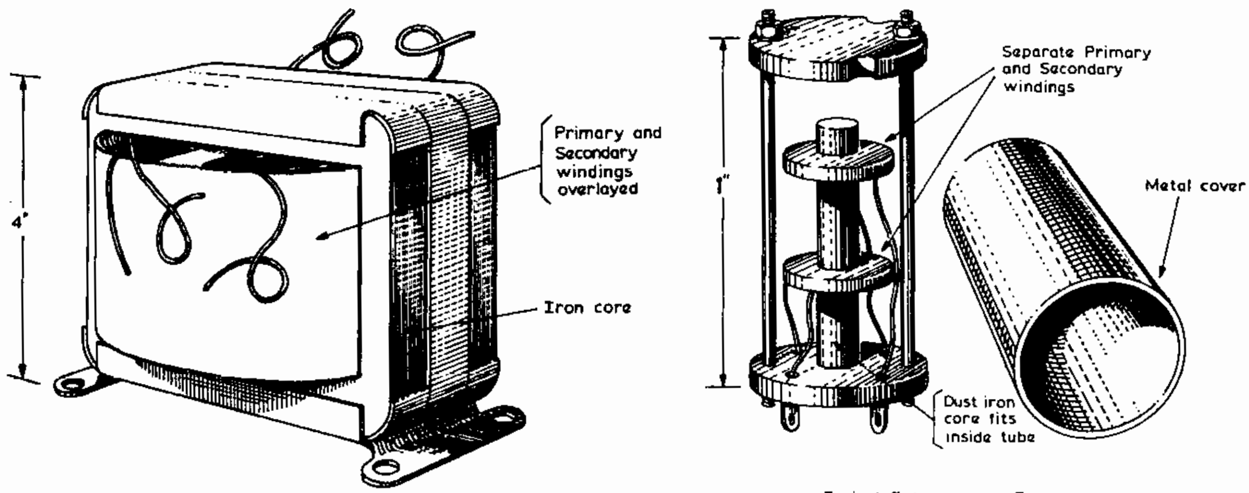
AN INTRODUCTION TO THE TRANSFORMER

Two or more coils possessing mutual inductance form a transformer. Transformers are used in a.c. circuits to transfer energy from one circuit to another without direct connection, usually with a change of magnitude of voltage by some chosen ratio. At audio and power distribution frequencies iron cores are generally used and the mutual inductance is large. At high frequencies iron cores cannot be used and the coupling is smaller; such transformers are often referred to simply as coupled circuits. The behaviour of iron cored transformers is most easily studied by considering first a perfect transformer, that is one without losses. The effects of the losses on a practical transformer can be considered later.

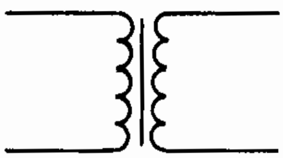


Small power transformer
240V 50Hz Primary

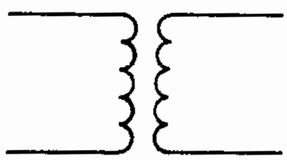
Typical Intermediate Frequency Transformer with cover removed. Used at approx. 500kHz

Fig. 1 : Examples of Practical Transformer Design

The circuit symbols used to represent the transformer are :-



Iron Cored



Air Cored

Block diagram

The input winding is called the primary winding and all other coupled coils are called secondary windings. There is no theoretical limit to the number of secondary windings.

INTRODUCTION TO THE TRANSFORMER

THE PERFECT TRANSFORMER

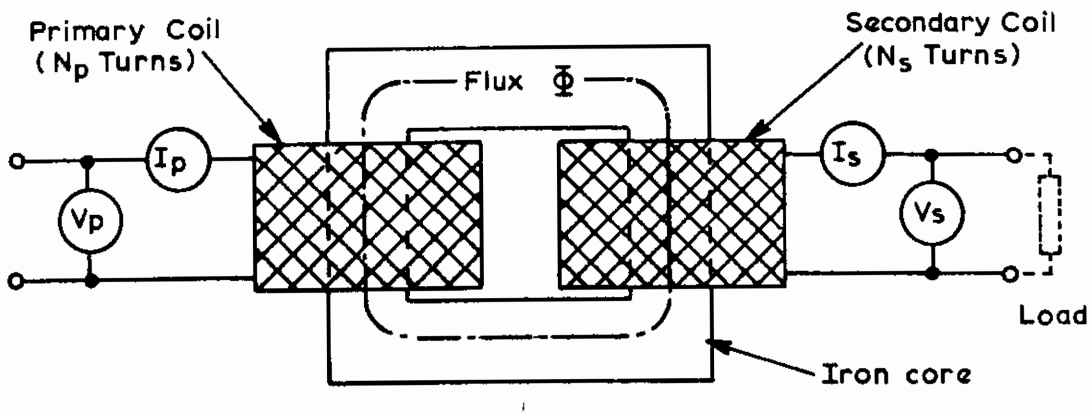


Fig. 2 : Simple Iron Cored Transformer

The arrangement shown in Figure 2 is a perfect transformer provided :-

a) The windings have negligible resistance.

b) All the flux produced by the primary winding couples with the secondary winding.

c) The iron core simply increases flux and coupling and does not cause power loss.

d) When the magnitude of the secondary current is zero the magnitude of the primary current should be very low, ideally zero.

In a practical transformer the current that flows in the primary when there is no load on the secondary is called the magnetising current, its only purpose is to produce the coupling flux. Although this current does not produce power loss it is normally kept as small as possible. This is achieved in low frequency transformers by using iron cores (more flux per ampere turn) and large number of turns, i.e. the inductance of the primary is made as large as is practicable. Typically a mains transformer will have 4-5 turns per volt giving a primary inductance of approx. 50H.

In a perfect transformer the coupling flux is determined entirely by the primary voltage since under all load conditions, $N_p \times \frac{d\Phi}{dt}$, must equal the applied voltage V_p. The primary current I_p that flows must be sufficient to maintain this flux.

VOLTAGE TRANSFORMATION

Under all conditions $V_p = N_p \frac{d\Phi}{dt}$

since the same flux couples with secondary $V_s = N_s \frac{d\Phi}{dt}$

hence, $\frac{V_p}{N_p} = \frac{V_s}{N_s}$ $\therefore$ $\frac{V_p}{V_s} = \frac{N_p}{N_s}$

The ratio $\frac{\text{primary turns } (N_p)}{\text{secondary turns } (N_s)}$ is called turns ratio and is often expressed as N:1 or 1:N depending on which has the larger number of turns.

CURRENT TRANSFORMATION

(Assuming the magnetising current to be negligible.)

When a secondary current flows it produces a demagnetising force which tends to reduce the core flux, this force is proportional to $N_s \times I_s$. To maintain core flux constant a primary current must flow to produce a magnetising force to oppose the demagnetising force, hence

$$N_p \times I_p = N_s \times I_s \qquad \therefore \quad \frac{I_p}{I_s} = \frac{N_s}{N_p}$$

POWER TRANSFORMATION

Input power = $V_p \times I_p$ Output power = $V_s \times I_s$

$V_s = V_p \times \frac{N_s}{N_p}$ $I_s = I_p \times \frac{N_p}{N_s}$

Hence output power = $V_p \times \frac{\cancel{N_s}}{\cancel{N_p}} \times I_p \times \frac{\cancel{N_p}}{\cancel{N_s}} = V_p \times I_p$

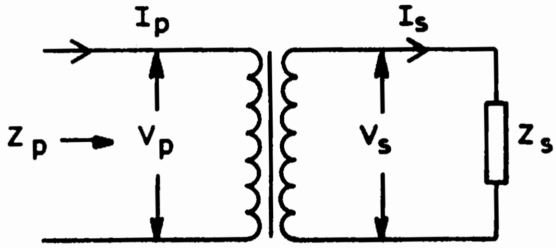
$\therefore$ Output power = Input power

A perfect transformer transfers energy from primary to secondary circuit without loss, i.e. the efficiency is 100%.

In a well designed transformer the losses are very small compared to the power transferred and at full load efficiencies above 90% are typical.

INTRODUCTION TO THE TRANSFORMER

IMPEDANCE TRANSFORMATION



$$Z_p = \frac{V_p}{I_p} \qquad Z_s = \frac{V_s}{I_s}$$

$$Z_p = \frac{V_s \times \frac{N_p}{N_s}}{I_s \times \frac{N_s}{N_p}} = \frac{V_s}{I_s} \times \left(\frac{N_p}{N_s}\right)^2$$

Hence $Z_p = Z_s \times \left(\frac{N_p}{N_s}\right)^2$ or $Z_s = Z_p \times \left(\frac{N_s}{N_p}\right)^2$

PRACTICAL TRANSFORMERS

The losses that have been ignored in considering the ideal transformer are :-

a) Copper loss - power loss produced by the resistance of the windings, this is referred to as copper loss or I^2R loss. This can only be minimised by using large cross section wire for the windings. The voltage drop produced by the resistance of the windings when the transformer is loaded can be compensated by a small increase in the number of secondary turns.

b) Eddy current loss - the alternating flux, as well as inducing voltages in the windings, induces voltages in the iron core causing eddy currents to circulate. At low frequencies these are minimised by laminating the core and at higher frequencies by using dust-iron cores.

c) Hysteresis loss - the reversing of magnetisation of iron produces a loss of energy which at higher frequencies can be significant. It is minimised by choosing the right type of iron for the core.

d) Flux leakage - it has been assumed that all of the flux produced by the primary links with the secondary, in practice even with iron cores a small amount will not and at higher frequencies when iron cannot be used the leakage will be significant. The effects of flux leakage can again be compensated by a small increase in the turns on the secondary winding.

e) Self capacitance of windings - the capacitance between the turns of the individual windings and also capacitance between primary and secondary coils is of little significance in power transformers but at audio and higher frequencies will have a significant effect on the transformer performance.

J. Fraser/MAG : 10.6.80