

positive terminal of the battery, an electron breaks a bond in the crystal and enters the positive terminal of the battery. For each electron that breaks its bond, a hole is created. This hole drifts towards the junction. Note that there is a continuous electron current in the external circuit. The current in the *P*-type material is due to the movement of holes. The current in the *N*-type material is due to the movement of electrons. The current continues as long as the battery is in the circuit. If the battery voltage is increased, the barrier potential is further reduced. More majority carriers diffuse across the junction. This results in an increased current through the *PN*-junction.

b. Define static and dynamic resistance of a diode. How will you determine these resistances?

4.5 STATIC AND DYNAMIC RESISTANCE OF A DIODE

No diode can act as an ideal diode. An actual diode does not behave as a perfect conductor when forward-biased, and as a perfect insulator when reverse-biased. It does not offer zero resistance when forward-biased. Also its reverse-resistance, through very large, is not infinite.

Figure 4.10 shows the forward characteristics of a typical silicon diode. This diode may be connected in a dc circuit. When forward biased, it offers a definite resistance in the circuit. This resistance is known as the dc or *static resistance* (R_F) of the diode. It is simply the ratio of the dc voltage across the diode to the dc current flowing through it. For instance, if the dc voltage across the diode is 0.7 V, the current through it can be found from Fig. 4.10. The operating point of the diode is at point *P*, and the corresponding current can be read as 14 mA. The static resistance of the diode at this operating point will be given as

$$R_F = \frac{OA}{AP} = \frac{0.7\text{ V}}{14\text{ mA}} = 50\ \Omega$$

80 Electronics and Linear Circuits

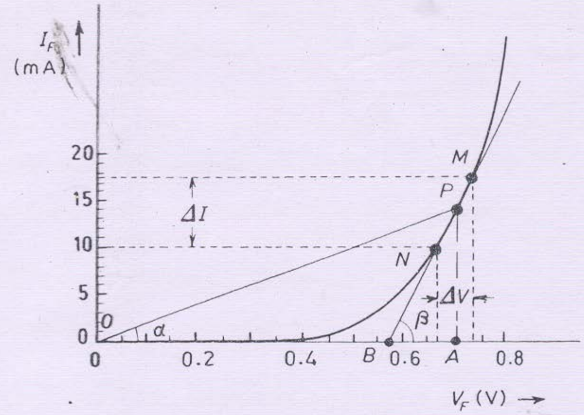


Fig. 4.10 Calculation of static and dynamic resistance of a diode

In general, the static resistance is given by the cotangent of the angle α. That is

$$R_F = \frac{OA}{AP} = \cot \alpha \qquad (4.1)$$

If the characteristic is linear, this ratio OA/AP will be a constant quantity. But, in case the characteristic is nonlinear, the dc resistance will vary with the point of measurement.

In addition to 14 mA of dc current, small ac current may be superimposed in the circuit. The resistance offered by the diode to this ac signal is called its *dynamic* or *ac resistance*. The ac resistance of a diode, at a particular dc voltage, is equal to the reciprocal of the slope of the characteristic at that point, i.e.

$$r_f = \frac{\text{change in voltage}}{\text{resulting change in current}} = \frac{\Delta V}{\Delta I}$$

[*Note*: The Greek letter Δ (delta) means "a change of", wherever it appears in formulae. So, ΔI is a change in current. Generally, it indicates a small-scale (or incremental) change.]

We can calculate the ac resistance of a diode as follows:

Around the operating point P, take two points M and N very near to it, as shown in Fig. 4.10. These two points will then indicate incremental changes in voltage and current. The dynamic resistance is related to the slope of the line MN and is calculated as follows.

$$r_f = \frac{\Delta V}{\Delta I} = \frac{(0.73 - 0.66)\text{ V}}{(17.5 - 10)\text{ mA}} = \frac{0.07\text{ V}}{7.5\text{ mA}} = 9.46\ \Omega$$

The smaller the incremental changes ΔV and ΔI, the closer is the above result to the exact value of the dynamic resistance. For making these incremental values smaller, the points M and N have to be closer. It then becomes difficult to read the voltage and current values accurately from the graph. We can circumvent this difficulty if we remember that as ΔV becomes smaller and smaller, the slope of the line MN becomes the same

Q.7 a. Draw block diagram of DC power supply and discuss working of half wave rectifier.

4.6 USE OF DIODES IN RECTIFIERS

Electric energy is available in homes and industries in India, in the form of alternating voltage. The supply has a voltage of 220 V (rms) at a frequency of 50 Hz. In the USA, it is 110 V at 60 Hz. For the operation of most of the devices in electronic equipments, a dc voltage is needed. For instance, a transistor radio requires a dc supply for its operation. Usually, this supply is provided by dry cells. But sometime we use a battery eliminator in place of dry cells. The battery eliminator converts the ac voltage into dc voltage and thus *eliminates* the need for dry cells. Nowadays, almost all electronic equipments include a circuit that converts ac voltage of mains supply into dc voltage. This part of the equipment is called *power supply*. In general, at the input of the power supply, there is a power transformer. It is followed by a diode circuit called *rectifier*. The output of the rectifier goes to a *smoothing filter*, and then to a *voltage* regulator circuit. A block diagram of such a power supply is shown in Fig. 4.11. The rectifier circuit is the heart of a power supply.

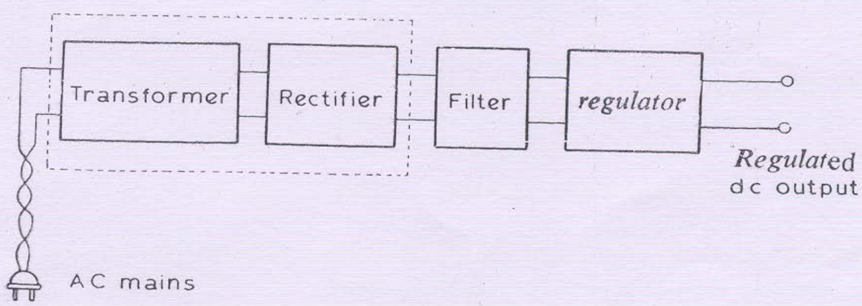


Fig. 4.11 Block diagram of a power supply

4.6.1 Half-Wave Rectifier

The unidirectional conducting property of a diode finds great application in rectifiers. These are the circuits which convert an ac voltage into dc voltage.

Figure 4.12 shows the circuit of a half-wave rectifier. Most electronic equipments have a transformer at the input. The transformer serves two purposes. Firstly, it allows us to step the voltage up or down. This way we can get the desired level of dc voltage. For example, the battery eliminator used with a transistor radio gives a dc voltage of about 6 V. We can use a step down transformer to get such a low ac voltage at the input of the rectifier. On the other hand, the cathode-ray tube used in an oscilloscope needs a very high dc voltage—of the order of a few kV. Here, we may use a step-up transformer. The second advantage of the transformer is the isolation it provides from the power line. It reduces the risk of electrical shock.

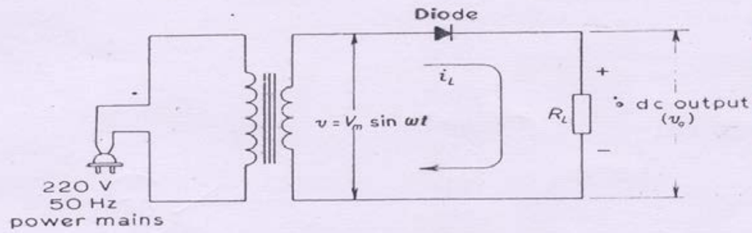


Fig. 4.12 Half-wave rectifier circuit

In Fig. 4.12, the diode forms a series circuit with the secondary of the transformer and the load resistor R_L. Let us see how this circuit rectifies ac into dc.

The primary of the transformer is connected to the power mains. An ac voltage is induced across the secondary of the transformer. This voltage may be less than, or equal to, or greater than the primary voltage depending upon the turns ratio of the transformer. We can represent the voltage across the secondary by the equation

$$v = V_m \sin \omega t \qquad (4.3)$$

Figure 4.13*a* shows how this voltage varies with time. It has alternate positive and negative half-cycles. Voltage V_m is the peak value of this alternating voltage.

During the positive half-cycle of the input voltage, the polarity of the voltage across the secondary is as shown in Fig. 4.14*a*. This polarity makes the diode forward biased, because it tries to push the current in the direction of the diode arrow. The diode conducts, and a current i_L flows through the load resistor R_L. This current makes the terminal *A* positive with respect to terminal *B*. Since a forward-biased diode offers a very low resistance, the voltage drop across it is also very small (about 0.3 V for Ge diode and about 0.7 V for Si diode). Therefore, the voltage appearing across the load terminals *AB* is practically the same as that the voltage v_i at every instant.

During the negative half-cycle of the input voltage, the polarity gets reversed. The voltage v tries to send current against the direction of diode

b. What is Zener diode? Explain working of Zener diode voltage regulator

4.9.3 Zener Diodes

Zener diodes are designed to operate in the breakdown region without damage. By varying the doping level, it is possible to produce zener diodes with breakdown voltages from about 2 V to 200 V.

As discussed in Sec. 4.2.3, the large current at breakdown is brought about by two factors, known as the zener and avalanche effects. When a diode is heavily doped, the depletion layer is very narrow. When the voltage across the diode is increased (in reverse bias), the electric field across the depletion layer becomes very intense. When this field is about 3×10^7 V/m, electrons are pulled from the covalent bonds. A large number of electron-hole pairs are thus produced and the reverse current sharply increases. This is known as the *zener effect*.

Avalanche effect occurs because of a cumulative action. The external applied voltage accelerates the minority carriers in the depletion region. They attain sufficient kinetic energy to *ionize* atoms by collision. This creates new electrons which are again accelerated to high-enough velocities to ionize more atoms. This way, an avalanche of free electrons is obtained. The reverse current sharply increases.

The zener effect is predominant for breakdown voltages less than about 4 V. The avalanche breakdown is predominant for voltages greater than 6 V. Between 4 and 6 V, both effects are present. It is the zener effect that was first discovered, and the term "zener diode" is in wide use for a *breakdown diode* whether it uses zener effect or avalanche effect, or both. If the applied reverse voltage exceeds the breakdown voltage, a zener diode acts like a *constant-voltage* source. For this reason, a zener diode is also called *voltage reference diode*.

The circuit symbol of a zener diode is shown in Fig. 4.28. A zener diode is specified by its breakdown voltage and the maximum power dissipation. The most common application of a zener diode is in the voltage stabilizing or regulator circuits.

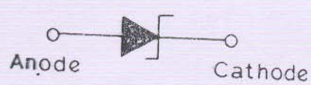


Fig. 4.28 Circuit symbol of a zener diode

Zener Diode Voltage Regulator After the ripples have been smoothed or filtered from the rectifier output, we get a sufficiently steady dc output. But for many applications, even this sort of power supply may not serve the purpose. Firstly, this supply does not have a good enough voltage regulation. That is, the output voltage reduces as the load (current) connected to it is increased. Secondly, the dc output voltage varies with the change in the ac input voltage. To improve the constancy of the dc output voltage as

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the load and/or the ac input voltage vary, a voltage-regulator circuit is used. The stabilizer circuit is connected between the output of the filter and the load (see Fig. 4.11).

The simplest regulator circuit consists merely of a resistor R_S connected in series with the input voltage, and a zener diode connected in parallel with the load (Fig. 4.29). The voltage from an unregulated power supply is used as the input voltage V_I to the *regulator* circuit. As long as the voltage across R_L is less than the zener-breakdown voltage V_Z, the zener diode does not conduct. If the zener diode does not conduct, the resistors R_S and R_L make a potential divider across V_I. At an increased V_I, the voltage across R_L becomes greater than the zener-breakdown voltage. It then operates in its breakdown region. The resistor R_S limits the zener current from exceeding its rated maximum $I_{Z\,max}$.

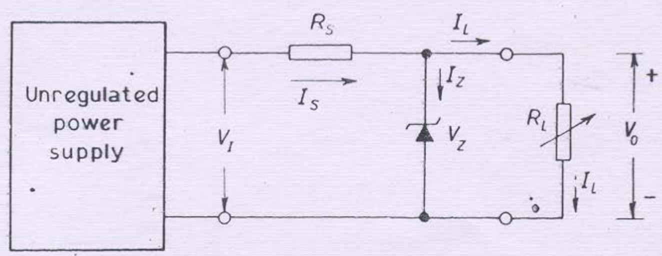

Fig. 4.29 The zener-diode voltage regulator

The current from the unregulated power supply splits at the junction of the zener diode and the load resistor. Therefore,

$$I_S = I_Z + I_L \qquad (4.33)$$

When the zener diode operates in its breakdown region, the voltage V_Z across it remains fairly constant even though the current I_Z flowing through it may vary considerably. If the load current I_L should increase (because of the reduction in load resistance), the current I_Z through the zener diode falls by the same percentage in order to maintain constant current I_S. This keeps the voltage drop across R_S constant. Hence, the output voltage V_O remains constant. If, on the other hand, the load current should decrease, the zener diode passes an extra current I_Z such that the current I_S is kept constant. The output voltage of the circuit is thus stabilized.

Let us examine the other cause of the output voltage variation. If the input voltage V_I should increase, the zener diode passes a larger current so that extra voltage is dropped across R_S. Conversely, if V_I should fall; the current I_Z also falls, and the voltage drop across R_S is reduced. Because of the self-adjusting voltage drop across R_S, the output voltage V_O fluctuates to a much lesser extent than does the input voltage V_I.

Q.8 a. Explain the functioning of a transistor in common base configuration and draw its Input and Output V-I characteristics

The circuit arrangement for determining CB characteristics of a transistor (here, we have taken *PNP* type) is shown in Fig. 5.11. The emitter-to-base voltage V_{EB} can be varied with the help of a ponentiometer R_1. Since the voltage V_{EB} is quite low (less than one volt) we include a series resistor R_S (say, 1 kΩ) in the emitter circuit. This helps in limiting the emitter current I_E to a low value; without this resistor, the current I_E may change by large amount even if the potentiometer (R_1) setting is moved slightly.

The collector voltage can be varied by adjusting the potentiometer R_2. The required currents and voltages for a particular setting of the potentiometers can be read from the milliammeters and voltmeters connected in the circuit.

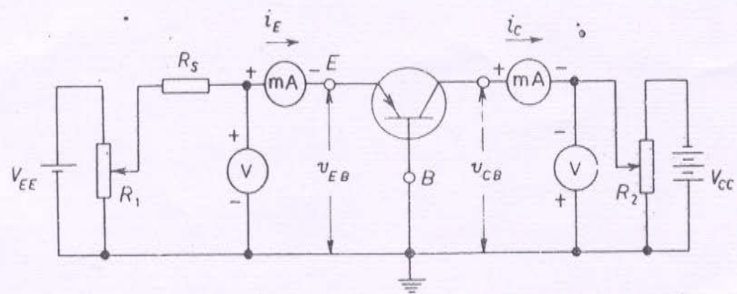

Fig. 5.11 Circuit arrangement for determining the static characteristics of a *PNP* transistor in CB configuration

Input CB Characteristics The common-base input characteristics are plotted between emitter current i_E and the emitter-base voltage v_{EB}, for different values of collector-base voltage V_{CB}. Figure 5.12 shows typical input characteristics for a *PNP* transistor in common-base configuration.

For a given value of V_{CB}, the curve is just like the diode characteristic in forward-bias region. Here, the emitter-base is the *PN*-junction diode which is forward-biased. This junction becomes a better diode as V_{CB} increases. That is, there will be a greater i_E for a given v_{EB} as V_{CB} increases, although the effect is very small.

For a diode, we had seen that its dynamic resistance is calculated from the slope of its forward characteristic curve. In a similar way, from the slope of the input characteristic we can get the *dynamic input resistance* of the transistor :

$$r_i = \left.\frac{\Delta v_{EB}}{\Delta i_E}\right|_{V_{CB} = \text{const.}} \qquad (5.4)$$

The dynamic input resistance r_i is very low (20 to 100 Ω). Since the curve is not linear, the value of r_i varies with the point of measurement. As the

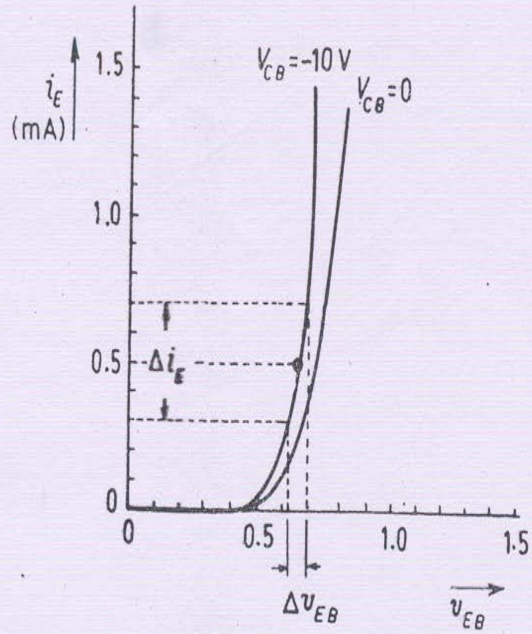

Fig. 5.12 Common-base input characteristics for a typical *PNP* silicon transistor

emitter-base voltage increases, the curve tends to become more vertical. As a result, r_i decreases.

The input characteristics of an *NPN* transistor are similar to those in Fig. 5.12, differing only in that both i_E and v_{EB} would be negative and V_{CB} would be positive.

Output CB Characteristics For the same *PNP* transistor in *CB* configuration, a set of output characteristics are shown in Fig. 5.13. The output characteristic curve indicates the way in which the collector current i_C varies with change in collector-base voltage v_{CB}, with the emitter current I_E kept constant. As per standard convention, a current entering into a transistor is positive. For a *PNP* transistor, current i_C is flowing out of the transistor and is negative. Since the collector junction is reverse biased, the voltage v_{CB} is negative. The emitter current is entering into the transistor, and is taken as positive.

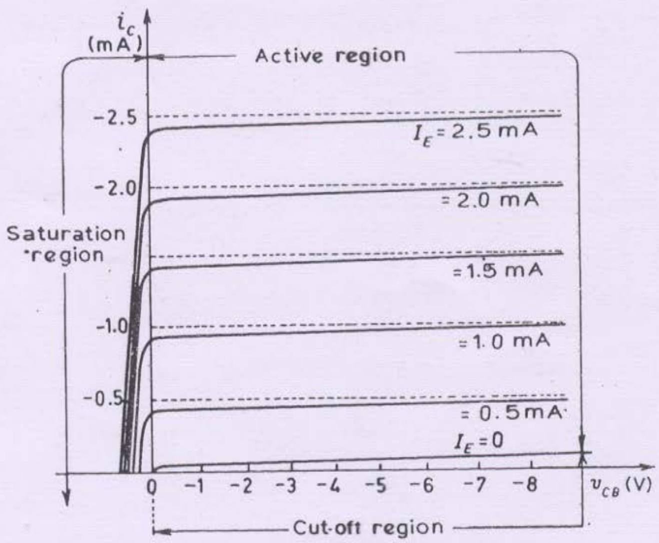

Fig. 5.13 Common-base output characteristics for a *PNP* transistor

A close look at the output characteristics of Fig. 5.13 reveals the following interesting points:

(i) The collector current I_C is approximately equal to the emitter current I_E. This is true only in the *active* region, where collector-base junction is reverse-biased.

(ii) In the active region, the curves are almost flat. This indicates that i_C (for a given I_E) increases only slightly as v_{CB} increases. Is it not what happens in a constant current source? The transistor characteristic (in *CB* configuration) is similar to that of the current source. It means that the transistor should have high output resistance (r_o).

(iii) As v_{CB} becomes positive (the collector-base junction becomes forward-biased), the collector current i_C (for a given I_E) sharply decreases. This is the *saturation* region. In this region, the collector current does not depend much upon the emitter current.

(iv) The collector current is not zero when $I_E = 0$. It has a very small value. This is the reverse leakage current I_{CO}. The conditions that exist when $I_E = 0$ for *CB* configuration is shown in Fig. 5.14. The

b. What is DC load line? How you draw DC load line on collector Characteristics for CE amplifier with simple bias?

5.10.1 DC Load Line

Let us consider the amplifier circuit of Fig. 5.24, when no signal is applied to its input. This condition (of having no input signal) is described as a *quiescent condition*. The circuit then reduces to the one shown in Fig. 5.25. The battery V_{CC} sends current I_C through the load resistor R_C and the transistor. There is some voltage drop across the load resistor R_C due to the flow of current I_C. The polarity of this voltage drop $I_C R_C$ is shown in the figure. The remaining voltage drops across the transistor. This voltage is written as V_{CE}. Applying Kirchhoff's voltage law to the collector circuit, we get

$$V_{CC} = I_C R_C + V_{CE} \tag{5.26}$$

We can rearrange the terms of the above equation and put it as

$$I_C = \left(-\frac{1}{R_C}\right) V_{CE} + \frac{V_{CC}}{R_C} \tag{5.27}$$

We have rewritten Eq. 5.26 in above form, because we wanted to put it in the form

$$y = mx + c \tag{5.28}$$

which is the equation of a straight line. If Eq. 5.27 is plotted on the transistor's output characteristics (i.e. the curves between v_C and i_{CE}), we get a straight line. Comparison of Eq. 5.27 with Eq. 5.28 indicates that the slope of this line is

$$m = -\frac{1}{R_C} \tag{5.29}$$

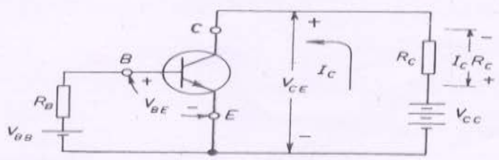

Fig. 5.25 CE amplifier in quiescent condition

$$c = \frac{V_{CC}}{R_C} \tag{5.30}$$

The straight line represented by Eq. 5.27 is called the *dc load line*.

Plotting of the dc load line on collector characteristics is easy. Find any two points satisfying Eq. 5.27, and then join these points. The simplest way, then, is to take one point on the v_{CE} axis and the other on i_C axis. On the v_{CE} axis, the current I_C must be zero. Hence, from Eq. 5.27, we should have $V_{CE} = V_{CC}$. When $V_{CE} = 0$, Eq. 5.27 gives $I_C = V_{CC}/R_C$. Thus, the two points on the dc load line are

(i) $V_{CE} = V_{CC}$; $\quad I_C = 0$

(ii) $V_{CE} = 0$; $\quad I_C = \dfrac{V_{CC}}{R_C}$

These two points can be located on the collector characteristics. See Fig. 5.26. Join these two points. This is the dc load line. The slope of this line is $(-1/R_C)$ and is decided by the value of resistor R_C. Since this resistance is the dc load* of the amplifier, we call the line as dc load line.

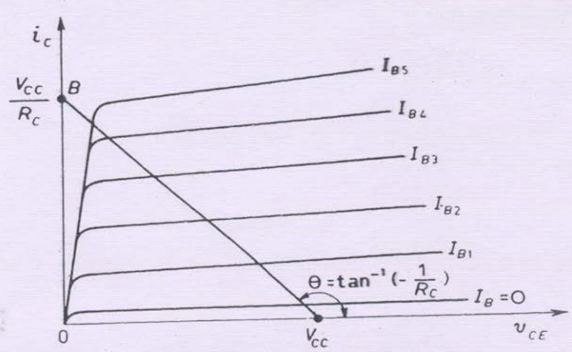

Fig. 5.26 Plotting of dc load line on collector characteristics

Q.9a. Draw circuit diagram of two stage capacitor coupled amplifier and explain it.

9.3.1 Resistance-Capacitance Coupling

Figure 9.2 shows how to couple two stages of amplifiers using resistance-capacitance (*RC*) coupling scheme. This is the most widely used method. In this scheme, the signal developed across the collector resistor R_C of the first stage is coupled to the base of the second stage through the capacitor C_C. The coupling capacitor C_C blocks the dc voltage of the first stage from reaching the base of the second stage. In this way, the dc biasing of the next stage is not interfered with. For this reason, the capacitor C_C is also called a *blocking capacitor*.

Some loss of the signal voltage always occurs due to the drop across the coupling capacitor. This loss is more pronounced when the frequency of the input signal is low. (This point is discussed in more detail in Sec. 9.4.1). This is the main drawback of this coupling scheme. However, if we are interested in amplifying ac signals of frequencies greater than about 10 Hz, this coupling is the best solution. It is the most convenient and least expensive way to build a multi-stage amplifier.

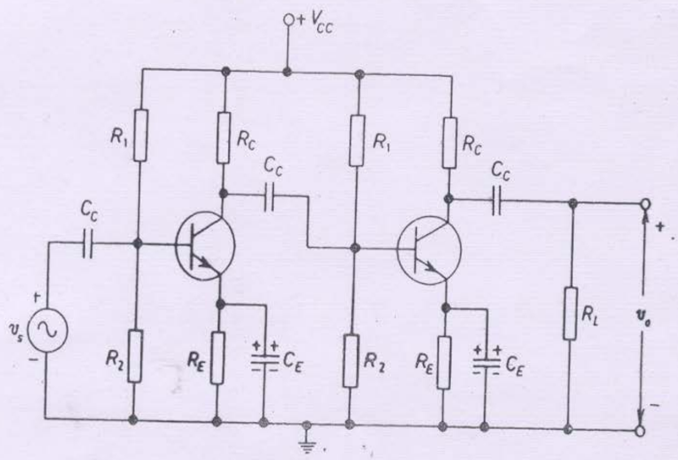

Fig. 9.2 Two-stage *RC*-coupled amplifier using transistors

RC coupling scheme finds applications in almost all audio small-signal amplifiers used in record players, tape recorders, public-address systems, radio receivers, television receivers, etc.

Triode (or pentode) amplifiers can also be cascaded by *RC* coupling. Figure 9.3 illustrates how *RC* coupling is used for two stages of triode amplifiers. Here, the cathode resistor R_K and capacitor C_K provide the self bias in the circuit. The operating point of a triode amplifier is independent of temperature. Therefore, the need of stabilization of the operating point does not arise. The circuit is much simpler than the one using transistors. But it requires high dc voltage (of the order of 300 V) supply.

b. With the help of diagram explain the working of BJT Phase – shift oscillator.

Ans. 9 (b) 669-670-Text Book-II

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1. Basic Electrical Engineering, V.N. Mittle and Arvind Mittal, Tata McGraw-Hill

2. Electronic Devices and Circuits, Fourth Edition, David A Bell, PHI (2006)