Electromechanical Systems

003.0

Introduction

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Transformers

Ideal Transformer

- Transformer covers very wide range of applications; power generation, audio transformer, electronics power supplies, etc
- Operation follows **Faraday's law** of induction

$$\boldsymbol{emf} = \frac{\boldsymbol{d\emptyset}}{\boldsymbol{dt}}$$

- Where: **emf** is the electro-motive force, **it is the electric action produced by a non-electric source**
- $\emptyset$, is the manetic flux
- **t**, is the time

From Faraday's Law

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

For ideal transformer

The voltage ratio is equal to the turns ratio, and power in equals power out.

From conservation of energy

$$P_P = V_P I_P = V_S I_S = P_S$$

Show

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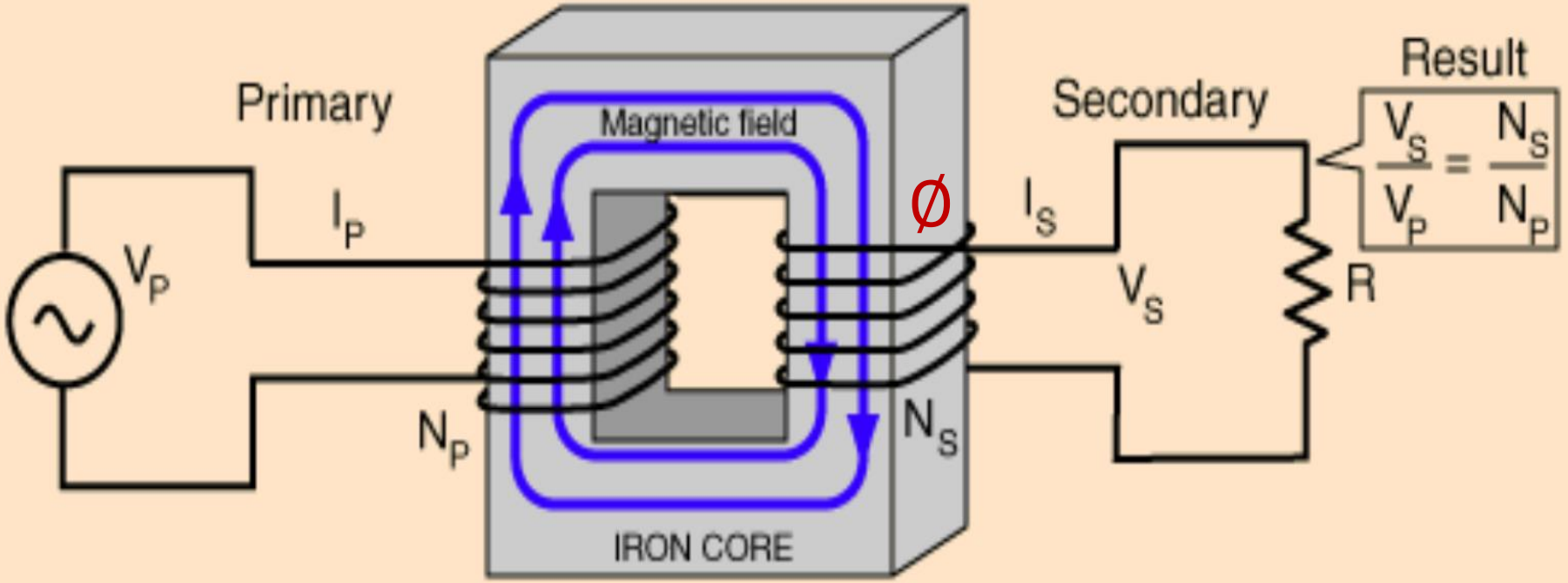
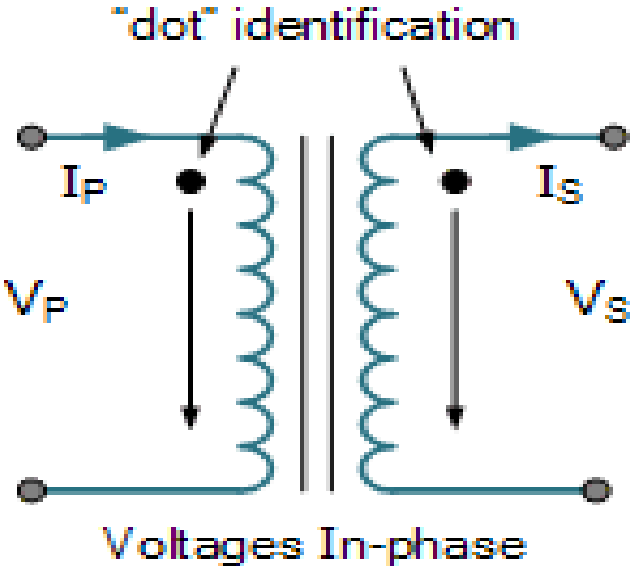
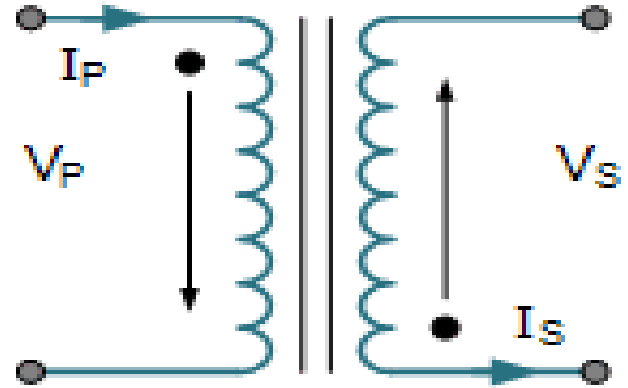
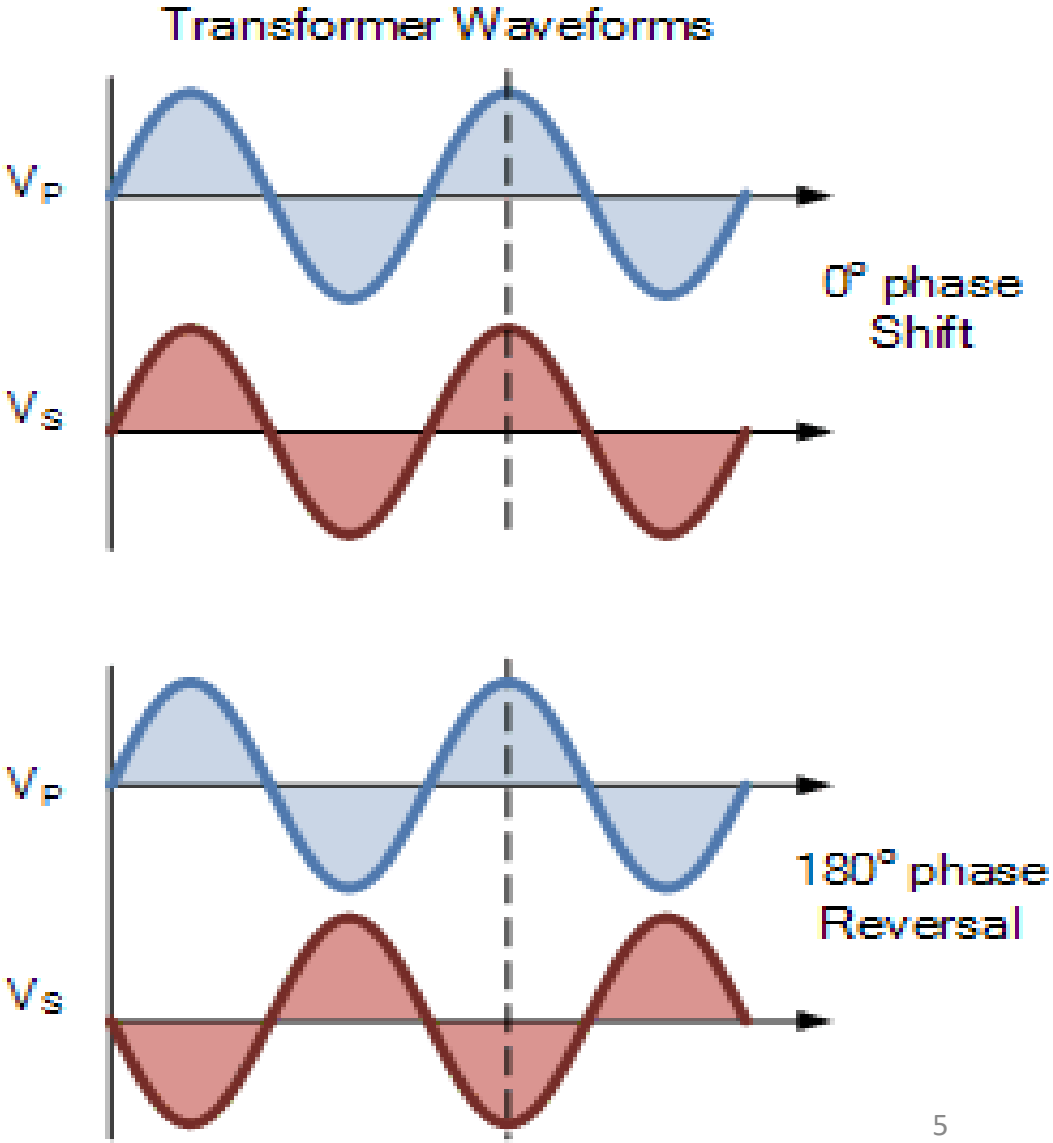




Voltages In-phase



Voltages Out-of-phase



Assumptions

- Winding have zero resistance
- Permeability of the core is very high
- Leakage flux is nil
- The whole flux links both coils
- This is a conceptual device

Linkage Flux in Transformers

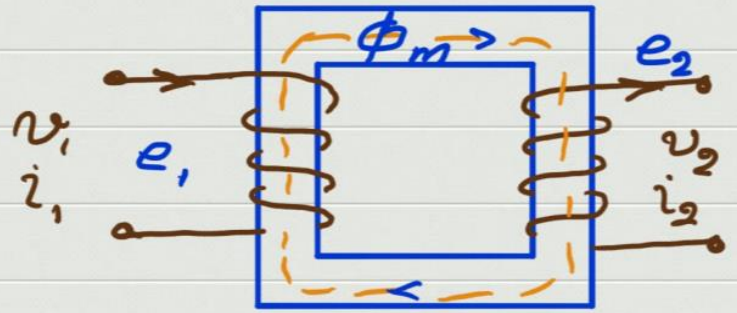
Transformer

Any Sinusoidal function can be written as:

$$i_1(t) = I_{1max} \sin(\omega t)$$

$$\omega = 2\pi f = \frac{2\pi}{T}$$

$$\Phi_m = \Phi_{mMax} \sin(\omega t)$$



As per Faraday's Law, an emf will be induced

$$emf = e_1 = N_1 \frac{d\Phi_m}{dt}$$

$$e_1 = N_1 \phi_{mMax}\, \omega \cos(\omega t)$$

$$e_2 = N_2 \phi_{mMax}\, \omega \cos(\omega t)$$

$$\frac{d}{dt}(\sin(x)) = \cos(x)$$

$$\frac{d}{dt}(\cos(x)) = -\sin x$$

RMS of a sinusoidal function:

$$v_1 = e_1 \qquad V_{1rms} = \frac{2\pi}{\sqrt{2}} N_1 f \phi_{mMax}$$

$$V_{1rms} = 4.44\, N_1 f \phi_{mMax} \quad \text{-----(1)}$$

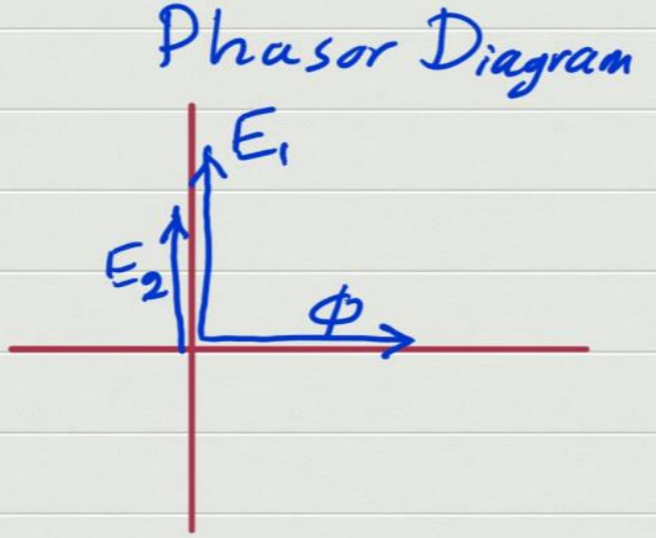
$$V_{2rms} = 4.44\, N_2 f \phi_{mMax} \quad \text{-----(2)}$$

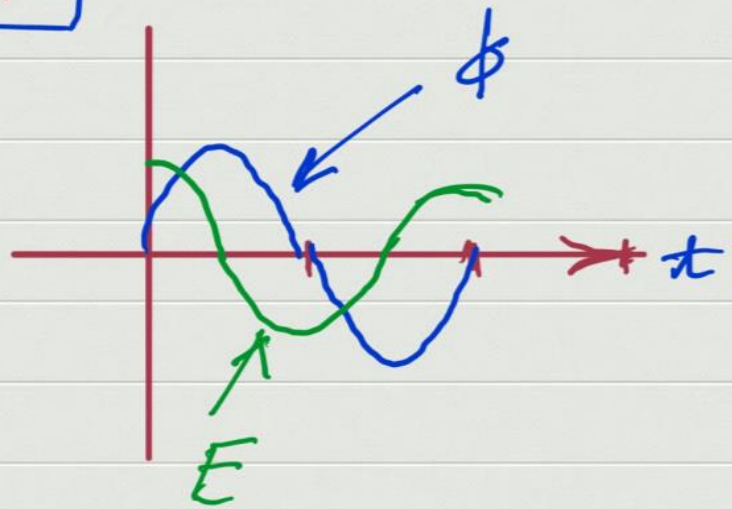
Phasor Diagram

From equations (1) and (2);

$$\frac{V_{1rms}}{V_{2rms}} = \frac{E_1}{E_2} = \frac{N_1}{N_2}$$

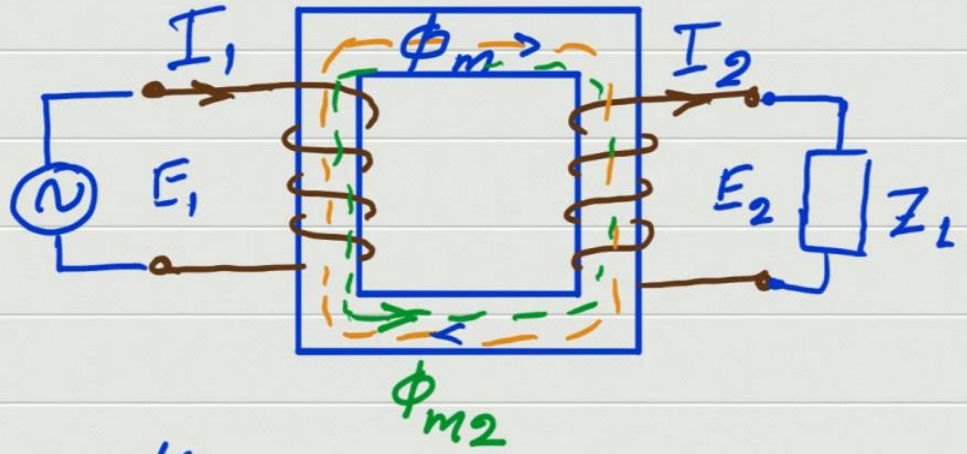
No Load





Ideal Transformer with Load

With presence of load a current I_2 is flowing through the secondary. I_2 will produce a flux of its own in the core, and according to Lenz's Law the flux ϕ_{m2} is in the opposite direction of ϕ_{m1}



$$N_1 I_1 = N_2 I \quad , \quad I_1 = \frac{N_2}{N_1} I_2 = I_2'$$

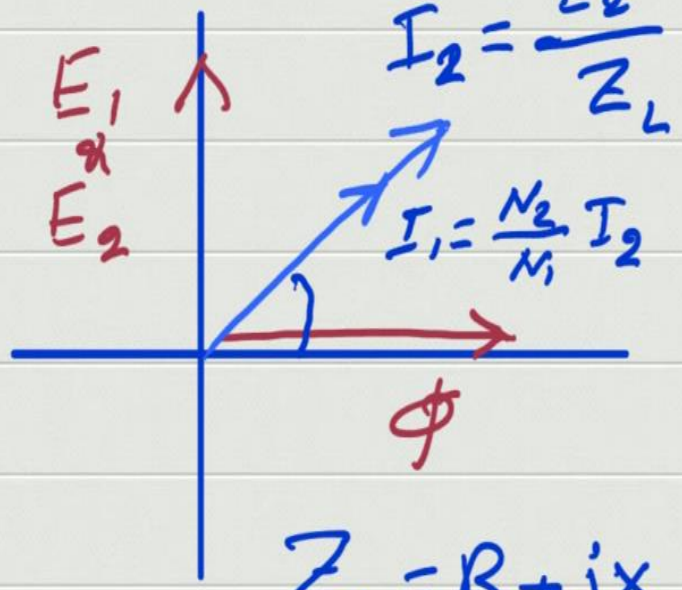
Phasor Diagram with Impedance

Ideal Transformer Under Load

$E_1 = V_1$

$E_2 = \frac{N_2}{N_1} V_1$

$N_1 V_1 = N_2 V_2$, $I_1 = \frac{N_2}{N_1} I_2$



$Z_L = R + jX$

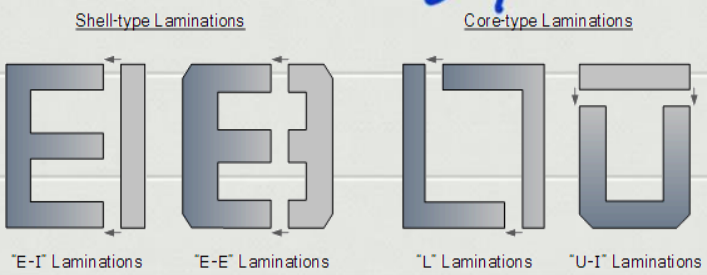
$Z_L = |Z_L| \angle \tan^{-1} \frac{X}{R}$

Transformer Construction

Practical Transformer

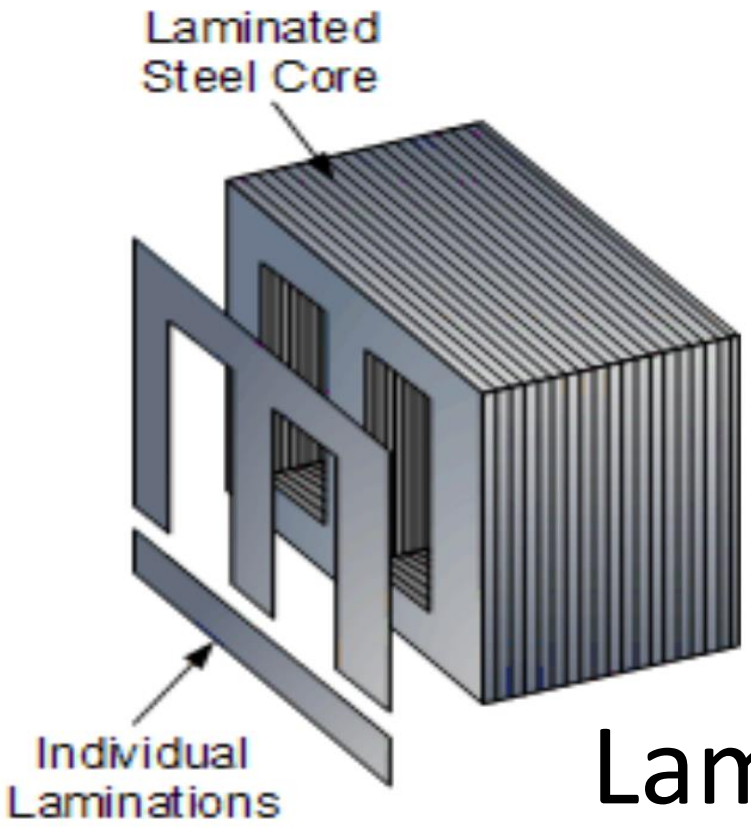
- Core is constructed with laminations

E-I Type or [-I type



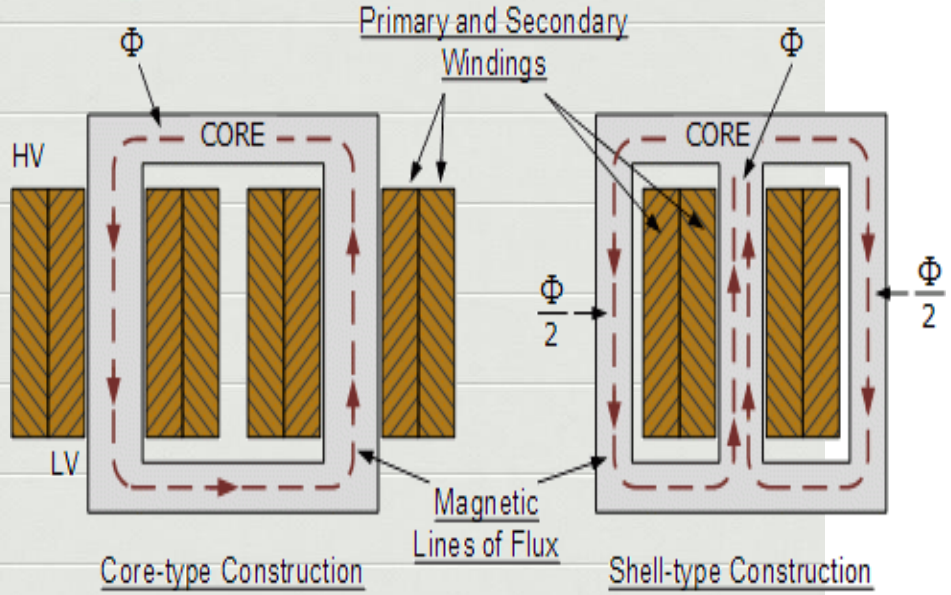
- Eddy Current

Eddy Current Reduction

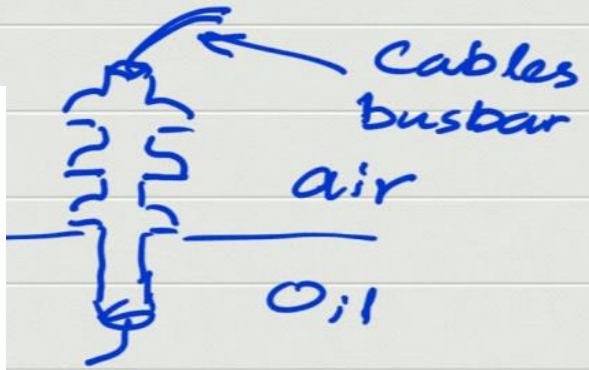


Laminated Core

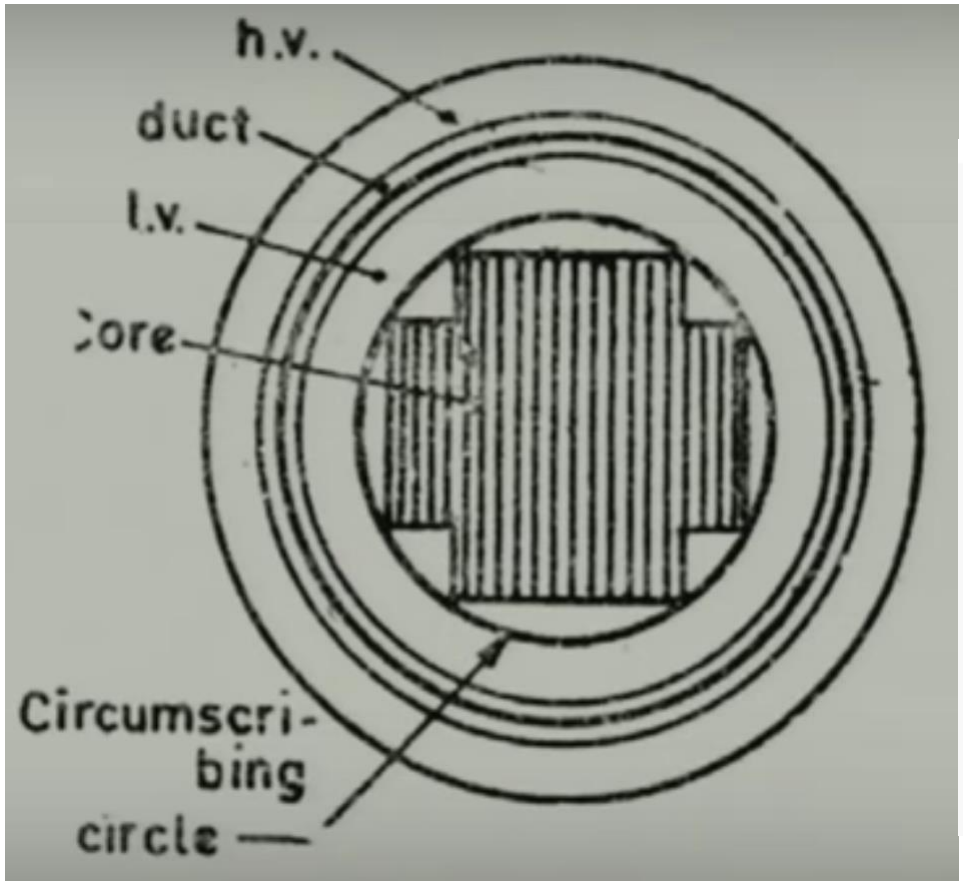
- Shell & Core types
- Winding
  1- LV (LT)
  2- H (HT)
- Insulation:
  1- Minor Insulation
  2- Major Insulation

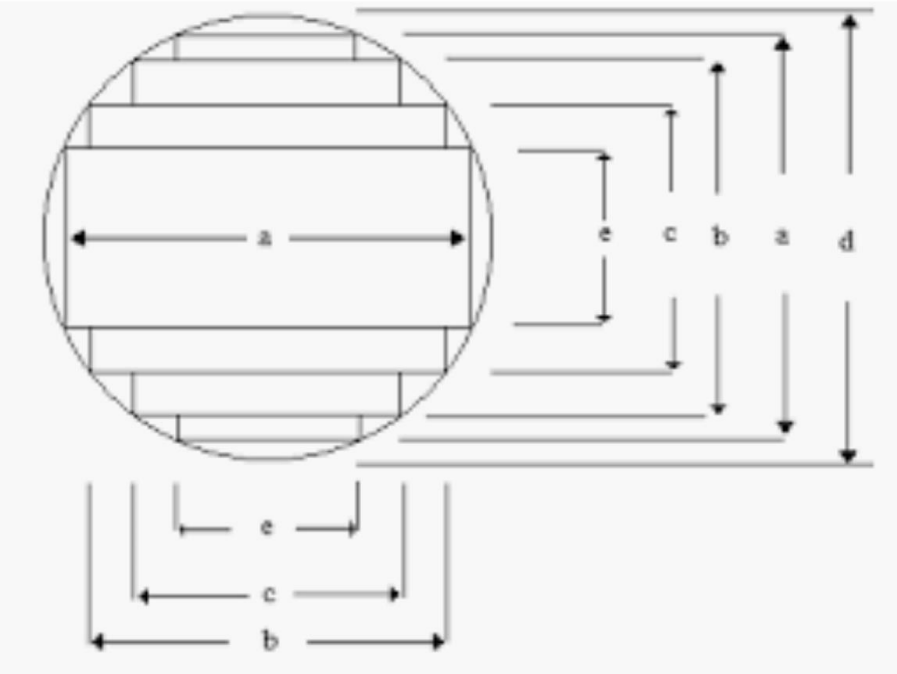


- Porcelain Bushings



- Cooling
  - air cooling
  - Oil cooling
  - Radiator/Tank
  - Pumped Oil cooling (Fan)
  - Cooling Tower


h.v.
duct
l.v.
Core
Circumscri-
bing
circle


a
e
c
b
a
d
e
c
b