UNIT 3 Fundamentals of Electrical Machines

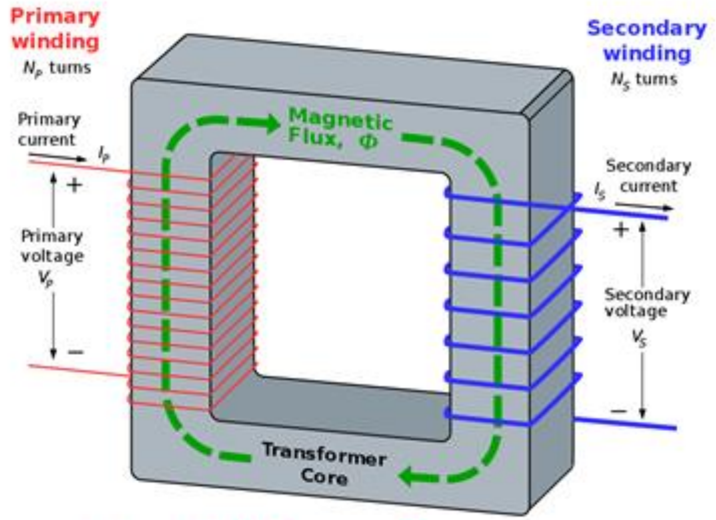
Unit III

Fundamentals of electrical machines : Fleming's left hand and right hand rule, mutual inductance and mutual coupling phenomena in transformer, transformer – working, concept of turns ratio and applications, transformer on DC, instrument transformers, auto-transformer, dc machines- working principles, classification, starting, speed control and applications of dc motors, working principle of single and three phase induction motors, applications of ac motors

Introduction to Transformer

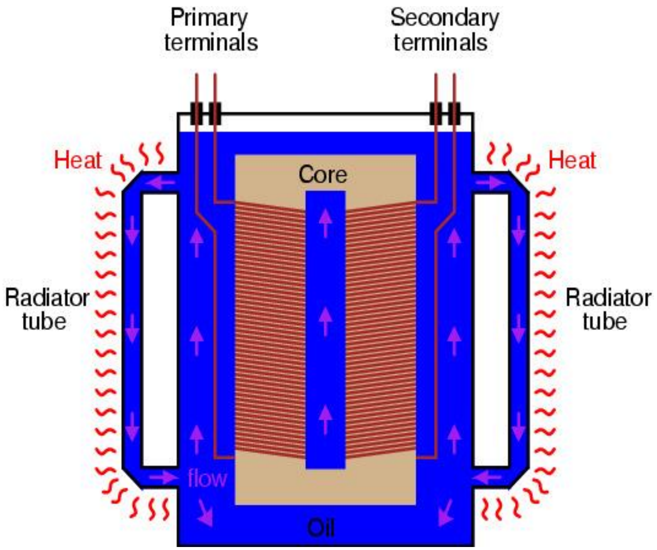
Definition of Transformer

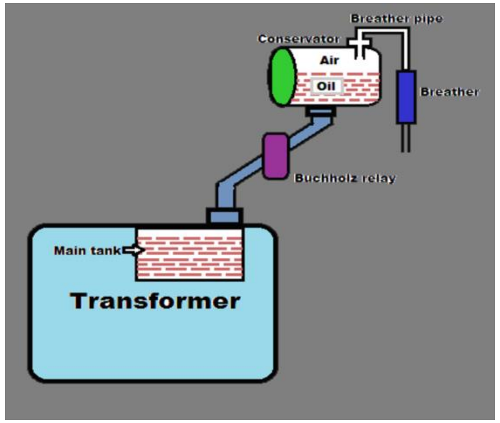
TRANSFORMER: transformer is a static device which transforms electrical energy from one circuit to another without any direct electrical connection and with the help of mutual induction between two windings. It transforms power from one circuit to another without changing its frequency but may be in different voltage level.



Inside Transformer

Transformer parts

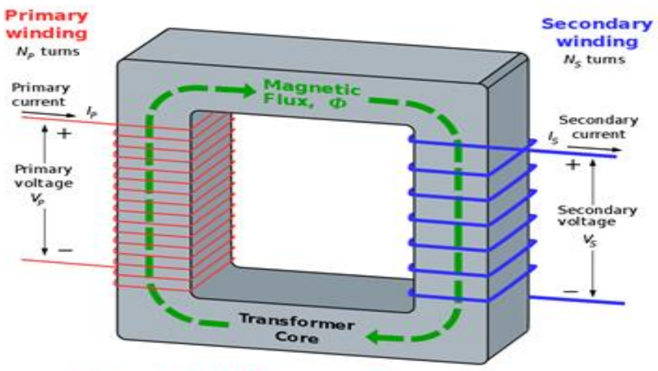




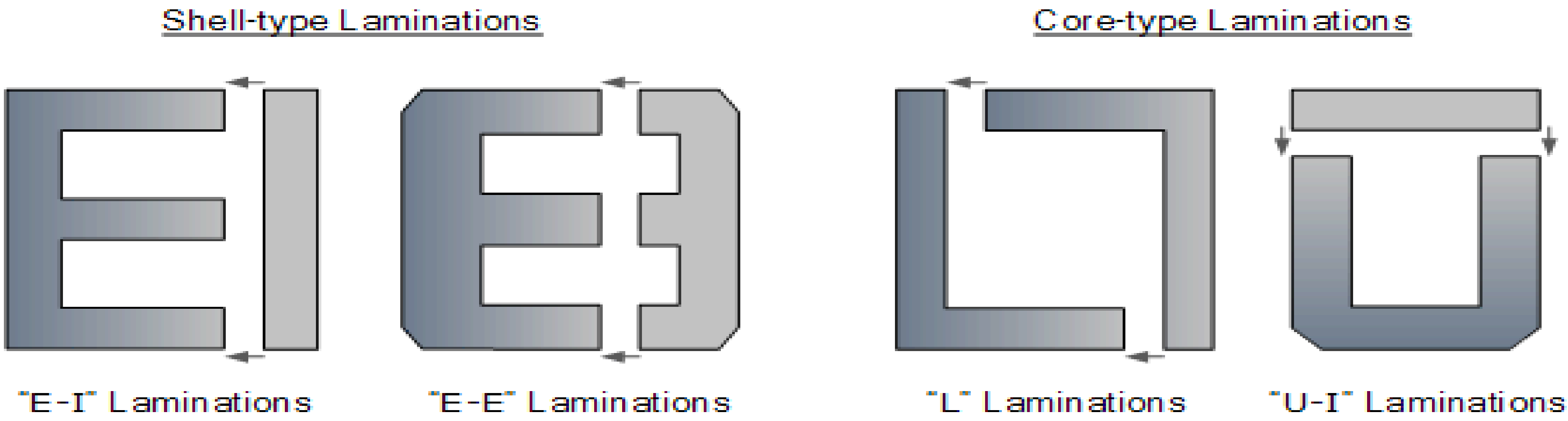
Basic components of a Transformer.

- Laminated core
- Windings
- Insulating materials
- Transformer oil
- Oil Conservator
- Breather
- Cooling tubes
- Buchholz Relay
- Explosion vent

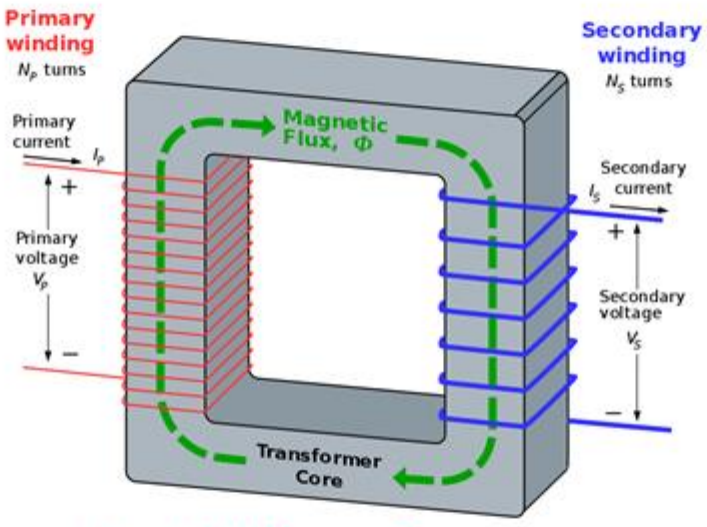
CORE



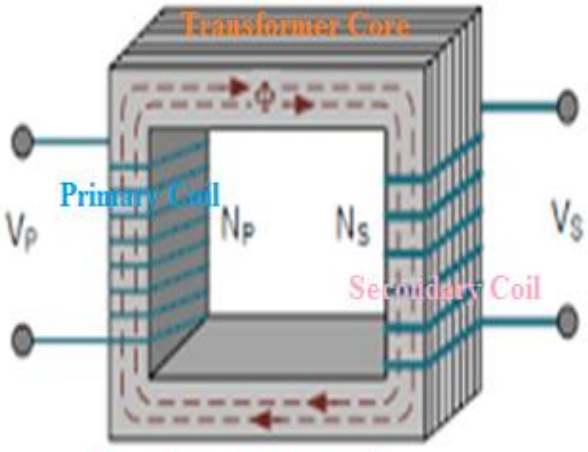
Inside Transformer



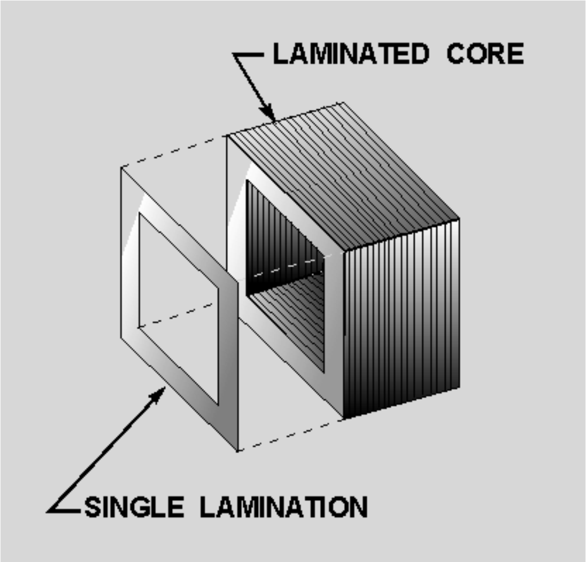
Transformer Construction

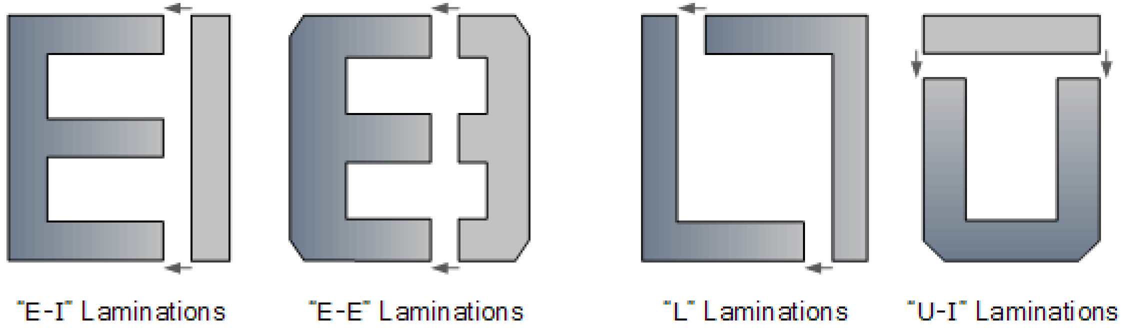


Inside Transformer



Transformer Construction





Explanation Slide

QUICK QUIZ (POLL)

Which of the following is the static device?

A. D. C Motor
B. Induction Motor
C. Generator
D. Transformer

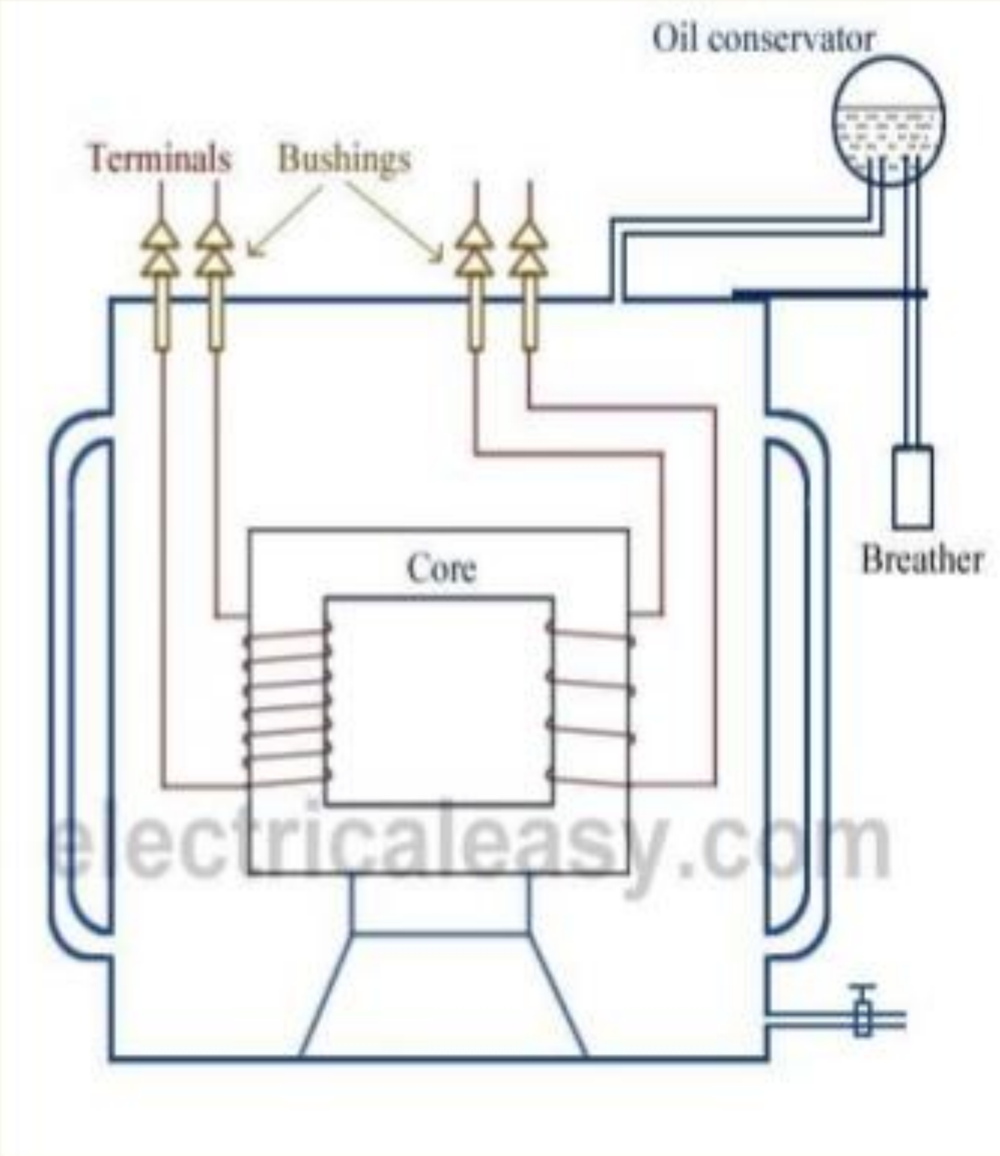
Construction of Transformer

•Basically a transformer consists of two inductive windings and a laminated steel core. The coils are insulated from each other as well as from the steel core.

•core is constructed by assembling laminated sheets of steel, with minimum air-gap between them (to achieve continuous magnetic path).

•The silicon steel used is to provide high permeability and low hysteresis loss.

•Laminated sheets of steel are used to reduce eddy current loss.



CORE

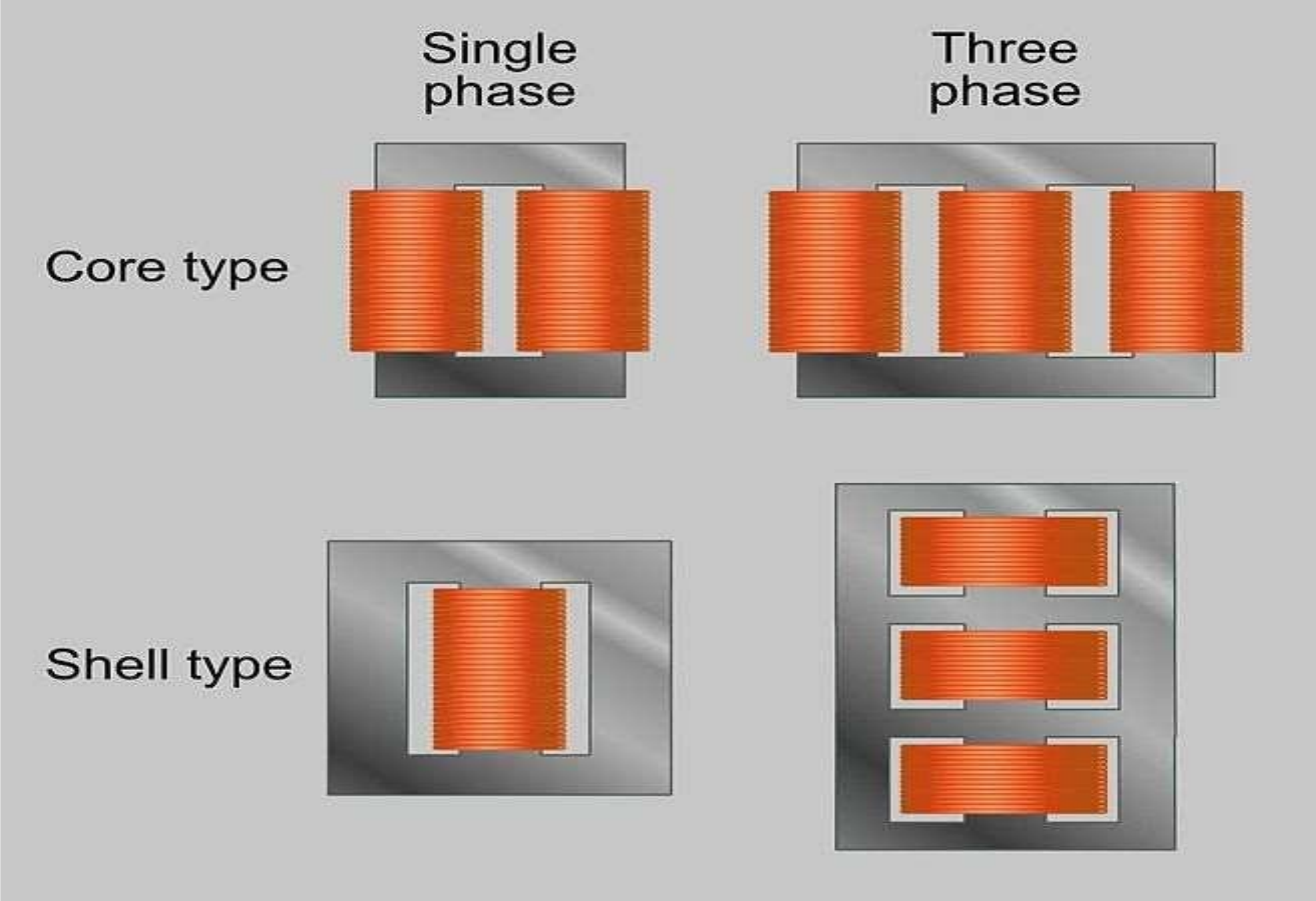
- The core acts as support to the winding in the transformer. It also provides a low reluctance path to the flow of magnetic flux.
- It is made of laminated soft iron core in order to reduce eddy current loss and Hysteresis loss.
- The composition of a transformer core depends on such as factors voltage, current, and frequency.
- The diameter of the transformer core is directly proportional to copper loss and is inversely proportional to iron loss.
- When the diameter of the core is increased, the vice versa occurs.

QUICK QUIZ (POLL)

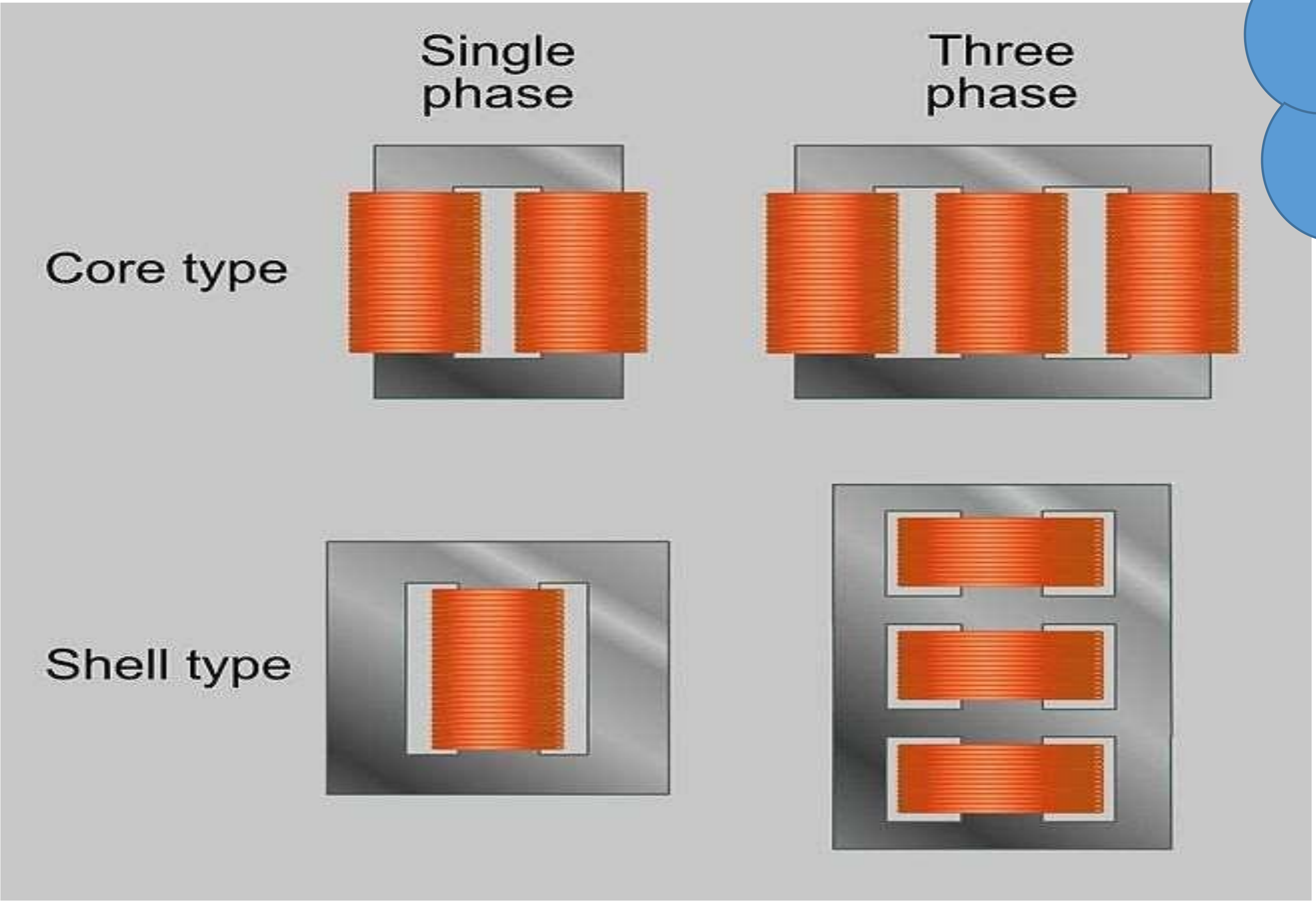
Transformer core are laminated in order to:

A. Decrease hysteresis loss
B. Decrease hysteresis and eddy loss
C. Decrease winding losses
D. Decrease eddy current losses

WINDING



WINDING



POLL

Application of Three Phase transformer is

A)Phone chargers
B) Television
C) Distribution Transformer

Copper Winding

- Copper has high conductivity. This minimizes losses as well as the amount of copper needed for the winding (volume & weight of winding).
- Copper has high ductility. This means it is easy to bend conductors into tight windings around the transformer's core, thus minimizing the amount of copper needed as well as the overall volume of the winding.

QUICK Quiz Poll

Radiator Tubes are used

A) For the circulation of the oil
B) To cool the transformer Oil
C) to open the explosion vent
D) None of the above

POLL

Function of the Breather

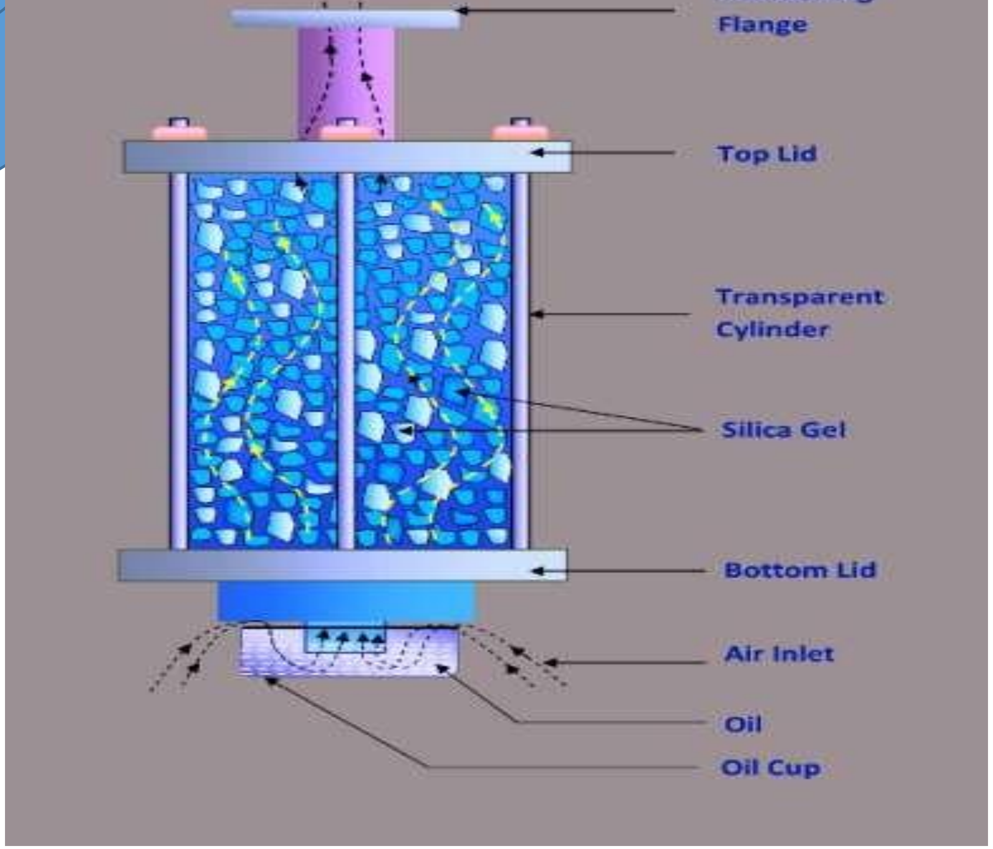
A) the moisture level in the transformer

B) To prevent impurity particles to enter into the transformer

C) Both A and B

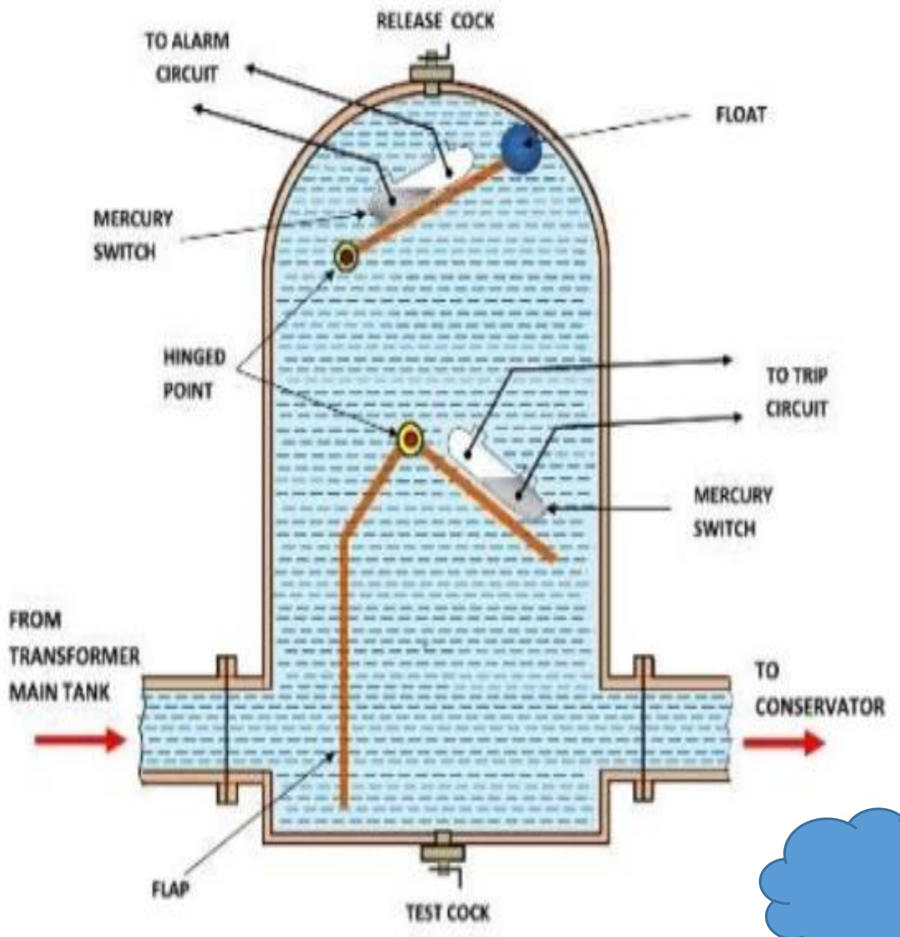
D) None of the above

- BREATHER



Buchholz Relay

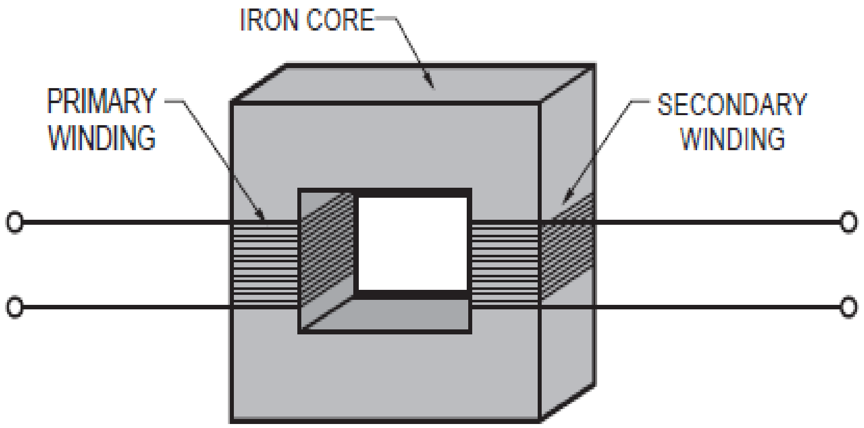
The [Buchholz Relay] is a protective device container housed over the connecting pipe from the main tank to the conservator tank. It is used to sense the faults occurring inside the transformer. It is a simple relay that is operated by the gases emitted during the decomposition of transformer oil during internal faults. It helps in sensing and protecting the transformer from internal faults.



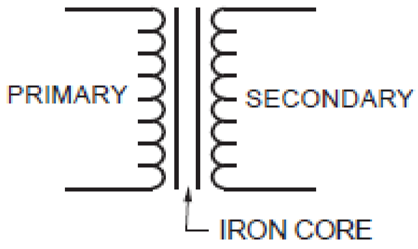
Explosion Vent

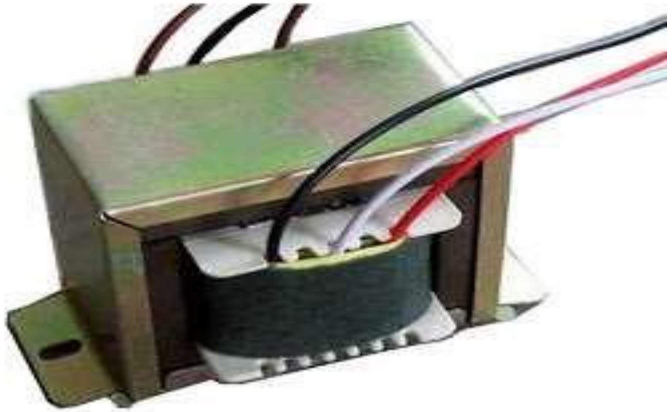
The explosion vent is used to expel boiling oil in the transformer during heavy internal faults in order to avoid the explosion of the transformer. During heavy faults, the oil rushes out of the vent. The level of the explosion vent is normally maintained above the level of the conservatory tank.

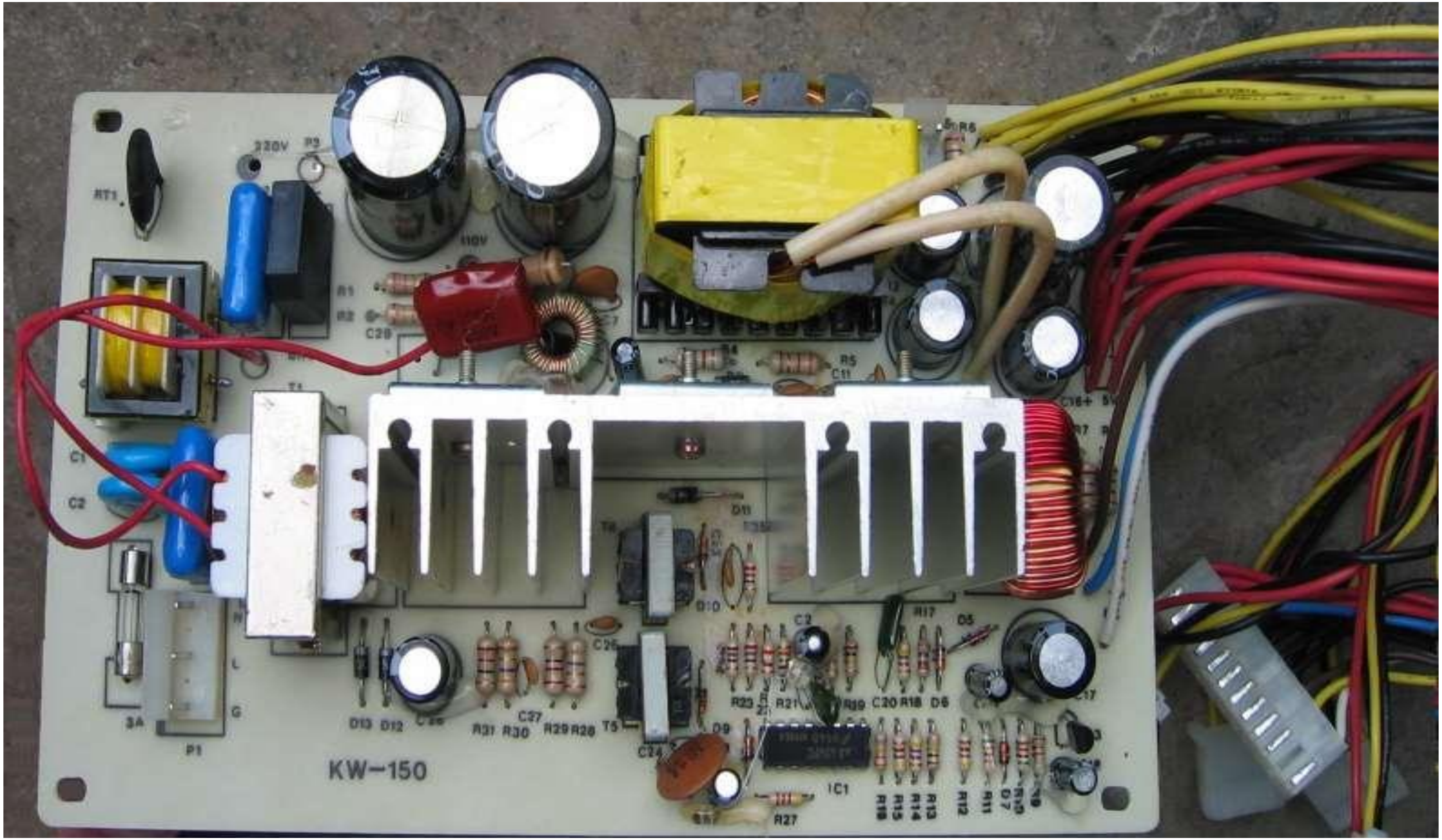
Single phase Transformer



SCHEMATIC SYMBOL






KW-150
220V
110V
RT1
C1
C2
3A
P1
IC1

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Definition of Transformer

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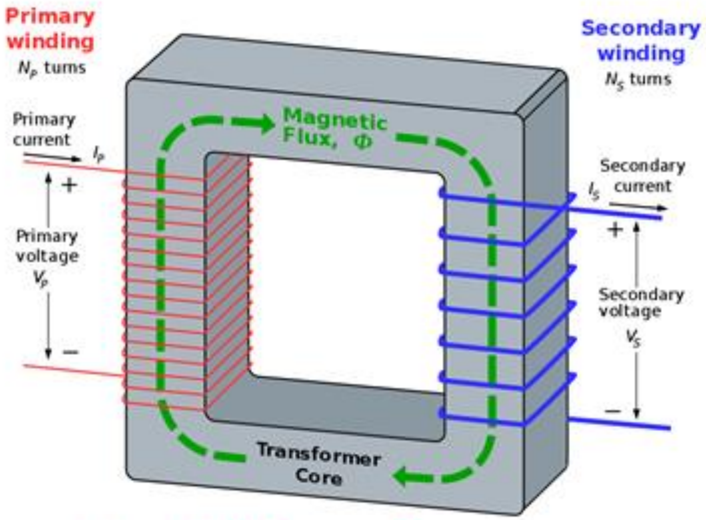


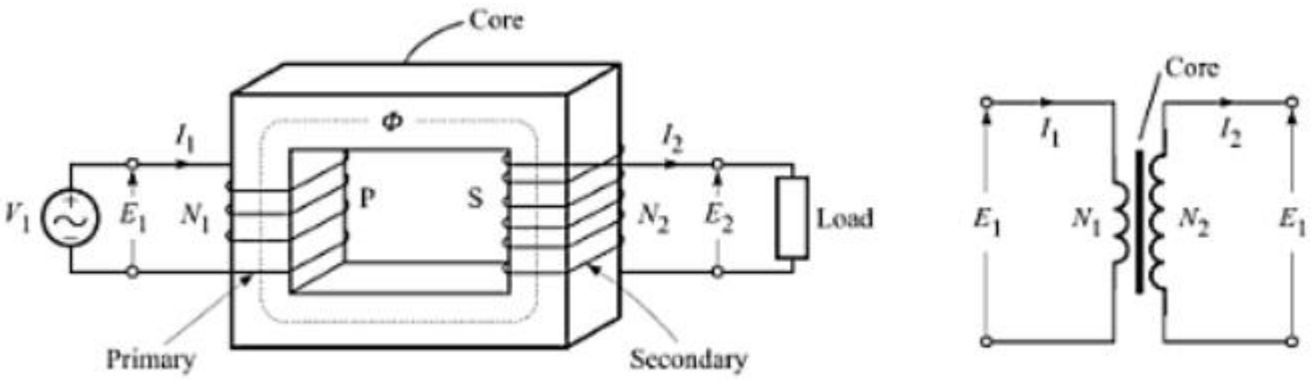
Inside Transformer

Principle of Operation

Two principles are involved:

- First: An electrical current produces a magnetic field (electromagnetism).
- Second: A changing magnetic field within a coil induces an emf across the ends of the coil (electromagnetic induction).

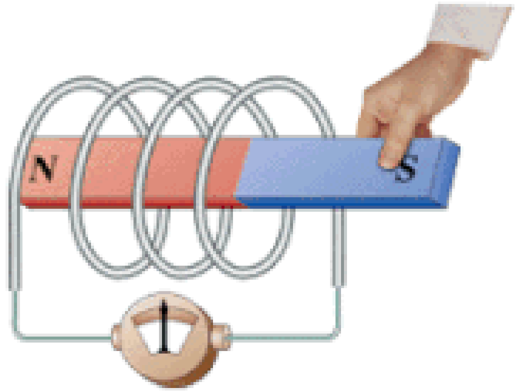
A changing current in the primary circuit creates a changing magnetic field: in turn: this magnetic field induces a voltage in the secondary circuit.



(a) Construction. (b) Circuit symbol.

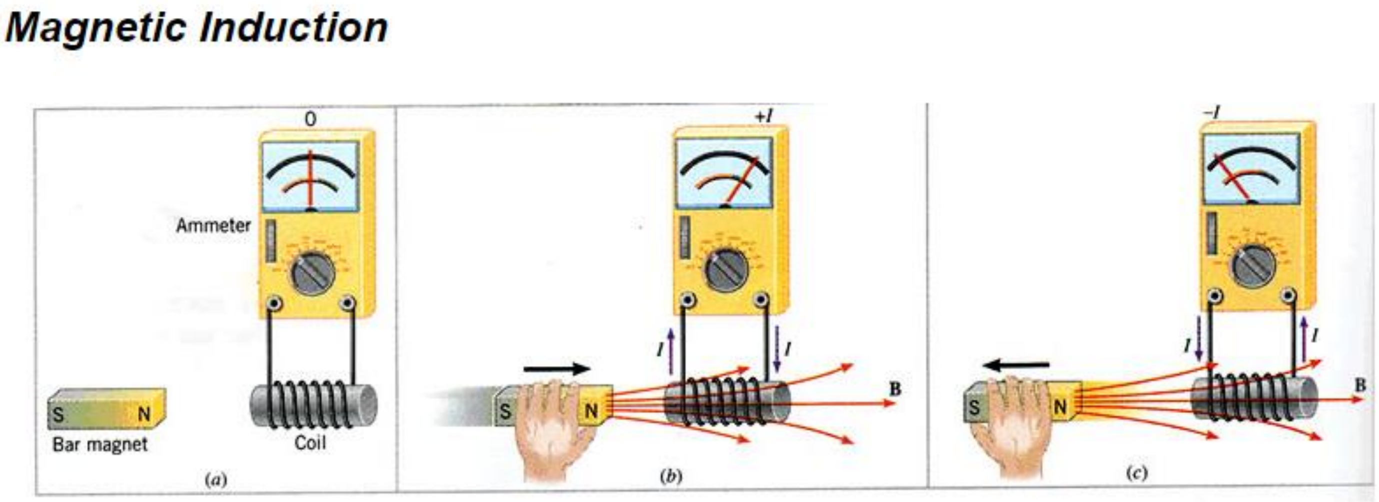
Electromagnetic Induction

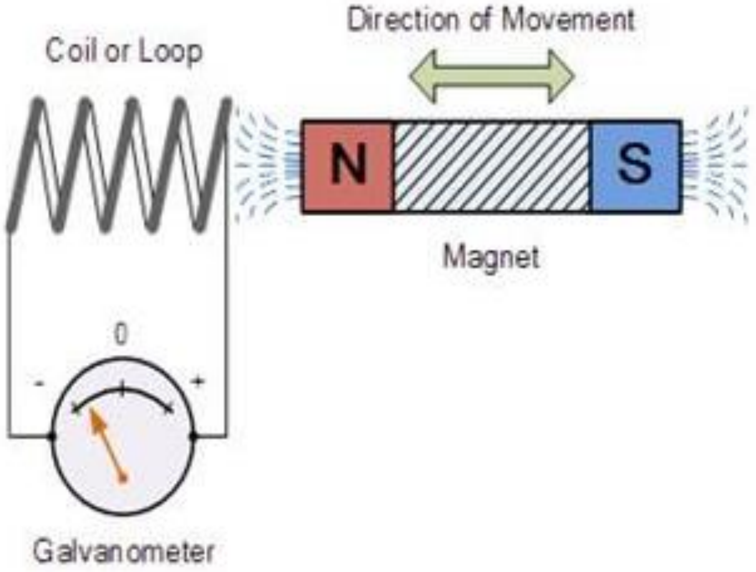
- Whenever an electric current flows through a conductor, a magnetic field is immediately brought into existence in the space surrounding the conductor.
- The converse of this is also true i.e. when a magnetic field embracing a conductor moves relative to the conductor, it produces a flow of electrons in the conductor.
- This phenomenon whereby an e.m.f. and hence current (i.e. flow of electrons) is induced in any conductor which is cut across or is cut by a magnetic flux is known as electromagnetic induction.



Faraday’s Experiment

- Faraday took a magnet and a coil and connected a galvanometer across the coil.
- At starting, the magnet is at rest, so there is no deflection in the galvanometer i.e, the needle of the galvanometer is at the center or zero position.
- When the magnet is moved towards the coil, the needle of the galvanometer deflects in one direction.

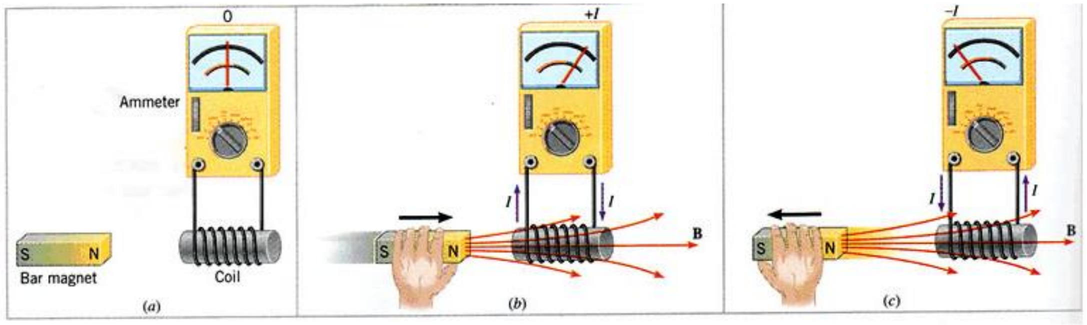


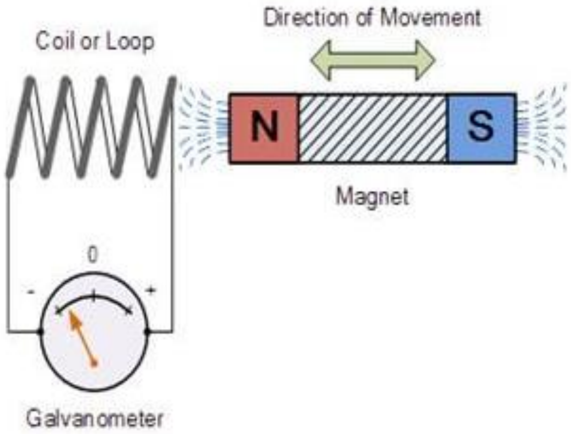


Faraday’s Experiment

- When the magnet is held stationary at that position, the needle of galvanometer returns to zero position.
- Now when the magnet moves away from the coil, there is some deflection in the needle but opposite direction, and again when the magnet becomes stationary, at that point respect to the coil, the needle of the galvanometer returns to the zero position.
- Similarly, if the magnet is held stationary and the coil moves away, and towards the magnet, the galvanometer similarly shows deflection. It is also seen that the faster the change in the magnetic field, the greater will be the induced EMF or voltage in the coil.

Magnetic Induction





Faraday's Laws of Electromagnetic Induction

First Law:

Whenever the magnetic flux linked with a circuit changes, an e.m.f. is always induced in it.

OR

Whenever a conductor cuts magnetic flux, an e.m.f. is induced in that conductor.

Second Law:

The magnitude of the induced e.m.f. is equal to the rate of change of flux-linkages

Mathematically, $E_{ind} = -N\frac{d\emptyset}{dt}$

- A minus sign signifies the fact that the induced e.m.f. sets up current in such a direction that magnetic effect produced by it opposes the very cause producing it (Lenz's Law)

Explanation Slide

QUICK QUIZ (POLL)

Which of the following is the static device?

A. D. C Motor
B. Induction Motor
C. Generator
D. Transformer

QUICK QUIZ (POLL)

In a transformer, energy is transferred from primary to secondary via?

A. Cooling coil

B. air

C. flux

D. None of these

EMF equation of a transformer:

Consider a sinusoidally varying voltage applied to the primary of a transformer. This will set an alternating magnetic flux in the core, and is represented as:

$$\emptyset = \emptyset_m sin\omega t = \emptyset_m sin2\pi f t$$

According to Faraday's law of electromagnetic Induction, the induced emf for N number of turns is given by:

$$e = -N\frac{d\emptyset}{dt} = -N\omega\emptyset_m cos\omega t = N\omega\emptyset_m \sin\left(\omega t - \frac{\pi}{2}\right)$$

$$= N\omega\emptyset_m \text{ (Peak value)}$$

Therefore, rms value of the induced emf E is given by:

$$E = \frac{e_m}{\sqrt{2}} = \frac{N\omega\emptyset_m}{\sqrt{2}} = 4.44\, fN\emptyset_m$$

EMF equation of a transformer:

Similarly, for the secondary side of the transformer, it can be proved that:

$$E = \frac{e_m}{\sqrt{2}} = \frac{N\omega\emptyset_m}{\sqrt{2}} = 4.44\, fN\emptyset_m$$

Equating the two equations we get:

$$\frac{E_P}{E_s} = \frac{4.44fN_P\emptyset_m}{4.44fN_S\emptyset_m}$$

Therefore, we get:

$$\frac{E_P}{E_S} = \frac{N_P}{N_S} = \frac{1}{K}$$

Effect of Frequency

Recall that:

$$\mathrm{E} = 4.44\, fN\emptyset_m$$

- With high frequency as the secondary emf becomes high, if we intentionally use high frequency we would be able design a compact transformer with fewer turns.
- But with high frequency there is increase in transformer losses like core loss and conductor skin effect.

Recap Poll

- The emf induced in the windings of a transformer :

A) Is in phase with the core flux

B) Is out of phase with the core flux

C) Lag the core flux by 90 degree

D)Leads the core flux by 90 degree

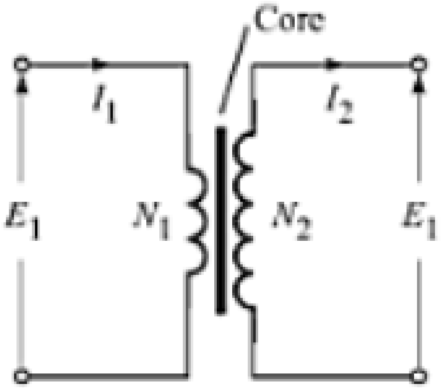
Transformation Ratio or Turns Ratio

- Ratio of secondary voltage to the primary voltage is known as **Transformation Ratio** or **Turns Ratio.**

$$K = \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1}$$

Thus, the side of the transformer with the larger number of turns has the larger voltage. Indeed, *the voltage per turn is constant for a given transformer*. By selecting K properly, the transformation of voltage can be done from any value to any other convenient value. There can be two* cases:

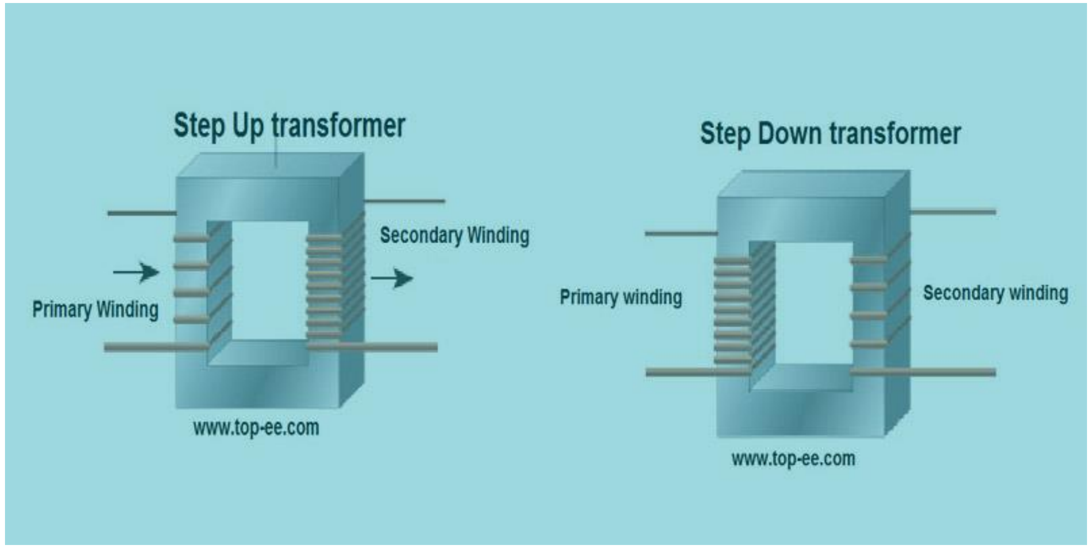
(*i*) When $K > 1$ (i.e., $N_2 > N_1$), $V_2 > V_1$; the device is known as ***step-up transformer***.
(*ii*) When $K < 1$ (i.e., $N_2 < N_1$), $V_2 < V_1$; the device is known as ***step-down transformer***.

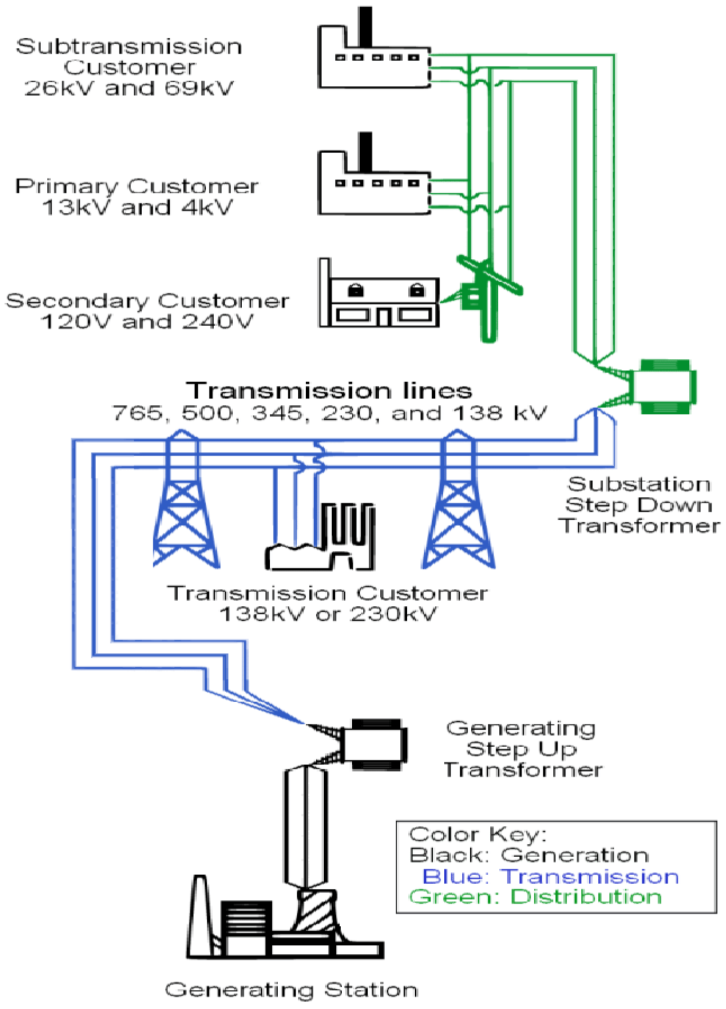


Step UP and Step Down Transformer

(i) When $K > 1$ (i.e., $N_2 > N_1$), $V_2 > V_1$; the device is known as ***step-up transformer.***

(ii) When $K < 1$ (i.e., $N_2 < N_1$), $V_2 < V_1$; the device is known as ***step-down transformer.***





QUICK QUIZ (POLL)

EXAMPLE: A transformer has 400 turns on the primary and 1200 turns on the secondary. If 120 volts of AC current are applied across the primary, what voltage is induced into the secondary?

A. 120
B. 360
C. 40
D. 1200

QUICK QUIZ (POLL)

If the supply frequency of a transformer increases in 99 percent usage of transformer, the secondary output voltage of the transformer:

A. increase
B. decrease
C. Remain same
D. Depends on the losses

Ideal Transformer

- ❖ A transformer that doesn't have any losses like copper and core is known as an ideal transformer.
- ❖ In this transformer, the output power is equivalent to the input power.
- ❖ The efficiency of this transformer is 100%, which means there is no loss of power within the transformer.

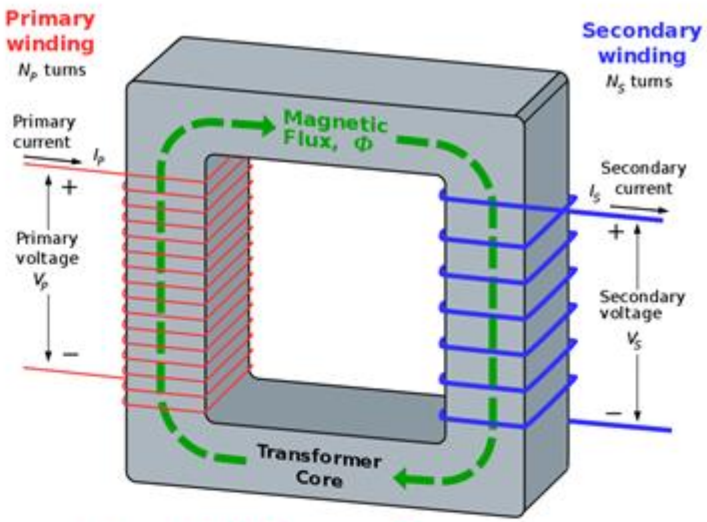
NOTE:

Such a transformer does NOT exist in a practical life. But the concept is very helpful for understanding the working of an actual transformer.

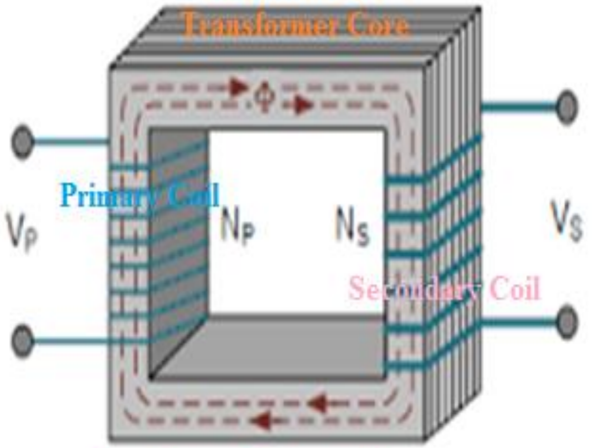
Characteristics/Conditions for an Ideal Transformer

1. Resistance of primary as well as secondary winding of an ideal transformer is **zero**. That is, both the coils are purely inductive in nature.
2. Leakage flux is a part of magnetic flux which does not get linked with secondary winding. In an ideal transformer, it is assumed that entire amount of flux get linked with secondary winding (that is, no leakage flux).
3. An ideal transformer does not have any losses like hysteresis loss, eddy current loss etc. So, the output power of an ideal transformer is exactly equal to the input power. Hence, 100% efficiency.
4. Higher the permeability, lesser the mmf required for flux establishment. That means, if permeability is high, less magnetizing current is required to magnetize the transformer core.

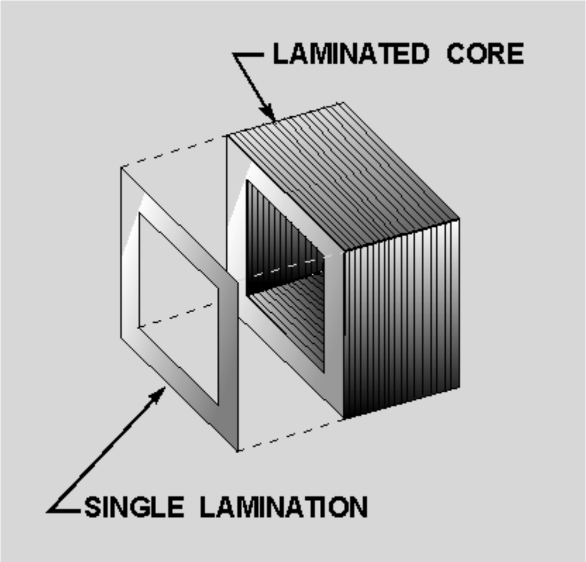
Transformer Construction

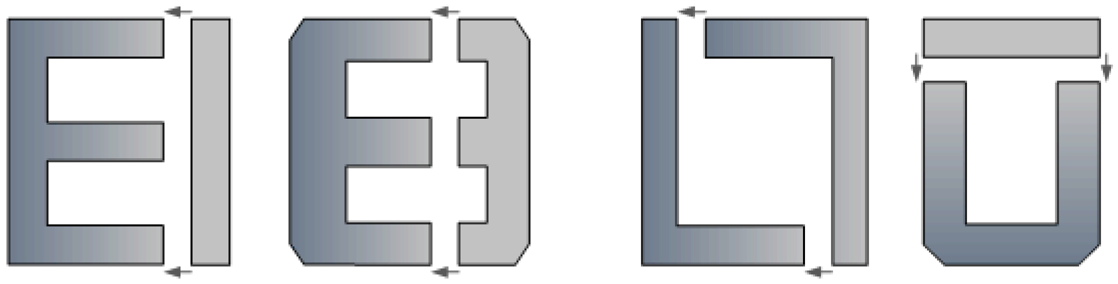


Inside Transformer



Transformer Construction





"E-I" Laminations "E-E" Laminations "L" Laminations "U-I" Laminations

QUICK QUIZ (POLL)

Transformer core are laminated in order to:

A. Decrease hysteresis loss
B. Decrease hysteresis and eddy loss
C. Decrease winding losses
D. Decrease eddy current losses

Volt Amperes

- For an ideal transformer, the current I1 in the primary is just sufficient to provide mmf $I_1 N_1$ to overcome the demagnetizing effect of the secondary mmf $I_2 N_2$. Hence,

$$I_1 N_1 = I_2 N_2 \quad \text{or} \quad \frac{I_2}{I_1} = \frac{N_1}{N_2} = \frac{1}{K}$$

- Therefore, current gets transformed as the reverse ratio of the voltage.
- So, we understand that:

$$E_1 I_1 = E_2 I_2$$

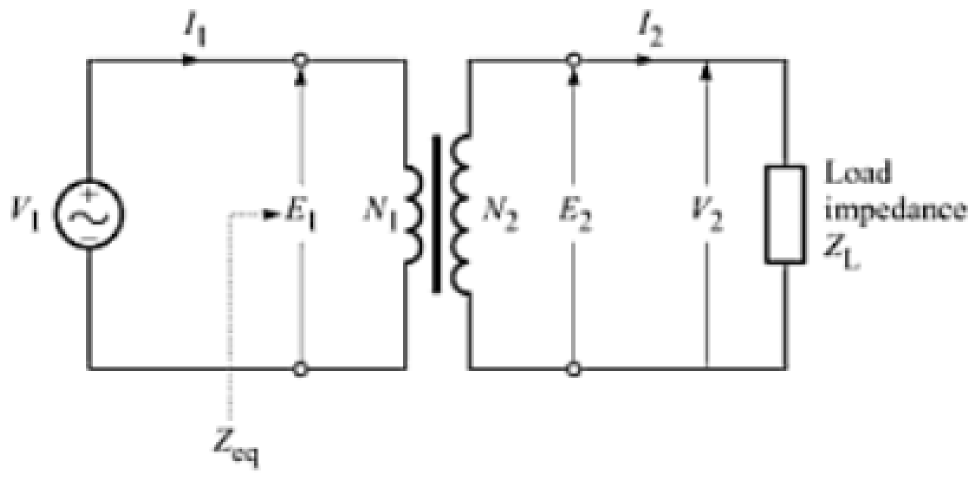
It means input VA of a transformer is same as output VA.

Impedance Transformation

- A load impedance ZL is connected to the secondary of the transformer.
- The equivalent impedance Zeq is defined at its primary as :

$$Z_{eq} = \frac{V_1}{I_1} = \frac{V_1 \times (V_2 I_2)}{I_1 \times (V_2 I_2)} = \left(\frac{V_1}{V_2}\right) \times \left(\frac{I_2}{I_1}\right) \times \left(\frac{V_2}{I_2}\right) = \left(\frac{1}{K}\right) \times \left(\frac{1}{K}\right) \times Z_L$$

$$Z_{eq} = Z_L / K^2$$

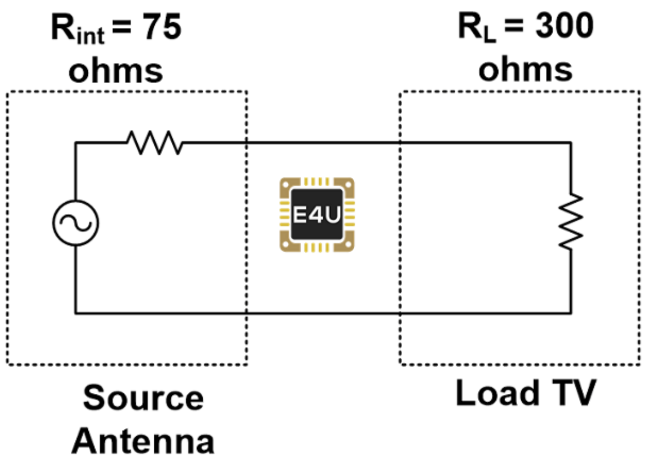


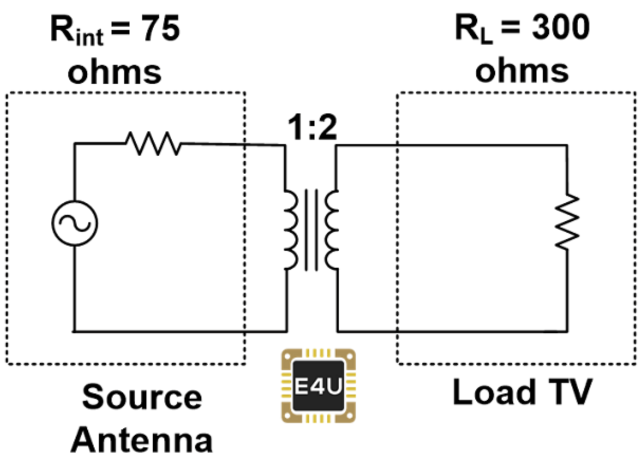
The concept of Impedance transformation is used for impedance matching.

Applications of Impedance matching

- to achieve maximum power that can deliver from the source to load.
- Examples:

1. **Impedance Matching Transformer**
2. **Antenna Impedance Matching**
3. **Audio / Headphone Impedance Matching**





QUICK QUIZ (POLL)

What must the turns ratio of a transformer be to match a 4-ohm speaker to a 100- ohm source?

A. 5

B. 0.25

C. 20

D. 50