



# Transformer Fundamentals

An Online Continuing Education Course for Engineers

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# Transformer Fundamentals

A **transformer** is a device that transfers electrical energy from one circuit to another by electromagnetic induction (transformer action). The electrical energy is always transferred without a change in frequency, but may involve changes in magnitudes of voltage and current. Because a transformer works on the principle of electromagnetic induction, it must be used with an input source voltage that varies in amplitude.

There are many types of power that fit this description; for ease of explanation and understanding, transformer action will be explained using an ac voltage as the input source. Alternating current has certain advantages over direct current. One important advantage is that when ac is used, the voltage and current levels can be increased or decreased by means of a transformer.

The amount of power used by the load of an electrical circuit is equal to the current in the load times the voltage across the load, or  $P = EI$ . If, for example, the load in an electrical circuit requires an input of 2 amperes at 10 volts (20 watts) and the source is capable of delivering only 1 ampere at 20 volts, the circuit could not normally be used with this particular source. However, if a transformer is connected between the source and the load, the voltage can be decreased (stepped down) to 10 volts and the current increased (stepped up) to 2 amperes. Notice in the above case that the power remains the same. That is, 20 volts times 1 ampere equals the same power as 10 volts times 2 amperes.

## BASIC OPERATION OF A TRANSFORMER

In its most basic form a transformer consists of:

- A primary coil or winding.
- A secondary coil or winding.
- A core that supports the coils or windings.

Refer to the transformer circuit in figure 1 as you read the following explanation: The primary winding is connected to a 60 hertz ac voltage source. The magnetic field (flux) builds up (expands) and collapses (contracts) about the primary winding. The expanding and contracting magnetic field around the primary winding cuts the secondary winding and induces an alternating voltage into the winding. This voltage causes alternating current to flow through the load. The voltage may be stepped up or down depending on the design of the primary and secondary windings.

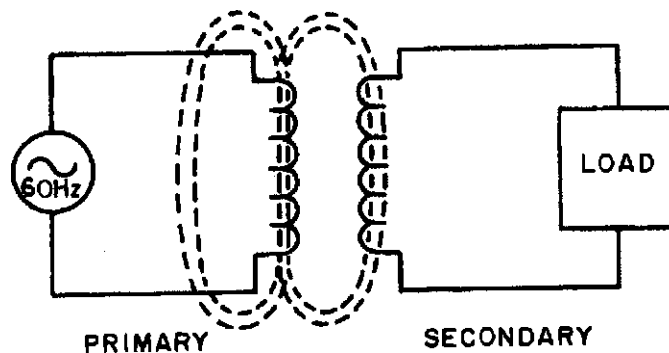


Figure 1.—Basic Transformer Action

## THE COMPONENTS OF A TRANSFORMER

Two coils of wire (called windings) are wound on some type of core material. In some cases the coils of wire are wound on a cylindrical or rectangular cardboard form. In effect, the core material is air and the transformer is called an **AIR-CORE TRANSFORMER**. Transformers used at low frequencies, such as 60 hertz and 400 hertz, require a core of low-reluctance magnetic material, usually iron. This type of transformer is called an **IRON-CORE TRANSFORMER**. Most power transformers are of the iron-core type. The principle parts of a transformer and their functions are:

- The **CORE**, which provides a path for the magnetic lines of flux.
- The **PRIMARY WINDING**, which receives energy from the ac source.
- The **SECONDARY WINDING**, which receives energy from the primary winding and delivers it to the load.
- The **ENCLOSURE**, which protects the above components from dirt, moisture, and mechanical damage.

## CORE CHARACTERISTICS

The composition of a transformer core depends on such factors as voltage, current, and frequency. Size limitations and construction costs are also factors to be considered. Commonly used core materials are air, soft iron, and steel. Each of these materials is suitable for particular applications and unsuitable for others. Generally, air-core transformers are used when the voltage source has a high frequency (above 20 kHz). Iron-core transformers are usually used when the source frequency is low (below 20 kHz). A soft-iron-core transformer is very useful where the transformer must be physically small, yet efficient. The iron-core transformer provides better power transfer than does the air-core transformer. A transformer whose core is constructed of laminated sheets of steel dissipates heat readily; thus it provides for the efficient transfer of power. The majority of transformers you will encounter in Navy equipment contain laminated-steel cores. These steel laminations (see figure 2) are insulated with a nonconducting material, such as varnish, and then formed into a core. It takes about 50 such laminations to make a core an inch thick. The purpose of the laminations is to reduce certain losses which will be discussed later in this course. An important point to remember is that the most efficient transformer core is one that offers the best path for the most lines of flux with the least loss in magnetic and electrical energy.

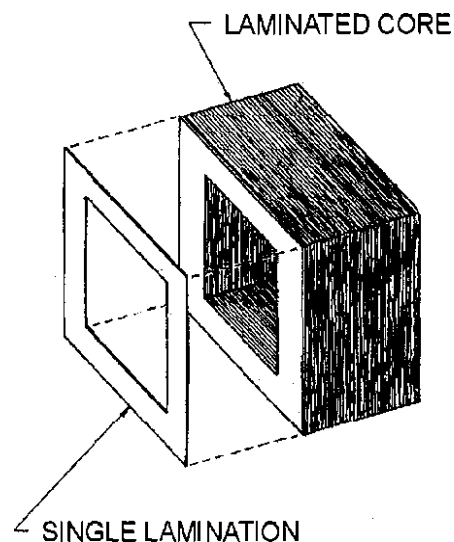


Figure 2.—Hollow-Core Construction

## Hollow-Core Transformers

There are two main shapes of cores used in laminated-steel-core transformers. One is the HOLLOW-CORE, so named because the core is shaped with a hollow square through the center. Figure 2 illustrates this shape of core. Notice that the core is made up of many laminations of steel. Figure 3 illustrates how the transformer windings are wrapped around both sides of the core.

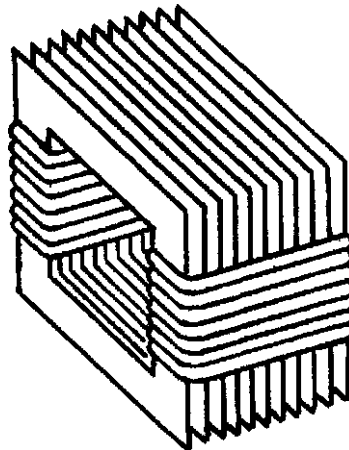


Figure 3.—Windings Wrapped around Laminations

## Shell-Core Transformers

The most popular and efficient transformer core is the SHELL CORE, as illustrated in figure 4. As shown, each layer of the core consists of E- and I-shaped sections of metal. These sections are butted together to form the laminations. The laminations are insulated from each other and then pressed together to form the core.

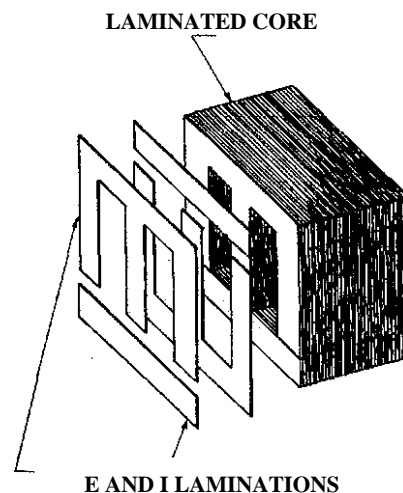


Figure 4.—Shell-Type Core Construction

## TRANSFORMER WINDINGS

As stated above, the transformer consists of two coils called WINDINGS which are wrapped around a core. The transformer operates when a source of ac voltage is connected to one of the windings and a load device is connected to the other. The winding that is connected to the source is called the PRIMARY WINDING. The winding that is connected to the load is called the SECONDARY WINDING. (Note: In this course the terms "primary winding" and "primary" are used interchangeably; the term "secondary winding" and "secondary" are also used interchangeably.)

Figure 5 shows an exploded view of a shell-type transformer. The primary is wound in layers directly on a rectangular cardboard form.

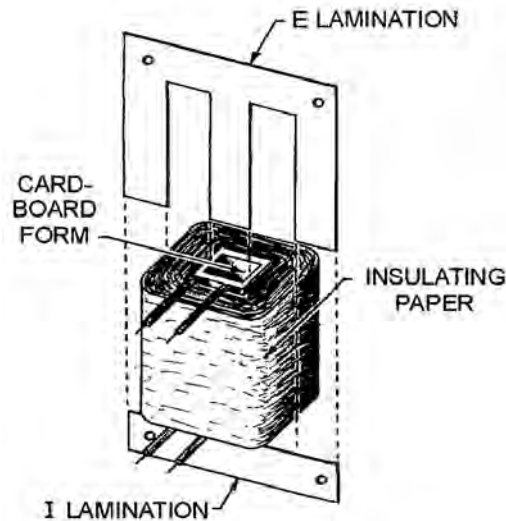


Figure 5.—Exploded View of Shell-Type Transformer Construction

In the transformer shown in the cutaway view in figure 6, the primary consists of many turns of relatively small wire. The wire is coated with varnish so that each turn of the winding is insulated from every other turn. In a transformer designed for high-voltage applications, sheets of insulating material, such as paper, are placed between the layers of windings to provide additional insulation.

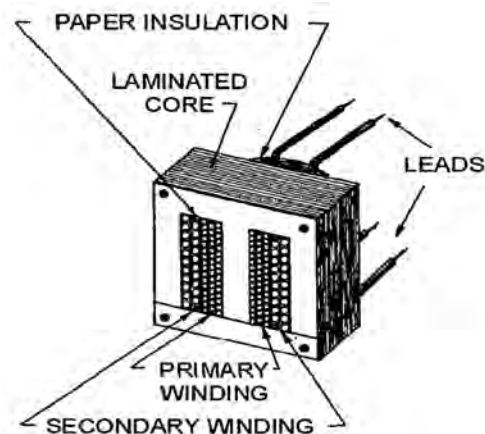


Figure 6.—Cutaway View of Shell-Type Core with Windings

When the primary winding is completely wound, it is wrapped in insulating paper or cloth. The secondary winding is then wound on top of the primary winding. After the secondary winding is complete, it too is covered with insulating paper. Next, the E and I sections of the iron core are inserted into and around the windings as shown.

The leads from the windings are normally brought out through a hole in the enclosure of the transformer. Sometimes, terminals may be provided on the enclosure for connections to the windings. The figure shows four leads, two from the primary and two from the secondary. These leads are to be connected to the source and load, respectively.

### SCHEMATIC SYMBOLS FOR TRANSFORMERS

Figure 7 shows typical schematic symbols for transformers. The symbol for an air-core transformer is shown in figure 7(A). Parts (B) and (C) show iron-core transformers. The bars between the coils are used to indicate an iron core. Frequently, additional connections are made to the transformer windings at points other than the ends of the windings. These additional connections are called TAPS. When a tap is made at the center of the winding, it is called a CENTER TAP. Figure 7(C) shows the schematic symbol for a center-tapped iron-core transformer.

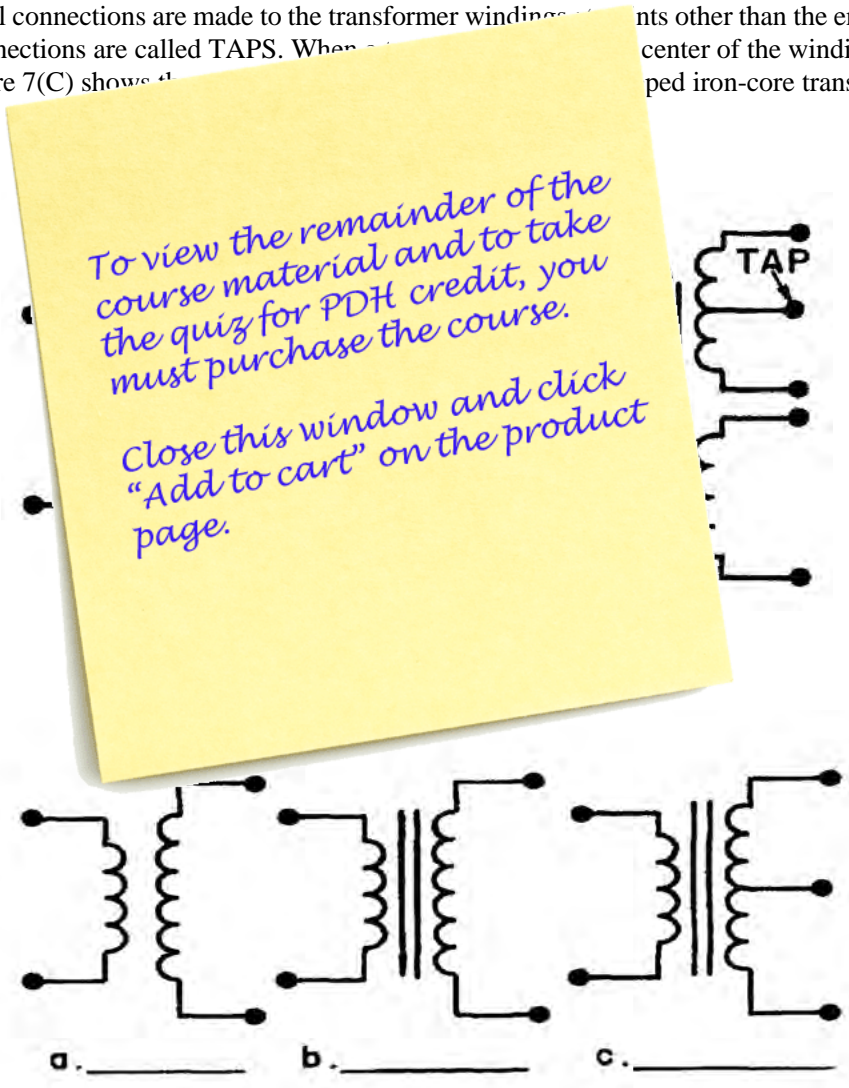


Figure 7.—Schematic Symbols for Various Types of Transformers