ADVANCED

Lesson 5A

TRANSFORMERS

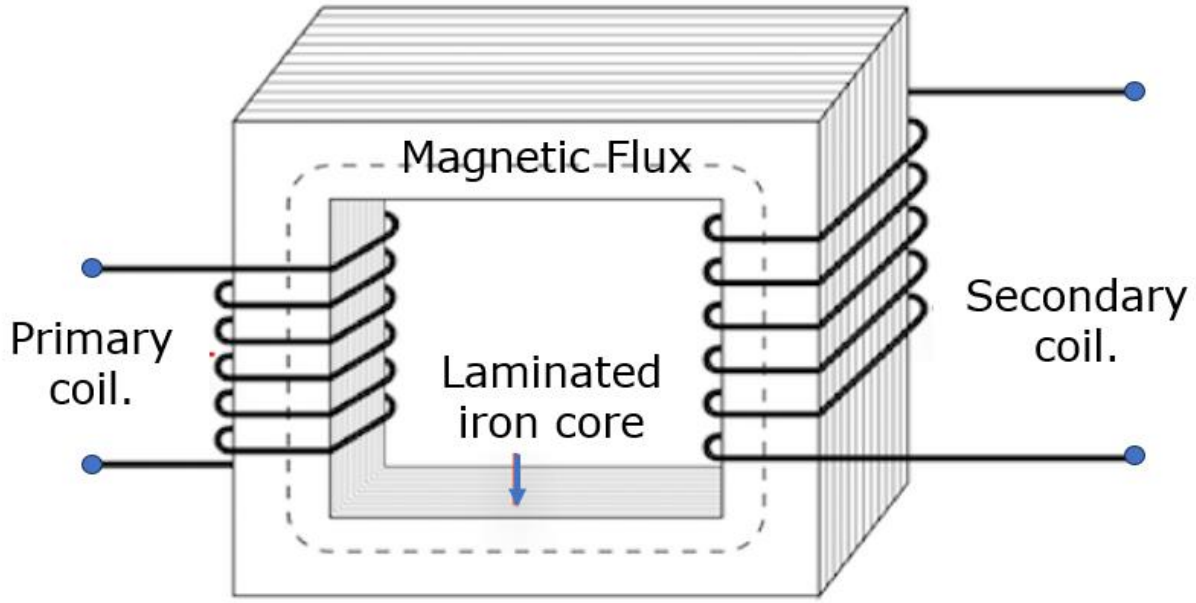
ACMA Syllabus February 2024 Chapters 1.4 , 1.6 and 2.4

Contents

Transformers

A transformer is a device that transfers electrical energy between circuits through electromagnetic induction. During this process the voltage level can be changed (stepping up or down) while maintaining the same frequency.

A transformer two coils positioned so the magnetic field of one coil, the primary coil, induces a current in the other coil, the secondary coil.



Transformer Types

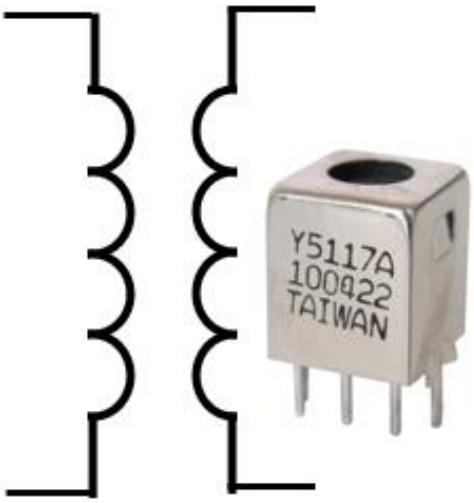
- Step-up transformer. Output voltage greater than input.
- Step-down transformer. Output voltage less than input.
- Isolation transformer. A ratio of 1:1 provides no change in voltage but only provides electrical isolation.
- Centre-tapped transformer. A centre tap on the secondary winding allows a single transformer to generate two output voltages that have half of the amplitude that appears across the entire secondary winding.
- An autotransformer has only one winding where portions of the same winding act as both the primary winding and secondary winding sides of the transformer.

Cores

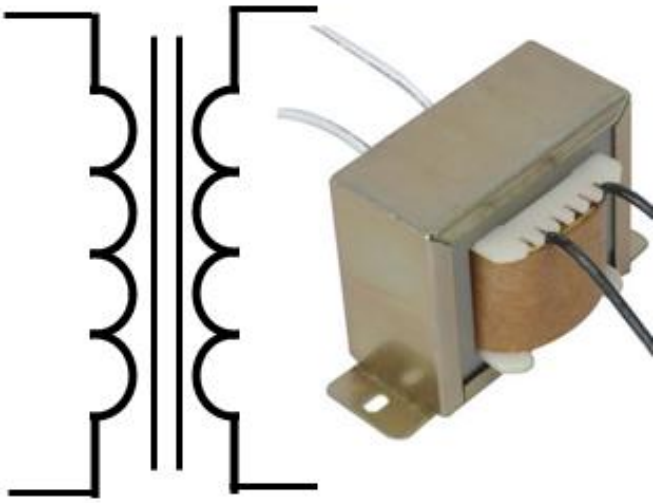
Air Core - High frequency transformers are usually air cored. An air core transformer uses air or non-magnetic material (like plastic/cardboard) rather than a ferromagnetic core (iron/steel) to couple magnetic fields between coils.

Iron Core - Low frequency transformers are usually wound on iron cores. The iron core helps direct the magnetic field created by the windings, making sure electrical energy moves efficiently from one winding to the other.

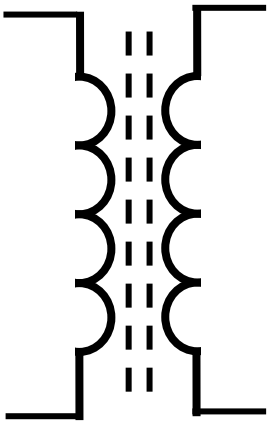
Ferrite Core - Ferrite core transformers are high-frequency components designed for superior efficiency in power conversion and signal processing.



Air core transformer



Iron core transformer



Ferrite core transformer

Ideal Transformer

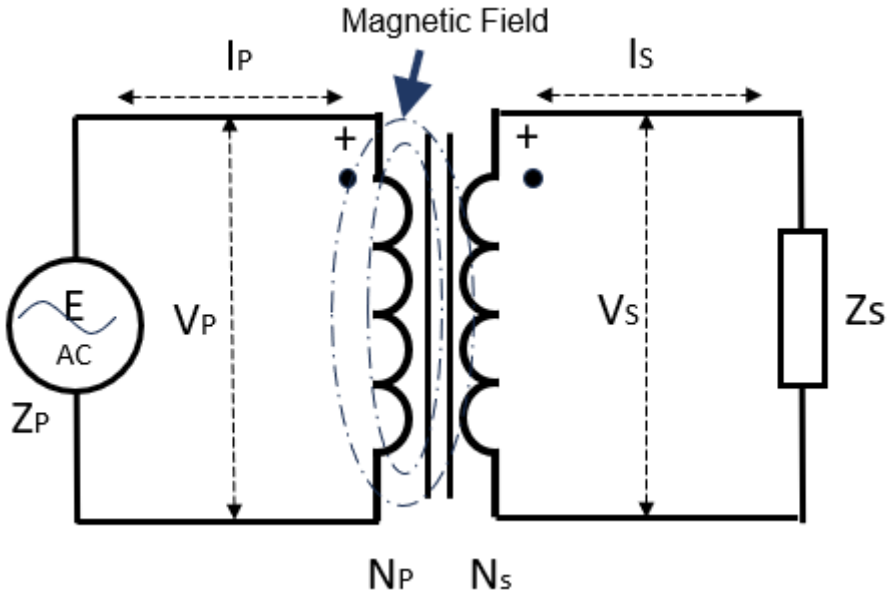


Figure 6

Primary		Secondary	
VP	Voltage on the primary windings.	VS	Voltage on the secondary windings.
IP	Current in the primary windings.	IS	Current in the secondary windings.
ZP	Impedance of the primary windings.	ZS	Impedance of the secondary windings.
NP	Number of turns in the primary windings.	NS	Number of turns in the secondary windings.

How it works

The transformer shown in Figure 6 represents an ideal transformer.

1. A primary AC voltage, **VP**, pushes an alternating current, **IS**, through the primary coil windings **NP** which has an impedance of **ZP**.
2. The primary coil in the transformer produces a magnetic field, which changes as the current alternates.
3. The iron core concentrates the strength of the magnetic field.
4. The magnetic field passes through (or cuts) the secondary coil.
5. The changing magnetic field induces a changing voltage, **ES**, in the secondary coil windings, **NS**, producing an alternating current, **IS**, and an impedance of **ZS**.

Dots

The dots represent matching polarities. As the dot side on the primary goes positive, the dot side on the secondary also goes positive. Correspondingly, as the dot on primary goes negative, the dot on the secondary also goes negative.

Losses

In this lesson, all transformers are considered 100% efficient. This is not normal as all transformers would have some losses.

Some of the losses are listed below.

- Hysteresis is loss due to nonlinear magnetic effects in the transformer core.
- Eddy current losses due to joule heating in the core.
- Resistive and inductive loss in the transformer windings.
- Leakage flux that escapes from the core and passes through one winding only resulting in primary and secondary reactive impedance.

Transformer Calculations

Voltage Ratio

The ratio of windings in the primary, **NP**, and secondary windings, **NS**, determines the transformation of voltages in the primary windings, **VP**, to the voltage in the secondary windings, **Vs**.

$$\frac{V_p}{V_S} = \frac{N_p}{N_S}$$

Example: Primary winding on the transformer has 1000 coils and an input of 240 V AC. The transformer steps down to 12 V AC. What is the turns ratio between the primary and secondary coils?

$$\frac{240}{12} = \frac{1000}{N_S}$$

$$20 = \frac{1000}{N_S}$$

$$\frac{20}{1000} = \frac{1}{N_S}$$

$$0.02 = \frac{1}{N_S}$$

$$50 = NS$$

The primary has 1000 turns and the secondary has 50 turns. **20:1 ratio**

Example: An ideal transformer has 750 turns on the primary coil and 50 turns on the secondary and the primary voltage is 30 V AC, what is the secondary voltage?

$$\frac{30}{X} = \frac{750}{50}$$

$$\frac{30}{X} = 15$$

$$\frac{30}{15} = x$$

X = 2 v

Example: A transformer has a turns ratio of 10:1 and the VP is 240V AC. What is the secondary voltage?

$$\frac{240}{\mathbf{x}} = \frac{10}{\mathbf{1}}$$

$$\frac{240}{\mathbf{x}} = \mathbf{10}$$

$$\frac{240}{\mathbf{10}} = \mathbf{x}$$

24 V AC

Current Ratio

The current ratio is opposite to the voltage ratio. If a transformer drops voltage from primary to secondary, the current capacity in the secondary will increase.

$$\frac{I_s}{I_p} = \frac{N_p}{N_S}$$

Example: A transformer has a turns ratio of 10:1. The VP is 240V AC and the secondary voltage is 24 V. If the primary current is 1 ampere, what is the secondary current?

$$\frac{x}{1} = \frac{10}{1}$$

$$\frac{x}{1} = 10$$

$$x = 10 \text{ A}$$

Example: You wish to draw 5 amps from the secondary at 12 V. The primary volage is 240v. What is the draw on the primary current?

Calculating the turns ratio you find that it is 20 to 1.

$$\frac{5}{x} = \frac{20}{1}$$

$$\frac{5}{20} = x$$

0.25A

Impedance Ratio

Transformers are also used to match impedances such as a Balun or an amplifier output matching transformers in amateur radio.

The formula for the transformer is the number of turns in the primary over the turns in the secondary, the turns ratio equals the square root of the impedance in the primary over the impedance in the secondary.

$$\frac{N_p}{N_S} = \sqrt{\frac{Z_P}{Z_S}}$$

Example: What is the transformer turns ratio to match the amplifier output impedance, ZP, of 0.25 Ω to a 4 Ω speaker, ZS? (Assume NS = 1.)

$$\frac{x}{1} = \sqrt{\frac{0.25}{4}}$$

$$\frac{x}{1} = 0.25$$

$$X = \frac{1}{0.25}$$

$$X = 4$$

The primary winding has four times as many windings as the secondary. 4:1

Ideal Power

An ideal transformer is where the input power equals output power without losses and rated at 100% efficiency.

$$P(out) = P(in)$$

Formula Relationships

Transformer formulas are interrelated, based on the principles of electromagnetism (Faraday's Law) and conservation of energy (ideal power transfer)

As shown below, voltage, current, number of turns and impedance can be derived from each other.

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$$\frac{V_p}{V_S} = \frac{I_S}{I_P} = \frac{N_p}{N_S} = \sqrt{\frac{Z_P}{Z_S}}$$

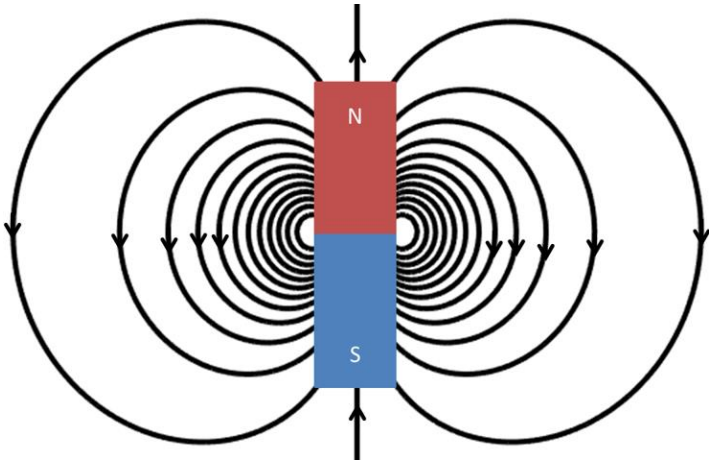
Shielding

Magnetic

There is no shield or substance that will effectively block magnetic fields. You can, however, redirect the magnetic field lines. To redirect magnetic field lines, you offer them a preferred path of least resistance. Magnetic field lines prefer to travel in materials that have certain magnetic properties, namely materials with high permeability.

Magnetic permeability refers to a material's ability to align itself with a magnetic field. Material with a high magnetic permeability shows that it can easily align itself to a magnetic field. Where a material does not align itself to the magnetic field, the material is said to have low magnetic permeability

Materials like Cobalt-iron, iron and electrical steel have a high permeability.



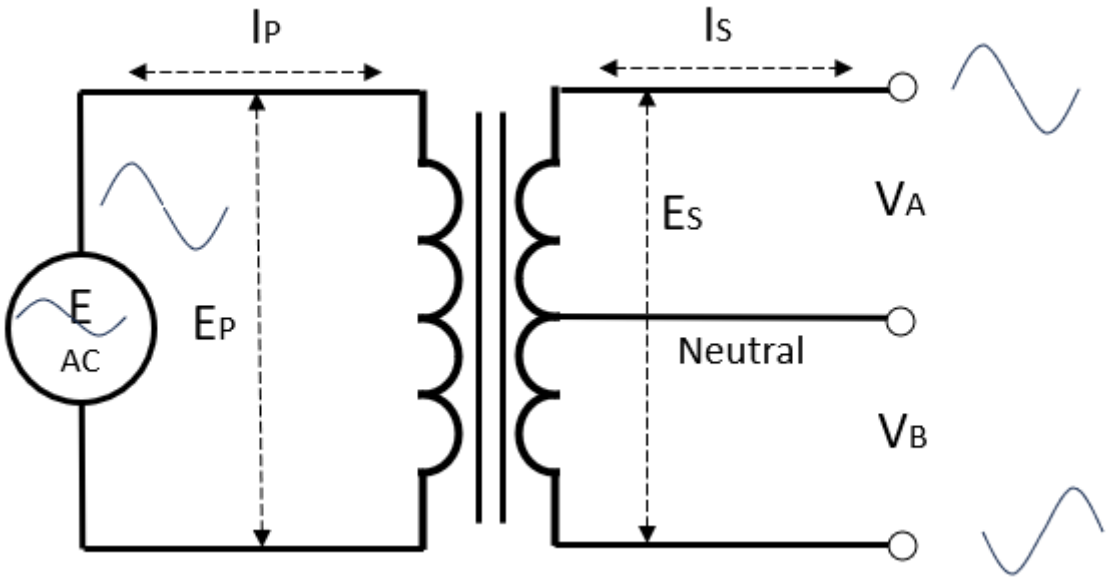
Electromagnetic

Electromagnetic shielding is the process of lowering the electromagnetic field in an area by barricading it with conductive or magnetic material. Copper is used for radio frequency (RF) shielding because it absorbs radio and other electromagnetic waves.

A common form of shielding is using both foil and braid. In multiconductor cables, individual pairs are sometimes shielded with foil to provide crosstalk protection between the pairs, while the overall cable is shielded with foil, braid, or both. All the shields are grounded to a common source

Centre Tapped Transformer

A centre-tapped transformer has a connection midpoint in the secondary winding. This midpoint connection divides the output into two equal, 180-degree out-of-phase voltages. Each outlet is made with respect to the centre tap. This transformer is common in power supplies. This configuration allows for full-wave rectification and generates a positive and negative voltage rail.



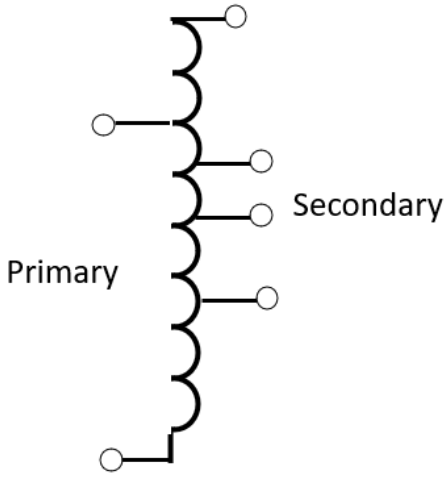
An example where tis is used is to produce a + 12 and – 12-volt output.

Autotransformer

An autotransformer has only one winding where portions of the same winding act as both the primary winding and secondary winding sides of the transformer.

The autotransformer lacks electrical isolation between input and output. The added feature is smaller size, lower cost, and higher efficiency.

An example of an autotransformer is a traveler's voltage converter that allows 230-volt devices to be used on 120-volt supply circuits, or the reverse.



Autotransformer

Baluns and UnUns

Definitions

A **balun**, "balanced to unbalanced," matches impedances between a balanced component and an unbalanced component. The balun improves signal transfer and reduces loss by aligning the antenna's impedance with the transmission line.

The balun is basically a transformer. The coaxial connection is Z_P and the antenna connection is Z_S.

The **unun**, “unbalanced to unbalanced”, matches impedances between an unbalanced component and another unbalanced component. The unun improves signal transfer and reduces loss by aligning the antenna's impedance with the transmission line.

More on this topic in antennas lesson.

Go to Lesson 5A Questions.