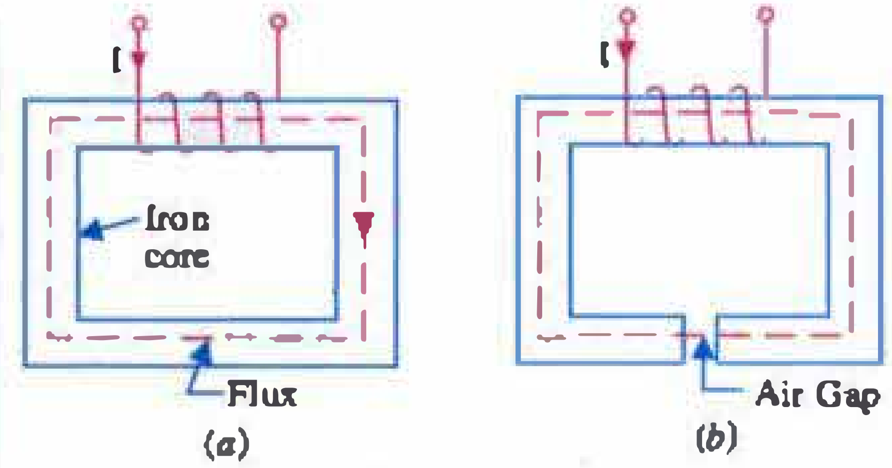


Fig. 7.12

The three quantities are :

1. Magnetomotive force (MMF)

It resembles voltage or *electromotive force* (*EMF*) in an electric circuit and is responsible for producing magnetic flux in a magnetic circuit. Its value is given by the product of current through the coil and its number of turns *i.e.*, NI. Its unit is ampere-turn*.

2. Magnetic flux (Φ)

It resembles *current* in an electric circuit. It consists of magnetic lines of force and its unit is weber.

3. Reluctance (S)

It resembles *resistance* in an electric circuit. It represents the opposition which a core offers to the production of flux through it. Its value is

$$S = \frac{l}{\mu A} = \frac{l}{\mu_0 \mu_r A}$$

Its unit is 'reciprocal' henry *i.e.*, per henry.

Ohm's law for magnetic circuit is

$$\text{flux} = \frac{\text{mmf}}{\text{reluctance}} = \frac{NI}{S}\text{ weber}$$

$$= \frac{NI}{l/\mu A}\text{ weber} = \frac{\mu NAI}{l}\text{ weber} = \frac{\mu_0 \mu_r NAI}{l}\text{ weber}$$

Example 7.1. *A mild-steel ring having a cross-sectional area of 5 cm² and a mean circumference of 40 cm has a coil of 200 turns wound uniformly around it. Calculate*

(i) reluctance of the ring

(ii) current required to produce a flux of 800 μ Wb in the ring.

Take relative permeability of mild-steel as 380.

Solution. (*i*) $\frac{l}{\mu_0 \mu_r A} = \frac{0.4}{4\pi \times 10^{-7} \times 380 \times (5 \times 10^{-4})} = 1.675 \times 10^6$ **henry**$^{-1}$

(*ii*) Now, $\Phi = \frac{NI}{S}$ ∴ $800 \times 10^{-6} = \frac{200 \times I}{1.675 \times 10^6}$ ∴ $I = 6.7$ **A**

7.8. Transformer

It is a static (or stationary) piece of apparatus that

1. transfers electric power from one circuit to another having mutual inductance with it.
2. Does so without change of frequency.
3. Does it by electromagnetic induction.


Autotransformer

Constructionally, transformers may be either isolation transformers (with electrically-insulated primary and secondary windings) or autotransformers (with electrically-connected primary and secondary windings). The two are shown in Figs. 7.13 and 7.14 respectively.

* Strictly speaking, it should be ampere only because turn has no units.

The two-winding isolation transformer may be further subdivided into

(*i*) core type transformer .... in which the windings surround a considerable part of the core (Fig. 7.15).

(*ii*) shell type transformer .... in which the core surrounds a considerable part of the windings (Fig. 7.16).

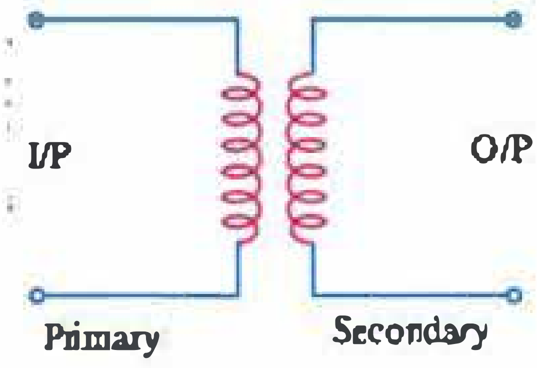


Fig. 7.13

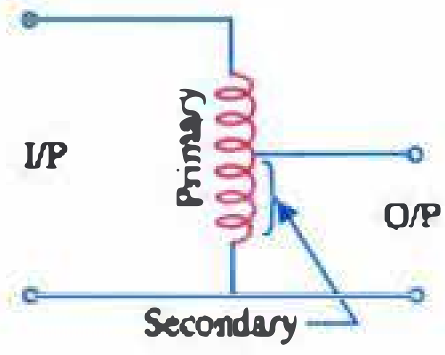
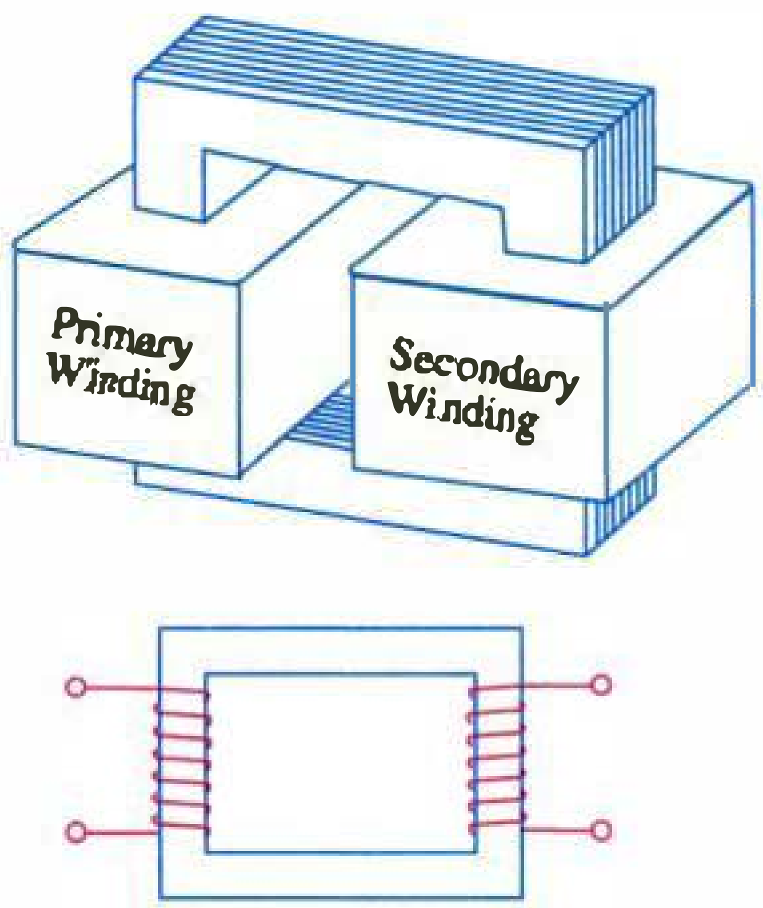


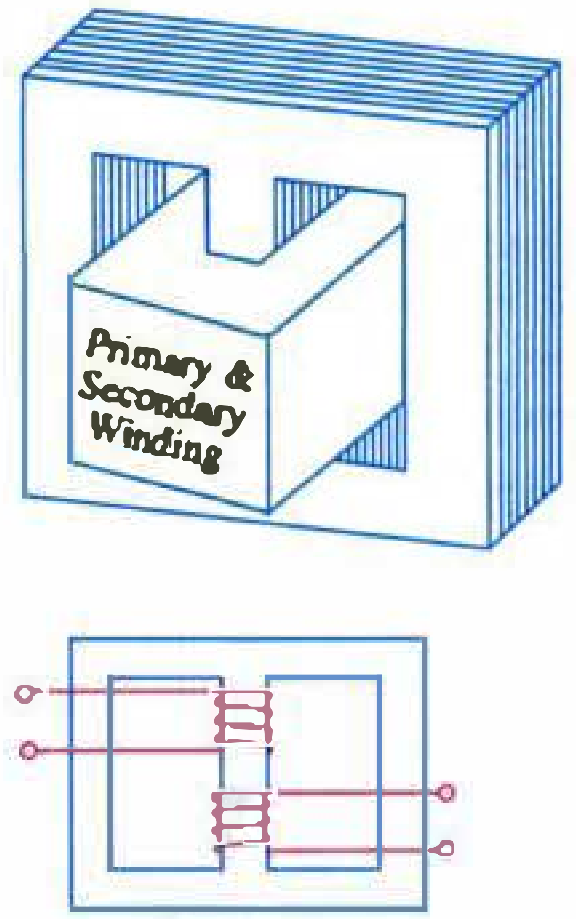
Fig. 7.14

As seen, core-type transformer is made up of a package of thin rectangular silicon steel laminations. Each lamination is coated with an insulating varnish and the total core pressed together. The primary and secondary windings are placed on each side of the common core (Fig. 7.15).



Core Type

Fig. 7.15



Shell Type

Fig. 7.16

The shell type constuction also consists of similar laminations. The two windings are wound in layers and fit over the centre section of the core as shown in Fig. 7.16.

Functionally, the transformers used in electronic circuits can be classified according to the frequency range over which they operate such as :

1. Audio Frequency (AF) Transformers

They are designed to operate over the audio frequency (AF) range of 20 Hz to 20 kHz, have laminated core and are usually smaller than power transformers. They are primarily used for impedance matching and, in some cases, for voltage amplification. Two such typical transformers are shown in Fig. 7.17. Such transformers are usually designated according to their applications as input or output transformer, microphone transformer, modulation transformer and interstage transformer etc. Usually, they are rated by their primary and secondary impedances and current-carrying capability.

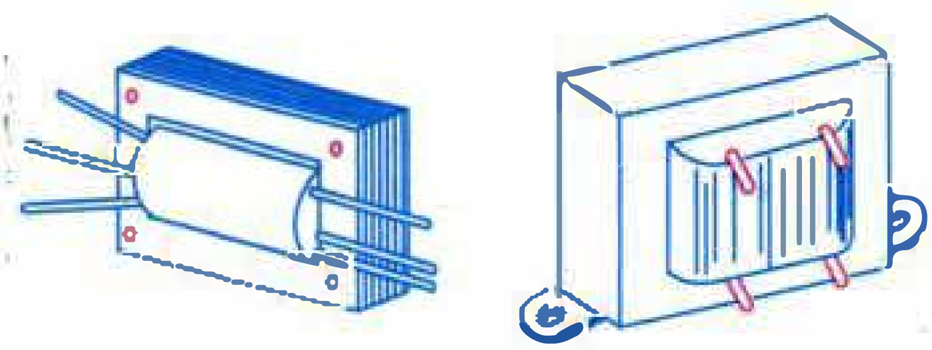


Fig. 7.17

2. Radio Freqdency (RF) Transformers

They are designed to operate at high frequencies (above audio range) and are referred to either as intermediate frequency (IF) transformers or radio frequency transformers. They may have air core or ferrite core (mostly adjustable). Most of the RF transformers have either one or both of the windings tuned *i.e.*, in conjunction with capacitor, they form a resonant circuit which works best at one particular frequency.

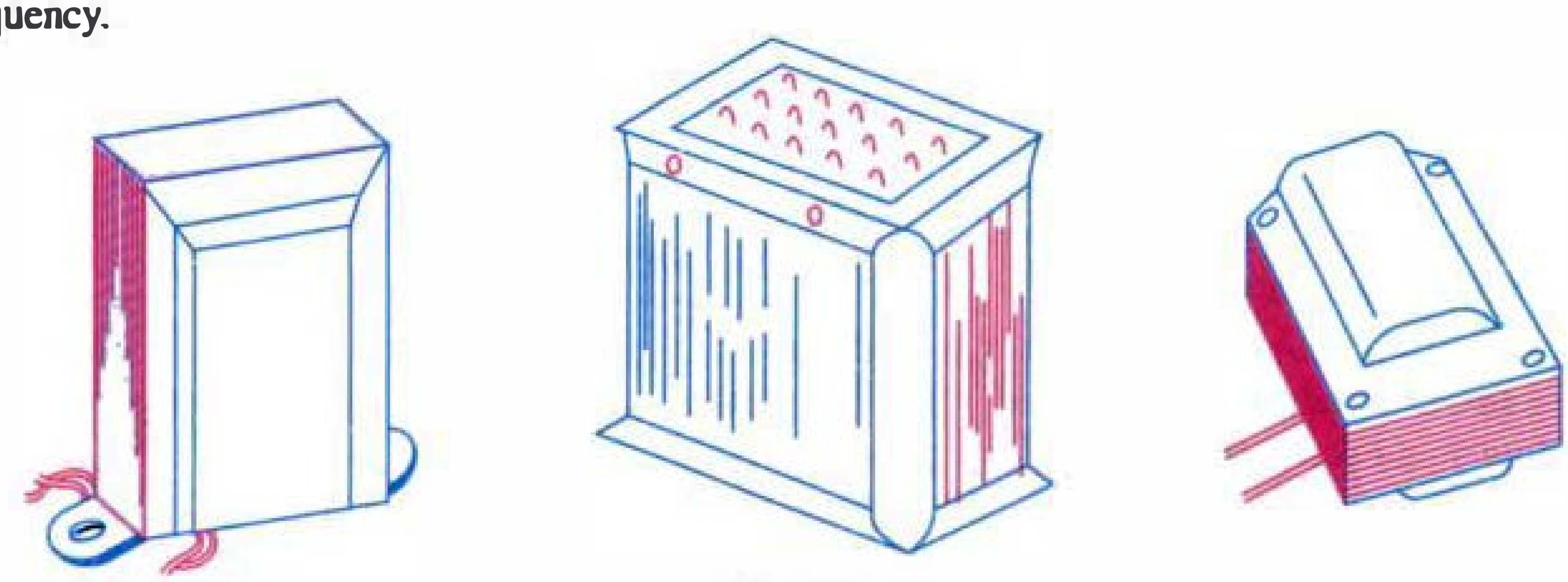


Fig. 7.18

3. Power Transformers

Usually, they have laminated core and have one primary winding but several secondary windings insulated from each other (Fig. 7.18). They are commonly used in the power supply of electronic equipment and provide various ac voltage necessary for the production of dc voltages. Typical transformers of this type are shown in Fig. 7.18.

7.9. Transformer Working

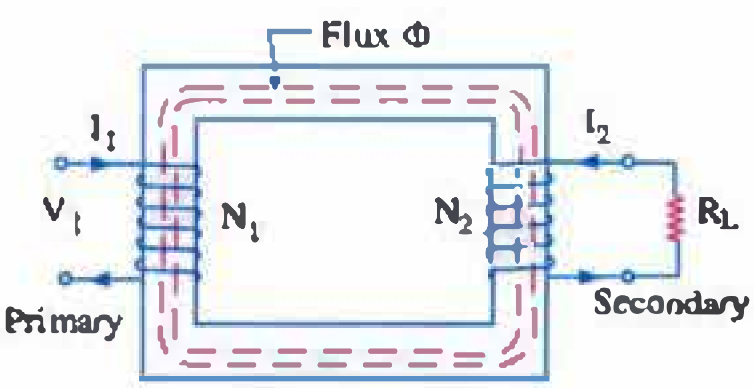


Fig. 7.19

Consider the core-type transformer shown in Fig. 7.19. It consists of two highly inductive coils which are electrically separate but magnetically linked through an iron core of low reluctance. The two coils possess high mutual inductance. If one coil is connected to source of alternating voltage, an alternating flux is set up in the laminated core most of which is linked with the other coil. Hence, mutually-induced voltage is produced in the second coil. If the second coil circuit is closed, a current flows in its and so electric energy is transfered (entirely magnetically) from the first coil to the second coil. The first coil in which electric energy is fed is called *primary* winding and the other from which energy is drawn out is called *secondary* winding. Whether secondary voltage V_2 is more or less than primary voltage V_1 depends on the turn ratio of the transformer. It is found that

$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$

If $N_2 > N_1$, then $V_2 > V_1$ and the transformer is called *step-up* transformer, since it steps up the input primary voltage. If $N_2 < N_1$, then $V_2 < V_1$ and the transformer is called *step down* transformer.

Voltage transformation ratio (K) of a transformer is given by V_2/V_1.

$$\therefore \quad K = \frac{V_2}{V_1} = \frac{N_2}{N_1} \quad \text{or} \quad V_2 = KV_1$$

As seen, voltage transformation ratio equals the turn ratio.

Assuming an ideal transformer and equal power factor for both windings,

input power = output power

$$V_1 I_1 = V_2 I_2 \qquad \therefore \quad I_2 = I_1 / K$$

$$\therefore \quad \frac{I_2}{I_1} = \frac{V_1}{V_2} = \frac{1}{K}$$

It is obviously from the above that a transformer which is *step-up for voltage is step-down for current*. If voltage is increased five times, current becomes one-fifth because output power has to equal the input power (in an ideal case). It means that current ratio is reciprocal of voltage ratio.

Suppose, we have transformer with $N_1 = 100$ and $N_2 = 600$. Let $V_1 = 200$ V and $I_1 = 3$ A. Then,

$$K = \frac{N_2}{N_1} = \frac{600}{100} = 6; \qquad V_2 = KV_1 = 6 \times 200 = 1200 \text{ V}$$

$$I_2 = I_1/K = 3/6 = 0.5 \text{ A}$$

It is seen that secondary voltage is 6 times the primary voltage but, at the same time, secondary current is one-sixth of the primary current.

$$P_1 = 200 \times 3 = 600 \text{ W}; \qquad P_2 = 1200 \times 0.5 = 600 \text{ W}$$

As seen, the two powers are equal.

It is worth noting that whatever the actual value of primary and secondary volts, *the voltage/turn is the same in both windings*. In the above case

Primary volts/turn = 200/100 = 2 V; Secondary volts/turn = 1200/600 = 2 V

The two values are equal even though V_1 and V_2 are themselves unequal.

7.10. Transformer Impedance

Each transformer winding has its own resistance, inductive reactance and hence impedance. As shown in Fig. 7.20,

Primary impedance, $Z_1 = \sqrt{R_1^2 + X_1^2}$; Secondary impedance, $Z_2 = \sqrt{R_2^2 + X_2^2}$

Another very interesting thing about these impedances is that they assume different values when *viewed from the other winding*. For example, when Z_2 is viewed from primary winding, it assumes a value $Z_2' = Z_2 / K^2$. But, when Z_1 is viewed from secondary, it appears to have a value of $Z_1' = K^2 Z_1$. This fact is made use of in the working of an impedance-matching transformer (Art. 7.14).

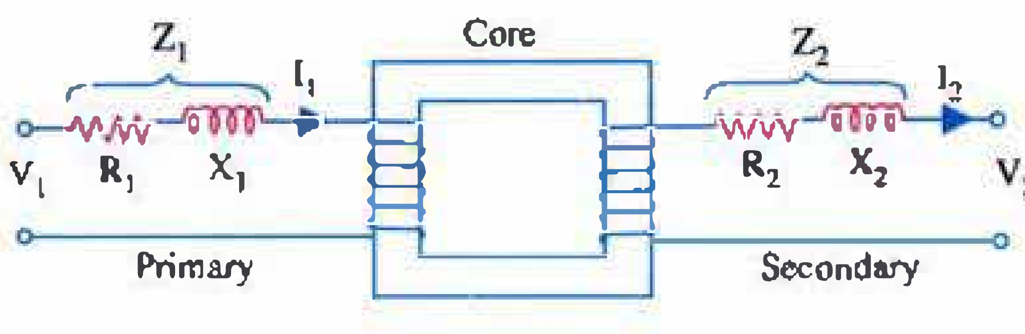


Fig. 7.20

Example 7.2. *A power transformer has 100 primary turns and 600 secondary turns. If primary voltage is 120 V and full-load primary current is 12 A, find secondary*

(i) voltage V_2 and (ii) current I_2.

Solution. Here $K = N_2/N_1 = 600/100 = 6$

(i) $V_2 = KV_1 = 6 \times 120 = 720$ V; (ii) $I_2 = I_1/K = 12/6 = 2$ A

Example 7.3. *A low-voltage soldering rod taking 40 A at 12 V is to be operated from the secondary of a 240 V transformer. Calculate*

(i) turn ratio of the transformer and (ii) primary current.

Solution. (i) $\frac{V_2}{V_1} = \frac{12}{240} = \frac{1}{20} \qquad \therefore \quad \frac{N_2}{N_1} = \frac{1}{20}$

Obviously, it is a step-down transformer having $K = 1/20$

(ii) $I_1 = KI_2 = \frac{1}{20} \times 40 = 2$ A

7.11. Can a Transformer Operate on DC ?

A transformer cannot operate on a steady or unchanging dc voltage such as that of a battery. It requires a voltage which rises and falls. Since an ac voltage not only changes its magnitude but its direction as well (Fig. 7.21), it is used to operate the transformers.

However, a transformer will operate from dc voltage if this voltage also undergoes changes. Transformers used for audio amplifiers work on pulsating dc voltage (Fig. 7.22). Main thing which causes the transformer to work is the *change* in voltage. It is immaterial whether the voltage changes from positive to negative values as in Fig. 7.21 or from positive to zero values as in Fig. 7.22 (it could, in fact, be from minus to zero values as well).

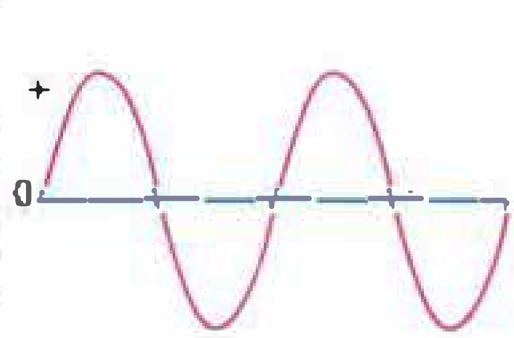


Fig. 7.21

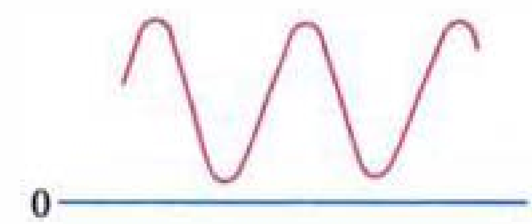


Fig. 7.22

7.12. RF Shielding

Coils are often encased in a metal cover, usually of copper or aluminium, in order to protect them from external varying flux of RF currents. Otherwise, unwanted eddy currents would be induced in them. Purpose of RF shielding is different from magnetic shielding (Art. 7.5) which protects against steady flux only. The shield cover not only isolates the coil from external varying magnetic fields but also minimizes the effect of coil's own RF currents on other external circuits.

7.13. Autotransformer

It is a transformer with one winding only, part of it being common to both primary and secondary. Here, primary and secondary are not electrically isolated from each other as is the case in a 2-winding transformer. However, its theory and operation are similar to that of a 2-winding transformer. Because of one winding, it is compact, efficient and cheaper

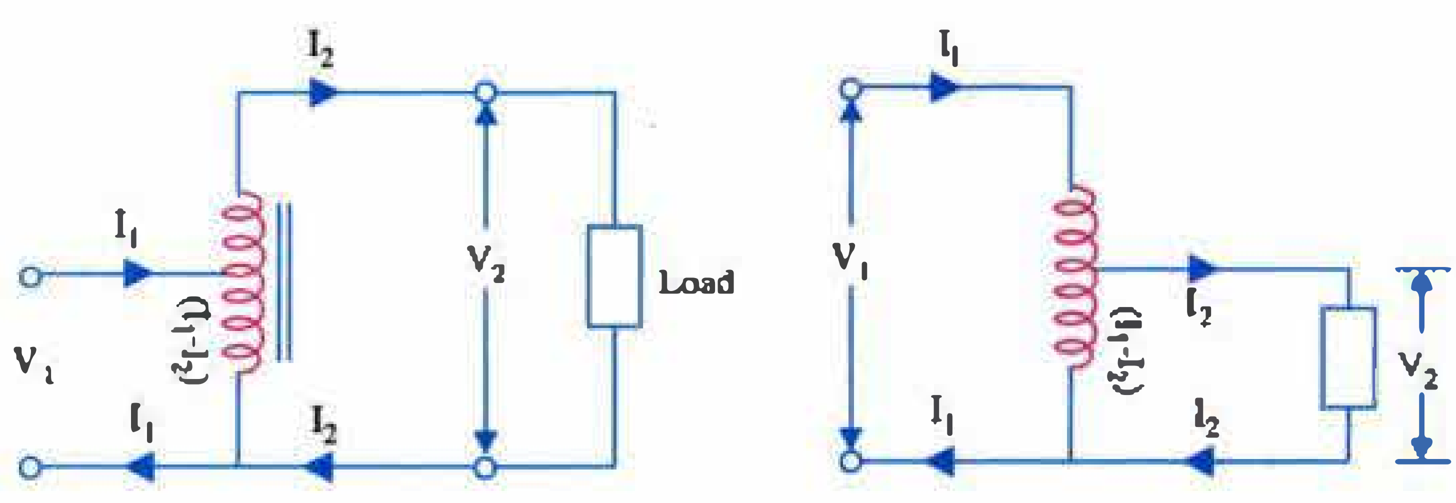


Fig. 7.23

Fig. 7.23 (*a*) shows a step-up autotransformer whereas Fig. 7.23 (*b*) shows a step-down type. As with other transformers, this step-up or step-down ratio depends on the turn ratio between the primary and secondary. Fig. 7.24 shows an audio output stage of an automobile radio that uses a step-down autotransformer.

Such a transformer is also used as an adjustable transformer for both stepping up or stepping down the input voltage (Fig. 7.25). It is often used for a light dimmer or for adjusting power to a radio transmitter.

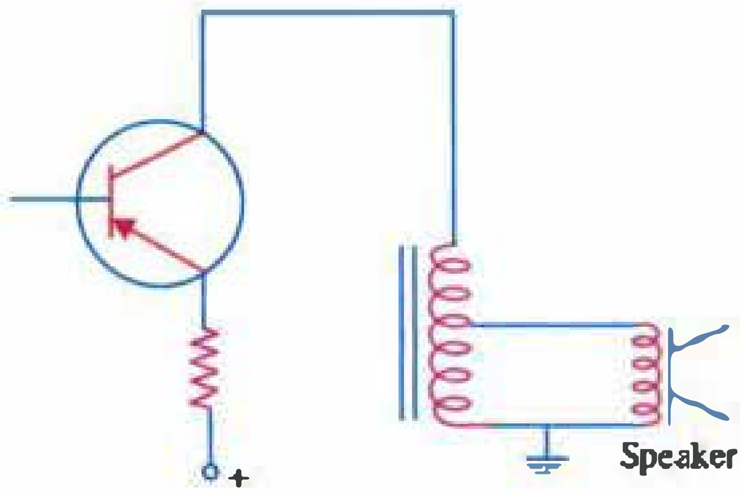


Fig.7.24

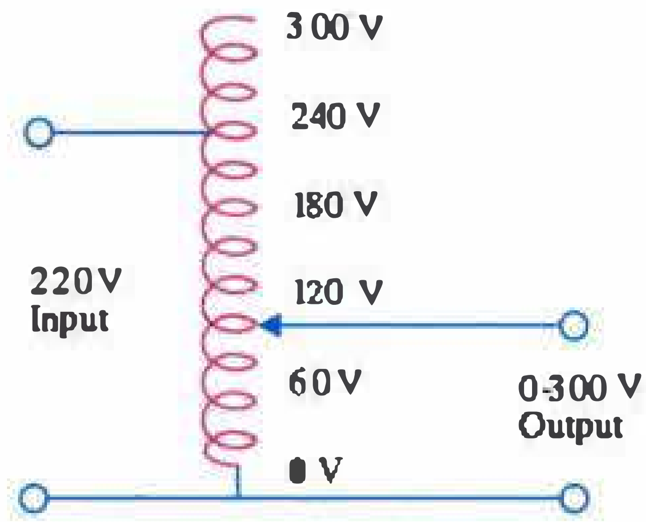
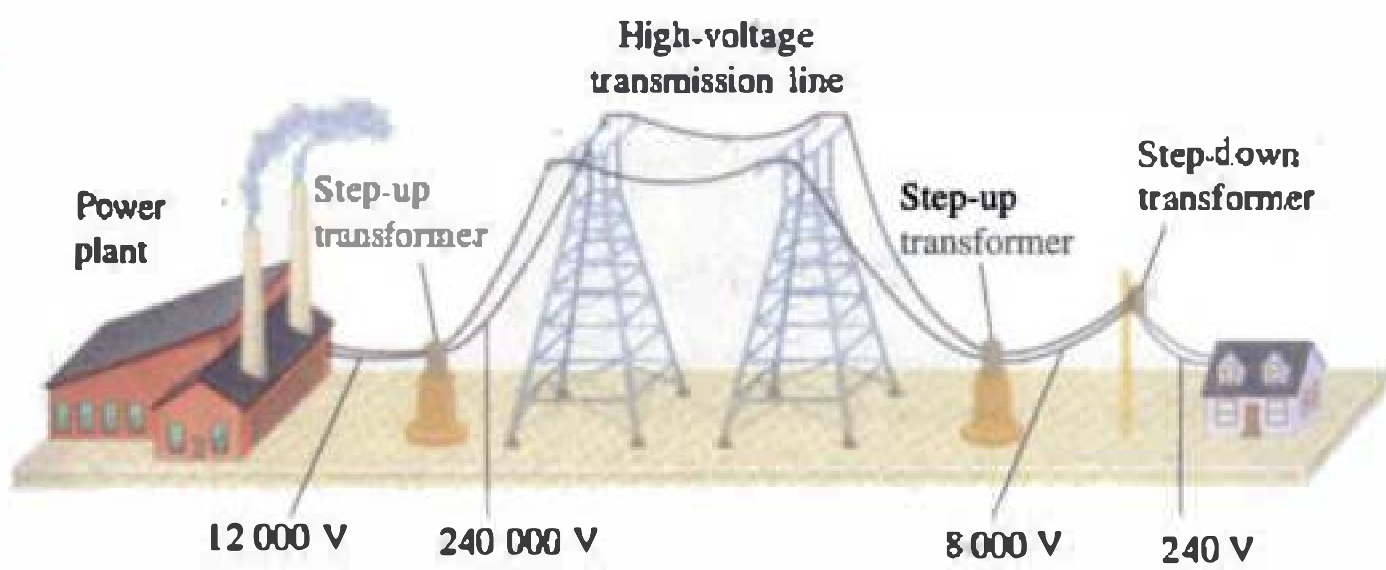


Fig. 7.25

Example 7.4. *The primary and secondary voltages of an autotransformer are 500 V and 400V respectively. Show on a diagram, the current distribution in the transformer if secondary current is 100 A.*



Transformers play an important role in the transmission of electric power.

Solution. $K = V_2/V_1$

$= 400/500 = 0.8$

Here, $I_2 = 100$ A --given

$I_1 = KI_2$

$= 0.8 \times 100 = 80$ A

As seen, current in the common portion of the winding is 20 A. Circuit diagram is shown in Fig. 7.26.

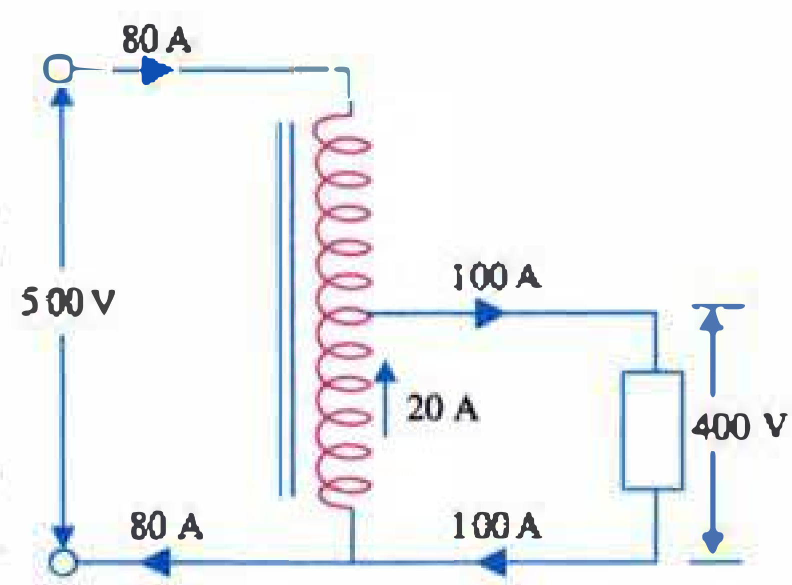


Fig. 7.26

7.14. Impedance Matching

For maximum transfer of power from one circuit to another the two should have equal impedances (Art. 4.9). If they do not have equal impedances, a transformer with suitable turn ratio can be used to achieve this impedance match. In electronic circuitry, it often becomes necessary to connect a circuit of high output impedance to one of low input impedance*. What it really means is that a certain circuit working at a high voltage but low current (hence high impedance) has sometime to be coupled to another circuit which requires lower voltages but higher current (hence low impedance). If two such circuits are coupled directly, energy transfer will not be maximum. In such cases, a transformer is used as an impedance-matching device because it can do the job of increasing or decreasing the voltages and currents very efficiently.

Suppose a circuit of *output* impedance 300 Ω is to be coupled to a circuit of *input* impedance 3 Ω. The turn-ratio (N_2/N_1) of the transformer should be such that when 3 Ω impedance in its secondary

* Usually, a higher-voltage low-current circuit is called a high impedance circuit, while a low-voltage higher-current one is referred to as low-impedance circuit.

is viewed by its primary, it should appear as 300 Ω. Now, when viewed from primary side, a 3 Ω resistance is seen as equal to $3/KC^2$ (Art. 7.9).

Hence, for equal matching $\dfrac{3}{K^2} = 300$

$K = \sqrt{1/100} = 1/10$ $\quad\therefore\quad \dfrac{N_2}{N_1} = \dfrac{1}{10}$

It means that secondary turns should be one-tenth the primary turns. Often, autotransformers are also used for impedance matching purpose.

Example 7.5. *A transformer is required to match the 400 Ω output impedance of a transistor power amplifier to a 4 Ω speaker coil. What should be the turn ratio?*

Solution. Obviously, the transformer primary would be fed from the amplifier whereas the secondary would be connected to the speaker.

$$K = \sqrt{Z_2 / Z_1} = \sqrt{4/400} = 1/10 \quad \therefore N_2/N_1 = 1/10$$

CONVENTIONAL PROBLEMS

1. A coil of 500 turns and resistance 20 Ω is wound uniformly on an iron ring of mean circumference 50 cm and cross-sectional area 4 cm². It is connected to a 24 V dc supply. Under these conditions, the relative permeability of iron is 800. Calculate the values of
   (*a*) mmf of the coil (*b*) magnetising force
   (*c*) total flux in iron core (*d*) reluctance of the iron ring
   [(*a*) 6000 AT (*b*) 1200 AT/m (*c*) 0.483 mWb (*d*) 1.24 × 10^6 H^{-1}]
2. A magnetic circuit consists of an iron ring of mean circumference 80 cm with cross-sectional area 12 cm² throughout. A current of 2 A in the magnetising coil of 200 turns produces a total flux of 1.2 mWb in the iron. Calculate
   (*i*) flux density in iron
   (*ii*) absolute and relative permeability of iron
   (*iii*) reluctance of the circuit **[(*a*) 1 T or Wb/m² (*b*) 0.002, 1590 (c) 3.33 × 10^5 $henry^{-1}$]**
3. A stepdown transformer with a voltage step-down ratio of 20 has 6 V across 0.3 Ω secondary. Calculate (*i*) secondary current and (*ii*) primary current. **[(*i*) 20 A (*ii*) 1 A]**
4. A stepdown transformer with 10 : 1 turn ratio is connected to 220 V, 50 Hz ac supply mains
   (*a*) What is the frequency of secondary voltage ?
   (*b*) How much is secondary voltage ?
   (*c*) If secondary load is 100 Ω, what is the secondary current and primary current ? Assume 100 per cent efficiency. **[(*a*) 50 Hz (*b*) 22 V (*c*) 0.22 A ; 0.022 A]**

SELF EXAMINATION QUESTIONS

A. Fill in the blanks with most appropriate word (s) or numerical value (s).

1. Even though wood is a non-magnetic material, it allows magnetic .... to pass through.
2. Ferromagnetic materials have high value of relative ....
3. Alnico is used for making permanent magnets because it has high ....
4. Ceramic material which has ferromagnetic properties of iron is called ....
5. Unit of magnetic flux density is ....
6. Ratio of B and H is called .... permeability.
7. Unit of magneto-motive force is ....
8. .... is reciprocal of reluctance.
9. An autotransformer has only .... winding.
10. An impedance-matching transformer couples two circuits of unequal ....