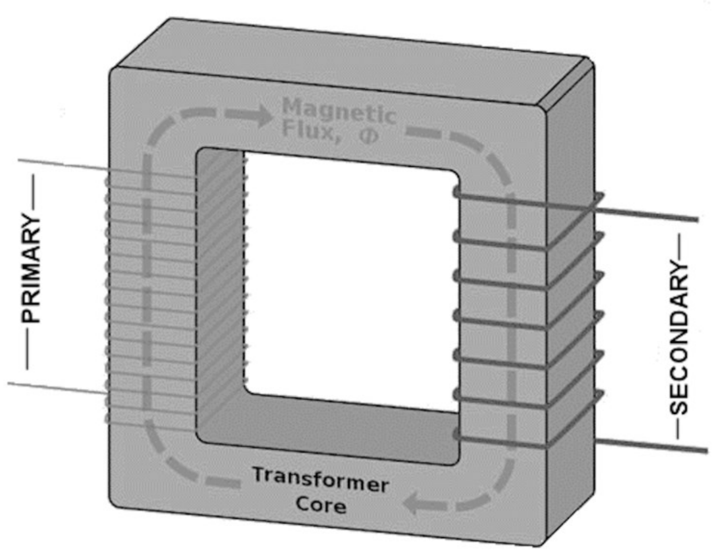
Transformers

When two coils are placed close to each other, such that the electromagnetic field of one intersects the other, variations in current in the first coil will cause its field to alternately expand and collapse, inducing a voltage in the second coil.

This phenomenon is called *transformer action*. The first coil is referred to as the *primary winding*, the other being called the *secondary winding*.



In a conventional transformer, the primary and secondary coils are wound around a magnetically permeable core. The electrical signal in the primary coil produces a corresponding magnetic field in the transformer's metal core. As the electrical current through the primary changes, it causes the magnetic field to expand or collapse accordingly. The changing magnetic field in the core then induces an emf in the secondary winding.

In order to minimize core losses, the core is made of thin sheets, rather than solid metal, the laminations being insulated from each other, and encapsulated by varnish.

The voltage induced in the secondary is determined by the primary/secondary *turns ratio*.

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

Thus, if the primary and secondary windings are identical, a ratio of 1:1, the voltage induced in the secondary will be equal to that applied to the primary.

A transformer designed such that the secondary voltage will be the same as that applied to the primary, is usually called a coupling transformer, or an isolation transformer. Where the secondary voltage will be higher than the voltage applied to the primary, the transformer is called a *step-up transformer*. The opposite is called a *step-down transformer*.

Power dissipation in the primary and secondary will always be balanced …

$$(IE)_P = (IE)_S$$

An interesting consequence of this is that if secondary is open and the secondary current is therefore zero, the current in the primary will also be zero, even though it is connected to a voltage source.

For the balanced power condition to be maintained, current in the windings must obviously vary *inversely* with voltage, which is a function of the transformer's turns ratio. Therefore …

$$\frac{I_S}{I_P} = \frac{N_P}{N_S}$$

As an example, suppose we need a step-down transformer to convert 120vac to 24vac. The primary/secondary turns ratio needed would therefore be …

$$120v{:}24v = 5{:}1$$

… so the primary winding will have five times as many turns as the secondary winding.

If on the secondary side, the load current is 100mA, the secondary power dissipation is therefore …

$$P_S = I \times E = 2.4\, watts$$

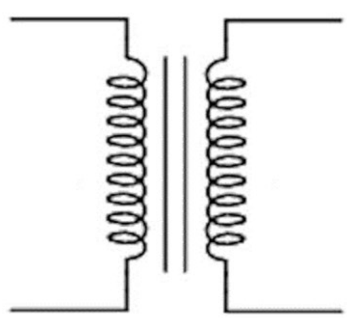
The current in the primary winding needed to support that load will therefore be …

$$I_P = \frac{P_S}{E_P} = \frac{2.4}{120} = 20mA$$

Notice that the primary/secondary current ratio is the inverse of the turns ratio.

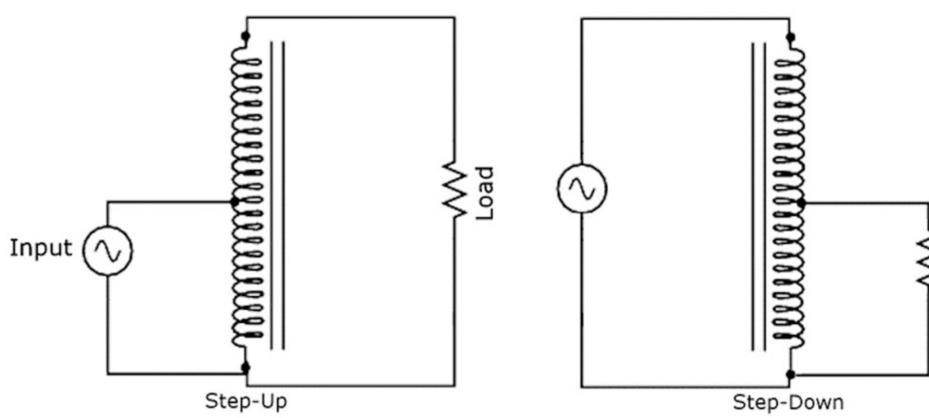
As explained before, this is what makes it possible for power utilities to support heavy load currents many miles away from the generating plant. The generated voltage is stepped-up dramatically by transformers at the generating plant, then stepped down to 240v/120v for residential users, a scheme which results in very low I^2R losses along the transmission lines.

Conventional transformers consist of separate primary and secondary coils wound on a laminated metal core, usually iron or a ferrous alloy, and schematically represented like this ...

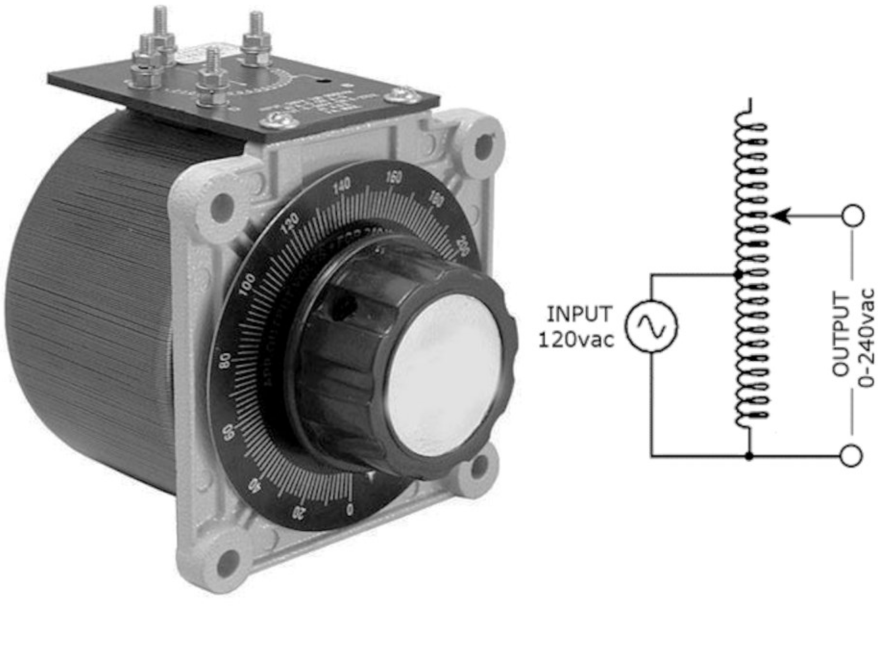


There are lots of varieties. Primary windings are sometimes tapped at several different points to allow for a selection of input voltages. Secondary windings also sometimes have multiple taps to provide a selection of output voltages, and are often center-tapped for use in power supply circuits.

Another variety is the *autotransformer*, which consists of a single winding, tapped somewhere between its two ends as necessary to provide the needed transformer ratio.



For an adjustable source of AC, the step-up configuration of the autotransformer is used with a continuously adjustable tap on the load side. Such a device is called a VARIAC.

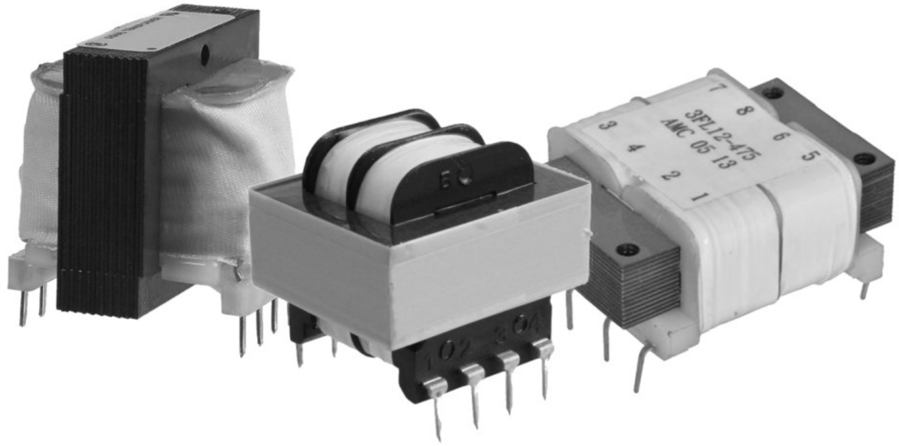


Power Transformers

The most commonly used class of transformers in today's electronics is the *power transformer*. They are often called *miniature* power transformers, to distinguish them from the huge transformers used in electric distribution systems.

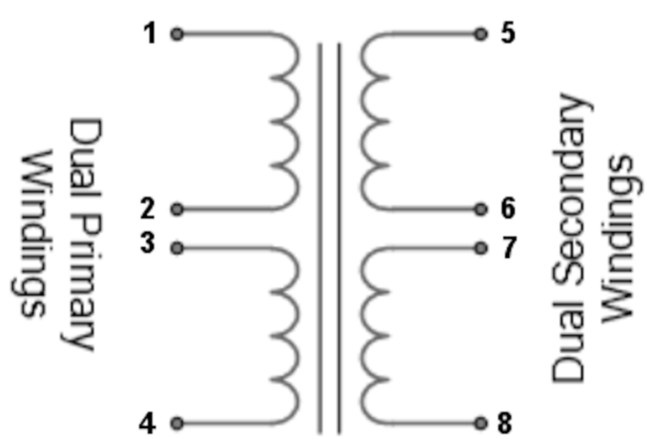
Power transformers are designed to work with 240/120vac 50/60Hz electrical power, and are used to provide input power for electronic systems, the AC input voltage being converted to appropriate levels of DC by a system of rectifiers and regulators.

These transformers come in a variety of



shapes, coil configurations, and electrical ratings. Their physical size is a function of the load current required.

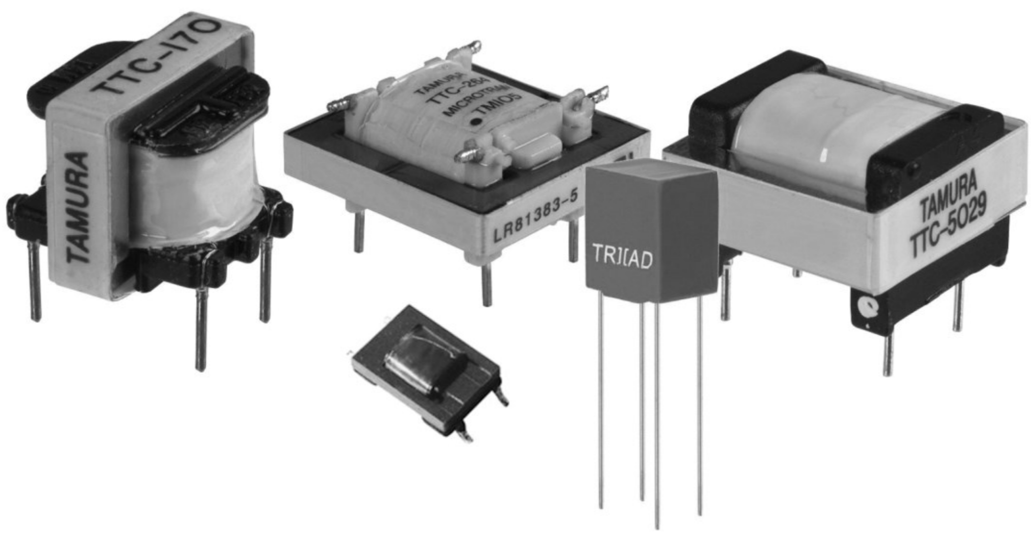
A very popular configuration provides dual identical primary windings and dual identical secondary windings. The primary



windings can be connected in series for 240vac power, or in parallel for 120vac. The secondary windings can be paralleled to double their load current capability using a bridge rectifier scheme, or in series for use with conventional full wave rectifier circuits.

Audio Transformers

Audio transformers are specially designed for low current signals in the range of 20Hz to 20KHz.



In the days of thermionic vacuum tube amplifiers, these were essential for coupling the output of one stage to the input of the next. The main reason was that these amplifier circuits depended on high DC plate voltages, so the amplified output taken from the plate connection included a high voltage DC component. Since transformers can pass only AC, the coupling transformer effectively blocked the DC component, presenting only the desired audio signal to the following amplifier stage or output.

In today's systems, if used at all, transformers of this type are employed for impedance matching, although even that isn't usually necessary anymore with modern solid-state equipment.

Other Transformer Types

Depending upon how your interests in electronics develop, you might hear about other kinds of transformers — *RF*, *IF*, *balun*, *pulse*, and so on.

RF and *IF* transformers were important in the days of thermionic vacuum tube radio circuitry, but the advent of solid-state electronics has, for the most part, consigned them to history.

All other types are special-purpose devices designed for narrowly defined applications.

In the event that you happen to become involved in those technologies, learning about them will be a part of your specialty training.

(… which is a round-about way of saying, *"beyond the scope of this course."* I hate it when people say that. I usually assume that means that it's something they don't really know much about.)

Electrical Isolation

An important difference between conventional transformers and autotransformers is the isolation provided between the primary and secondary windings of conventional transformers.

Most electronic circuitry is powered by DC voltages; typically 5v, 12v, and 15v.

These low DC potentials are provided by special circuits that convert AC to DC, and they present very little risk of electrical shock.

The AC input is provided by the 240/120vac power service, which *is* potentially dangerous, not only to personnel, but also to the equipment itself.

When a conventional transformer is used to reduce the input power to the needed lower levels, it also isolates the electronic circuit electrically from the high voltage AC power distribution system. Since its core conducts only magnetic flux, there is no physical connection between the primary and secondary windings, so the transformer provides positive protection from electric shock.

This completes our discussion of inductive components — at least for the time being.

The reality is that with the advent of solid-state electronics, and especially today's ultra-miniaturized equipment built using highly monolithic surface-mounted devices, the use of inductive components has become superannuated.

(I like that word — it's so much more whimsical than "obsolete". Why use a three-syllable word when one with six is available?)

With the exception of transformers and relays, I have never found any need to use an inductive component in anything that I've designed over the past 40-years.

We'll move on now to a much more useful and commonly encountered component — *capacitors*.
