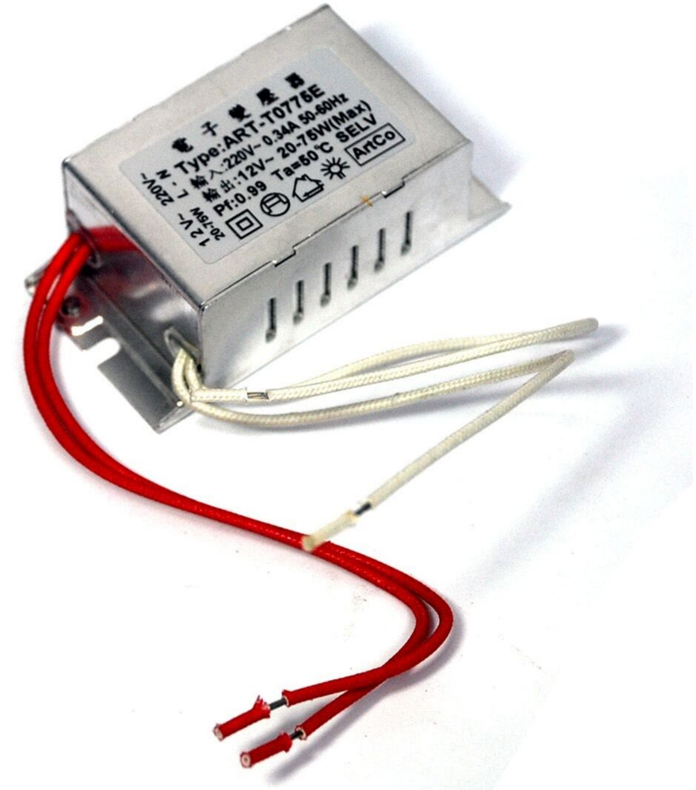
Electrical Transformers

YORK COLLEGE & UNIVERSITY CENTRE

What is a Transformer

- Transformers use electromagnetic induction to transfer energy between two or more circuits
- It changes the voltage level either “stepping up” (increasing) or “stepping down” (decreasing) voltage without changing frequency

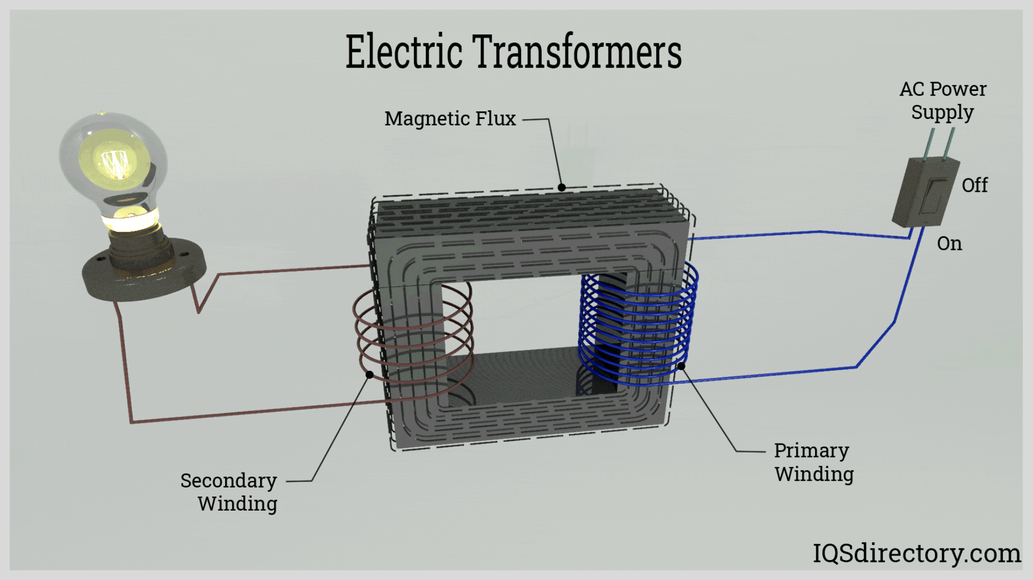


Why are Transformers important

- Step-up transformers are good for long distance power transmission as it reduces current and minimizes power losses in transmission lines
- Transformers allow devices to operate at different voltages whilst using the same grid
- Isolation transformers separate circuits to prevent shocks, equipment damage and interference
- They are very versatile and can be used in all kinds of different systems
- They improve overall energy efficiency by reducing power losses
- They have a long lifespan and require minimal maintenance making them cost effective

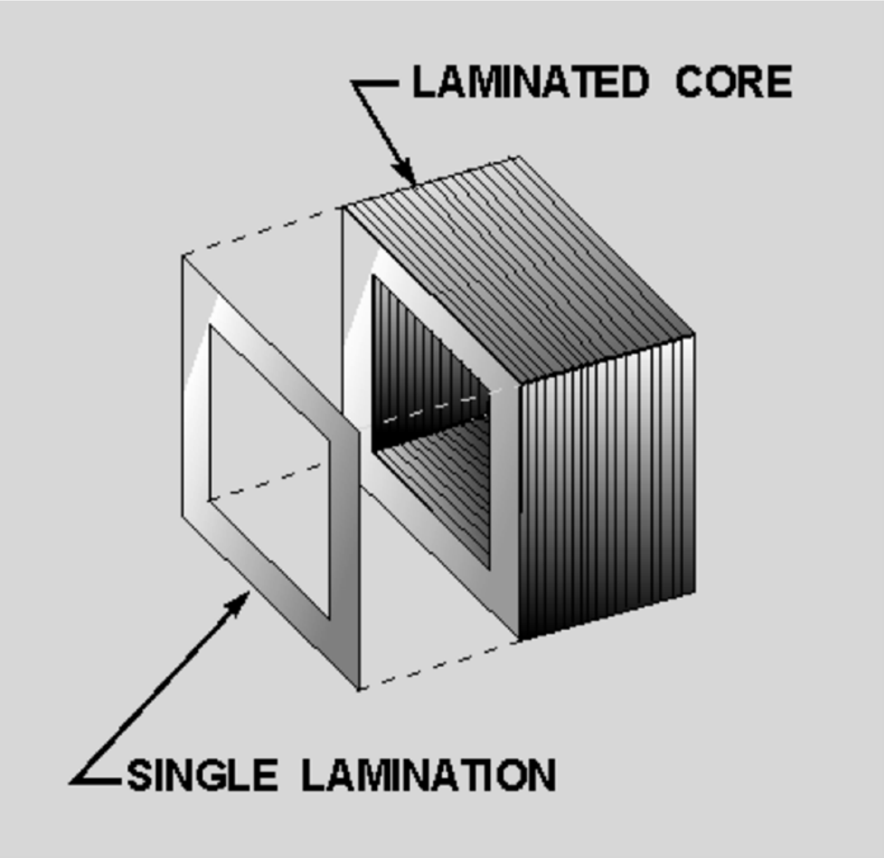
Electronic Transformer Components

- A transformer has three key components:
  - **The Primary Winding** receives the input voltage from the power source and induces a magnetic field
  - **The Secondary Winding** outputs the voltage from the system as the magnetic flux induces a current in the coil
  - **The Core** gets magnetised by the primary winding and transfer the magnetic flux between the primary and the secondary



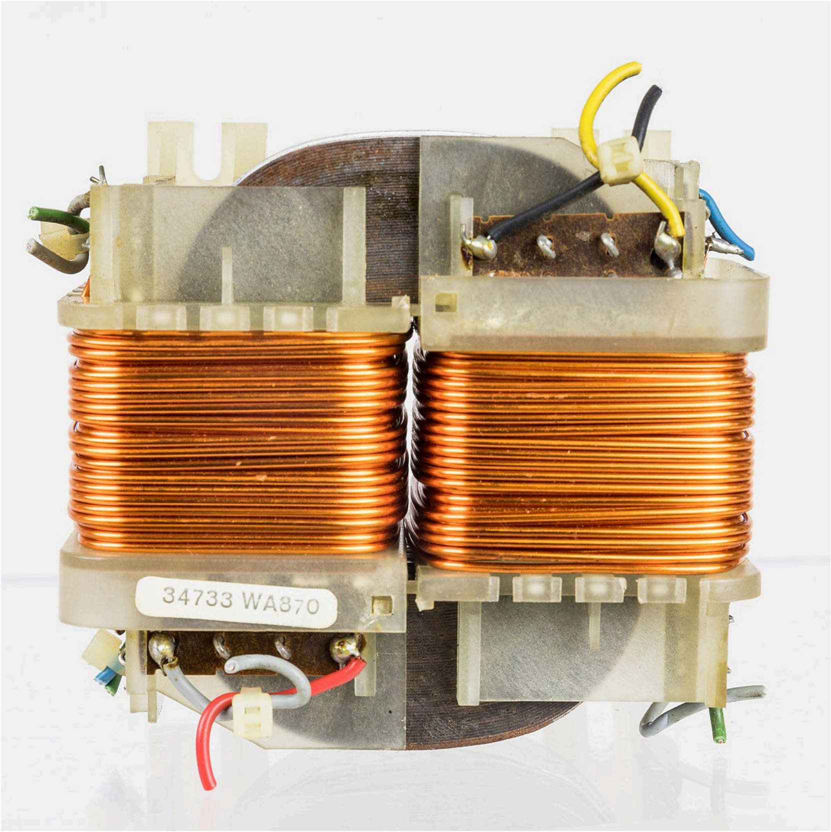
The Core

- The core has a magnetic flux induced in it
- This relies on Faraday's Law or electromagnet induction
- The core is constructed from thin sheets or laminations of ferromagnetic material
- The core isn't entirely necessary, but it helps the magnetic flux to transfer improving efficiency



The Windings

- There are two different sets of windings the primary and the secondary
- The amount of “turns” or “loops” in the winding determine the voltage change between the windings
- If the secondary winding has more turns the output voltage increases
- If the primary winding has more turns the output voltage decreases

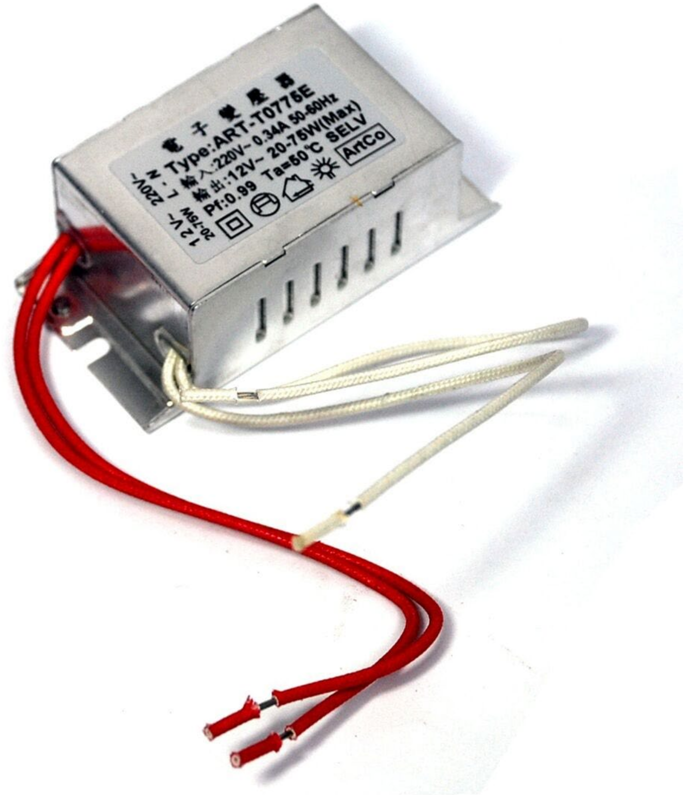


Types of Transformers

- There are 2 main types of transformers:

  - **Step up / Step Down**

  - **Isolation Transformers**



Step Up/Step Down

- Step up/down transformers are used for increasing or decreasing voltage to a source
- **Step up transformers** convert from a lower voltage to a higher voltage but also decrease current whilst doing so.
- **Step down transformers** convert from a higher voltage to a lower voltage but also increase current whilst doing so.
- Both are typically used in the national grid and inside of electronic devices to change voltage for transmission/use

Isolation Transformers

- The main goal of isolation transformers isn’t to change the voltage or current but instead to separate two circuits
- They typically don’t change voltage or current by using an equal amount of turns in their windings
- They are typically used to protect components from faults or noise and used to regulate voltage.
- They can change voltage or current it’s just not their main goal

Calculating Change (Voltage) (Ideal)

- The relationship between the amount of turns and the windings voltages can be written as:

  - $\boldsymbol{V_S = V_P * \frac{N_S}{N_P}}$

  - Where:
    - V_P = primary (input) voltage
    - V_S = secondary (output) voltage
    - N_S = number of secondary winding turns
    - N_P = number of primary winding turns

Calculating Change (Current) (Ideal)

- The relationship between the amount of turns and the windings current is the inversely proportional to the voltage

  - $\boldsymbol{I_S = I_P * \frac{N_P}{N_S}}$

  - Where:
    - I_P = primary (input) current
    - I_S = secondary (output) current
    - N_S = number of secondary winding turns
    - N_P = number of primary winding turns

Relating Voltage and Current (Ideal)

- The below is only true for an **ideal transformer** which has no power loss.
- We know **Power = Voltage * Current**
- In an ideal transformer: $\boldsymbol{Power_P = Power_S}$
- So, we know that $\boldsymbol{V_P * I_P = V_S * I_S}$
- We can rearrange this to find any of the values when we have the other 3

$$\boldsymbol{\frac{V_P * I_P}{V_S} = I_S}$$

Your Turn

Can you solve these questions:

1. A transformer has **8 primary windings**, **16 secondary windings** and an **input voltage of 8v** can you work out the output voltage?

2. The transformer in question 1 has an **input current of 2A**, can you work out the output current?

3. A different transformer has **56 primary windings**, **98 secondary windings** and an **output voltage of 10.6v** can you work out the input voltage?

4. The transformer in question 3 has an **output current of 8A**, can you work out the input current?

5. What is the input and output powers for transformers in questions 1 and 3.

6. What do you notice about the input and output power of transformer 1?

Your Turn - Answers

1. 16 volts
2. 1 amps
3. 6.0571 volts
4. 14 amps
5. Transformer 1:
   - $P_p = 16$
   - $P_s = 16$

   Transformer 2:
   - $P_p = 84.8$
   - $P_s = 84.8$
6. They are the same (the transformer has 100% power efficiency)

Calculating Change (Voltage) (Real)

- The relationship between the amount of turns and the windings voltages do not change when you factor in power inefficiencies
  - $\boldsymbol{V_S = V_P * \frac{N_S}{N_P}}$
  - Where:
    - V_P = primary (input) voltage
    - V_S = secondary (output) voltage
    - N_S = number of secondary winding turns
    - N_P = number of primary winding turns

Calculating Change (Current) (Real)

- The relationship between the amount of turns and the windings current does change when factoring in power inefficiencies
  - $\boldsymbol{I_S = I_P * \frac{N_P}{N_S} * \eta\%}$
  - Where:
    - I_P = primary (input) current
    - I_S = secondary (output) current
    - N_S = number of secondary winding turns
    - N_P = number of primary winding turns
    - η = the efficiency of the transformer

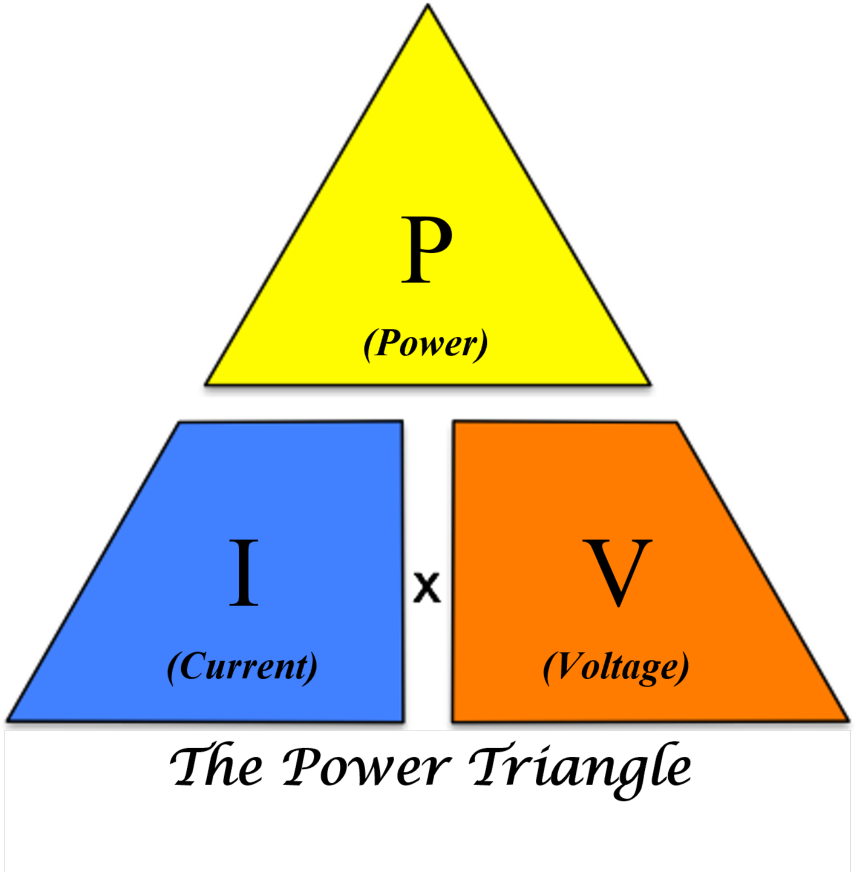
Relating Voltage and Current (Real)

- In a real scenario there will be power losses
- So, for a 2% power loss: $\boldsymbol{98\% Power_P = Power_s}$
- So, we can write it as: $\boldsymbol{98\%(V_P * I_P) = V_S * I_S}$
- Again we can rearrange this to find any of the values when we have the other 3 as well as the power loss of the transformer

$$\boldsymbol{\frac{\eta\%(V_P * I_P)}{V_S} = I_S}$$

Working out power efficiency/loss

- We can work out the power efficiency of a transformer using the equation:
- $\frac{Power_P}{Power_S}$ or $\frac{V_P * I_P}{V_S * I_S}$
- The equation for power loss is:
- $Power_P - Power_s$



Your Turn

- A **240V to 24V step-down transformer** has a **primary current of 5A** and an efficiency of 90%. Work out the secondary current

- A **500V to 50V transformer** with a **turns ratio** of 10 is supplying a load that requires **200 W** of power on the secondary side. This transformer has 85% efficiency, work out the primary power required and the power loss.

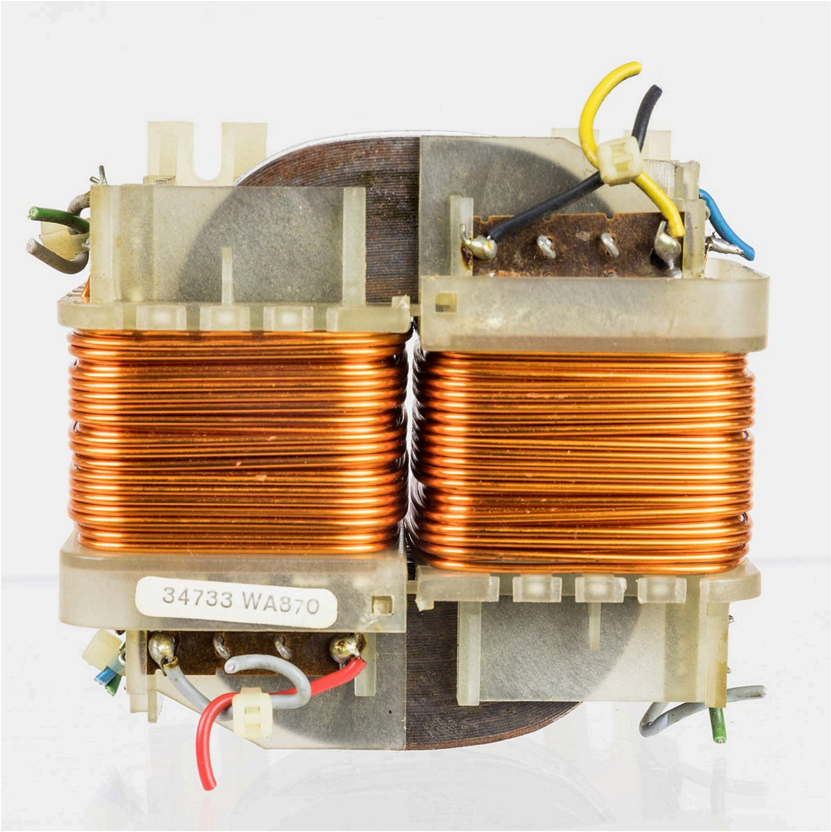
- A transformer steps down the voltage from **400 V to 50 V** with a **turns ratio of 8**, a **primary current of 4A** and a **power efficiency of 95%.** Calculate the secondary power and the secondary current.

Your Turn - Answers

- 45Amps
- Primary Power = 235.29W, Power Loss = 35.29W
- Secondary Current = 30.4 Amps, Secondary Power = 1520W

Combatting Power Loss - Windings

- One of the areas power loss can come from is the resistance of the wire that makes up the windings
- The formula for this is $\boldsymbol{P = I^2 R}$ where:
  - P = Power Loss
  - I = Current
  - R = Resistance
- This can be combatted by low resistance materials being used for the windings

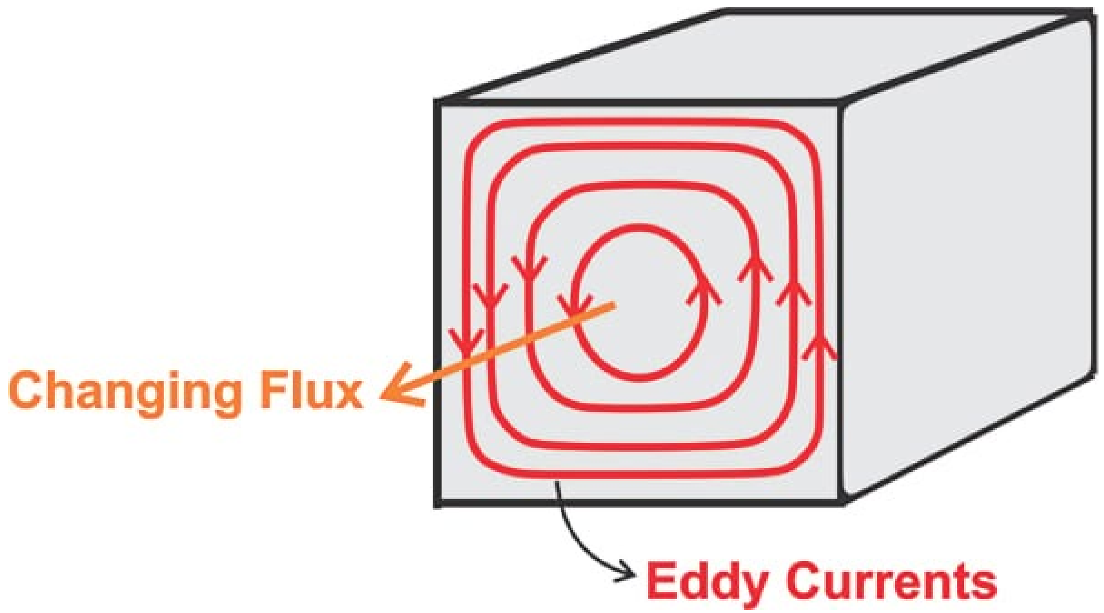


Source of Power Loss - Core

- Another area with potential for power loss is the core due to the magnetic effects it is under

- One source of power loss is **Hysteresis Loss** which happens when the magnetic field reverses with each AC cycle

- Another source is Eddy Current Loss which is when a current is induced in the core that makes energy dissipate as heat



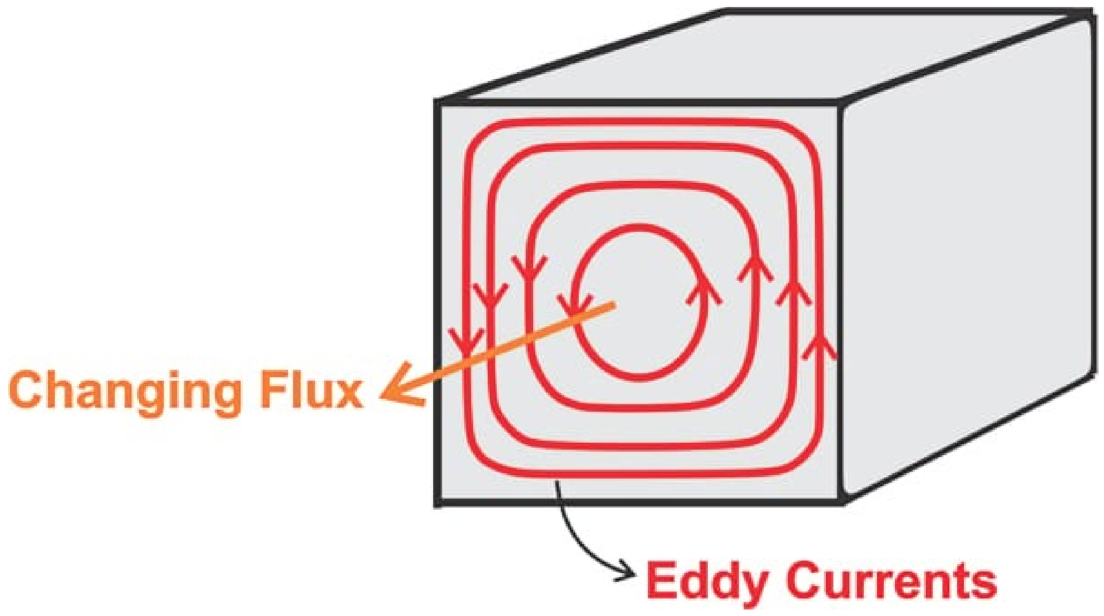
Source of Power Loss - Core

- The loss due to eddy current loss can be calculated using the equation:

- $\boldsymbol{P_{eddy} = K_e * B^2 * f^2 * t^2 * V}$

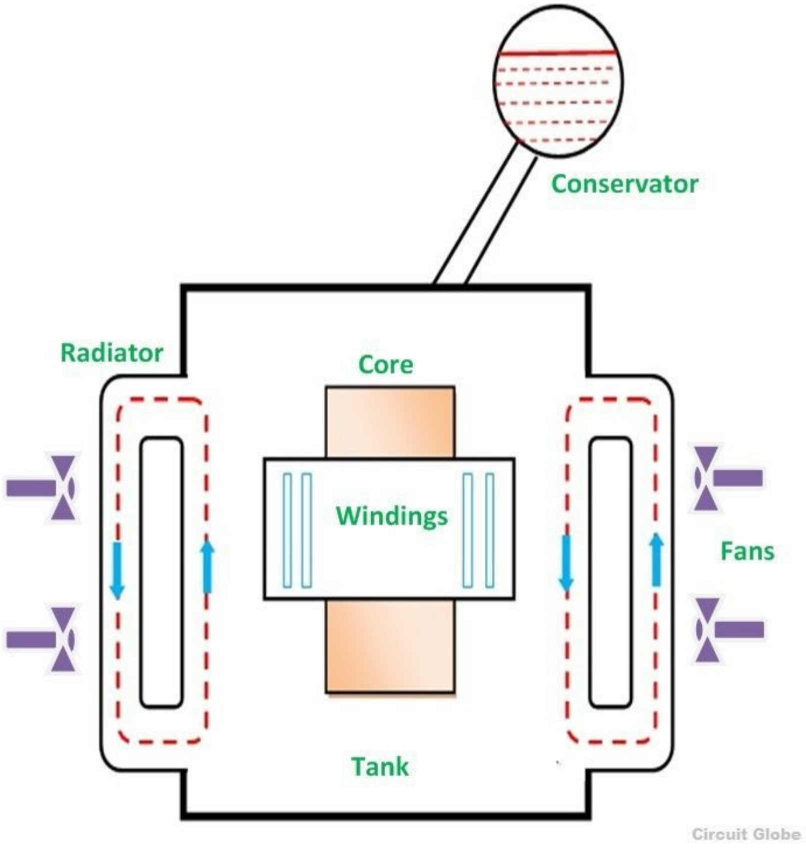
- Where:

  - P_{eddy} is the power loss
  - K_e is the constant from the core material
  - B is magnetic flux density
  - f is the frequency of the AC source
  - t is the thickness of the laminated sheets
  - V is the volume of the core material



Combatting Power Loss - Core

- **Cooling:** Improve efficiency by using oil or air-cooling systems to dissipate heat.
- **Laminated Cores**: Reduce eddy current losses by using thin layers of core material (laminations) insulated from each other.



Your Turn

- A transformer has a **copper winding resistance of 0.5Ω**. The current flowing through the **primary winding is 10A**. Calculate the copper losses in the transformer

- Given a **magnetic flux density of 1.2T** a **source frequency of 60Hz**, a core with **thickness laminations of 0.005m** and a **volume of 0.2**m^3 and a **constant of 0.001** find the eddy loss in the transformer core.

Your Turn - Answers

- 50 Watts
- 0.00026 Watts

Safety Considerations

- **High Voltage Hazards:** Transformers operate at high voltages, which can be dangerous. Always ensure transformers are properly insulated and grounded to prevent electrical shock.

- **Proper Grounding:** Ensure that the transformer is grounded correctly to prevent potential electric shock hazards and ensure safe operation. Faults in grounding systems can lead to electrical fires or system failures.

- **Overload Protection:** Use fuses or circuit breakers to prevent transformers from being overloaded, which could cause overheating and potential damage or fire. Overcurrent protection is essential for the safety of both the transformer and the connected circuit.

Safety Considerations

- **Transformer Ventilation:** Ensure that transformers have adequate ventilation or cooling systems (such as oil or air cooling) to prevent overheating. Excessive heat can degrade transformer insulation and increase the risk of fire.

- **Inspection and Maintenance:** Regularly inspect the transformer for any signs of wear, leaks, or damaged insulation. Perform routine maintenance to ensure efficient operation and detect any potential issues before they become safety hazards.

- **Environmental Considerations:** Be aware of any environmental hazards, such as temperature extremes or moisture, which can affect transformer operation and safety. In case of a transformer malfunction or failure, be prepared to handle toxic fumes or fire risks.