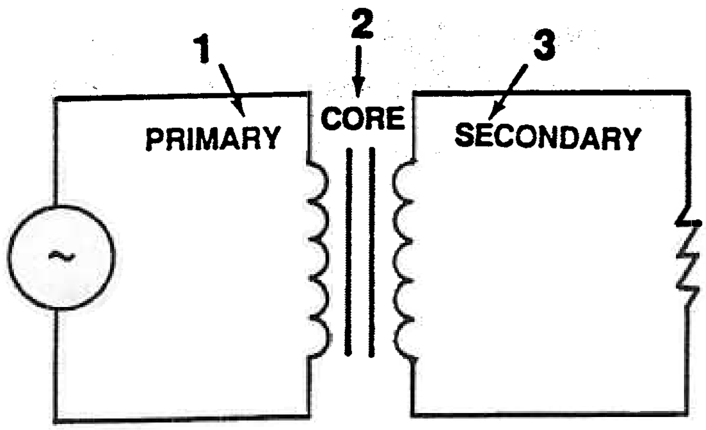

FIGURE 3

A transformer consists of two or more coils that couple energy from one to the other by means of mutual inductance. Depending on the frequency of operation and circuit requirements, a transformer may use a core material made of iron, a magnetic alloy or air. Transformers change AC voltage and current values, and also provide a means for efficiently transferring electrical current long distance.

As shown in Figure 4, the main purpose of a transformer is to change an input AC voltage and current of one value to an output having another value.

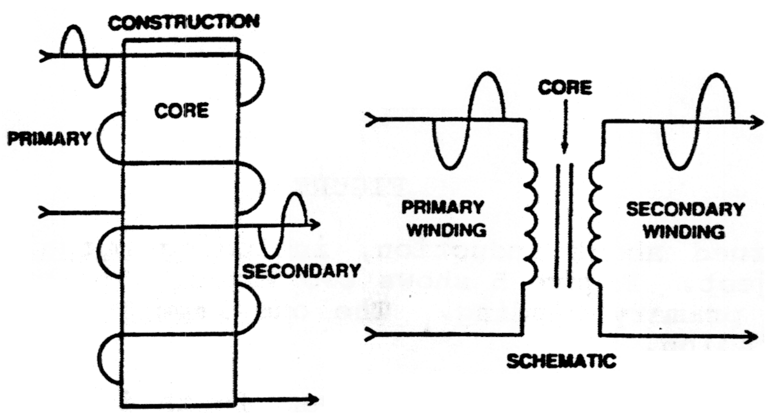

FIGURE 4

As stated before, a transformer consists of two or more coils that couple energy from one coil to another by mutual induction.

Note in FIGURE 4 that the transformer contains two or more coils, which are called "windings." The coils of wire are wound on some type of core material. You studied coils in the lessons covering Inductance, LCR and Resonance. They were called "Inductors."

The input winding is called the "Primary" winding. The output winding is called the "Secondary" winding. A transformer may have more than one primary winding. It may also have more than one secondary winding, depending on circuit requirements.

FIGURE 4 shows core material. The two parallel lines in the middle of the transformer schematic symbol indicate that the core is made of iron. Without lines, the symbol represents a transformer having an air core.

The type of core required is determined by the frequency of the AC signal applied. The efficiency of a transformer is determined by the frequency applied and the type core material used.

Although there will always be some power loss through a transformer, it is so small in a properly designed circuit that it is negligible. During this lesson, for all practical purposes, consider that a transformer is 100% efficient, with no measurable losses.

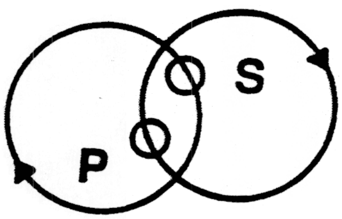

FIGURE 5

You learned about induction, including mutual induction, in an earlier subject. Figure 5 shows two wires. The one labeled "P" is a wire in the primary winding. The one labeled "S" is a wire in the secondary winding.

As the AC current surges back and forth in the primary wire, the magnetic field expands and contracts around it. This primary magnetic field cuts back and forth across the secondary wire, inducing an AC current in it.

The induced current, in the secondary, then causes a magnetic field around the secondary to cut back and forth across the primary wire inducing a counter current in it.

To sum it all up, the two wires interact with each other when AC is present.

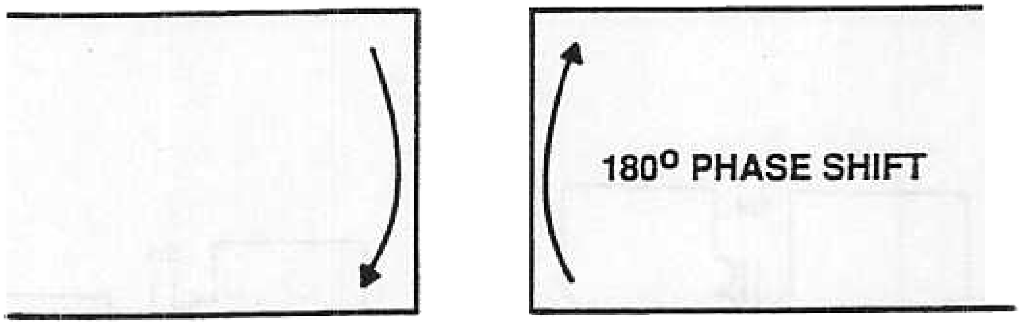

FIGURE 6

The nature of the expanding and contracting magnetic fields around wires is such that the current induced in the secondary wire flows in the opposite direction to the current in the primary which induced it. Normally, there is a 180 degree phase shift in the current and voltage across a transformer.

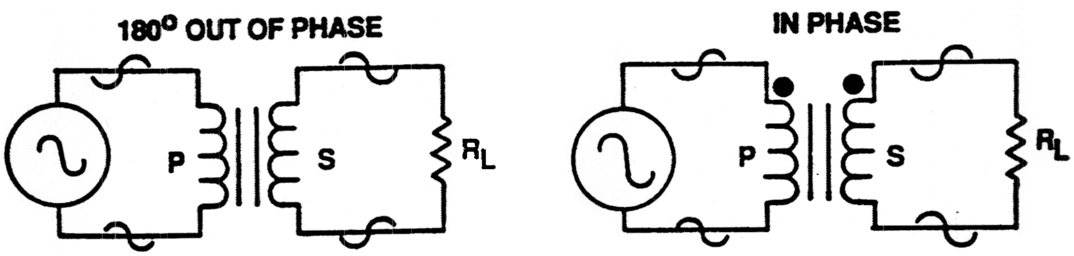

FIGURE 7

Wires can be wound around the core in either direction, so, the transformer can be designed to produce whichever phase is desired. In addition, the transformer can be connected in the circuit with its leads interchanged to produce either phase relationship. Where phase relationship is important in a circuit, the schematic will show two dots on the transformer symbol.

If there are no dots in the schematic symbol, the phase relationship of the primary is considered to be 180 degrees out of phase with the secondary.

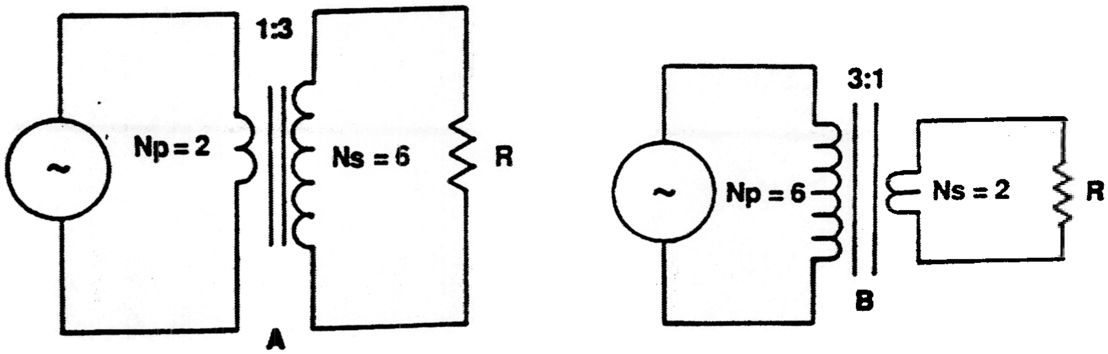

FIGURE 8

Another important fact to remember about transformers is that the ratio of turns of wire of each winding determines the voltage and current change across it.

The two drawings in Figure 8 show 2 turns of wire in the primary winding, and 6 turns of wire in the secondary winding. Drawing "A" is labeled to indicate this as 2 to 6, which is a ratio of 1:3.

Turns ratio is always expressed with the smallest number shown as a "1." The largest number represents how many times greater the larger winding is than the smaller.

For example, drawing "B" in figure 8 correctly represents the turns ratio of drawing A and is labeled as having a turns ration of 6 to 2. Note that the larger number is over the larger winding. This reduces to a ratio of 3:1.

Most schematics do not show the actual number of turns. If the ratio is high, the schematic sometimes show more turns in one winding than the other.

What would be the proper way to express the turns ratio for the two transformers shown in figure 9?

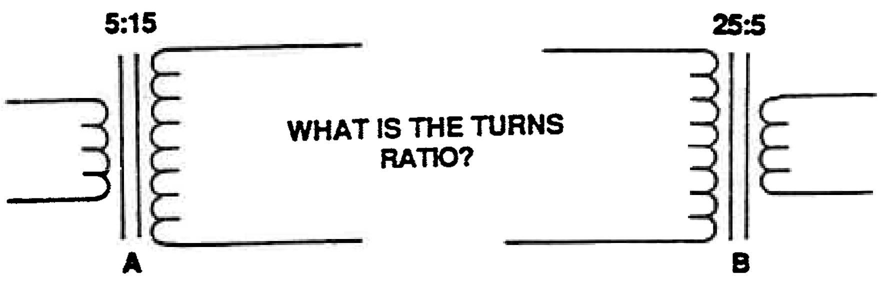

FIGURE 9

In figure 9, transformer "A" has a turns ratio of 1 to 3, and transformer "B" has a turns ratio of 5 to 1. This is the correct way of labeling the turns ratio. Most schematics will not show the turns ratio.

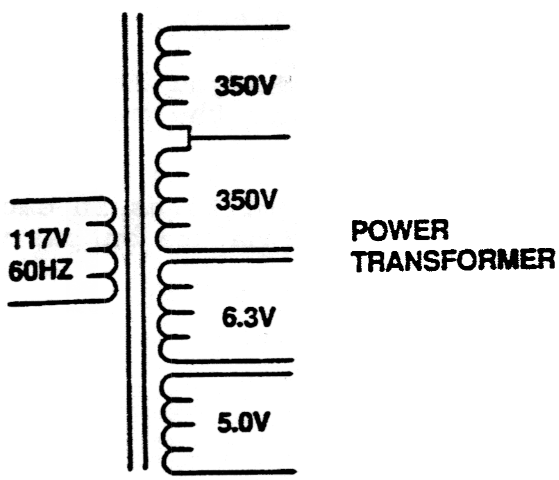

FIGURE 10

The windings are labeled with normal voltage values. This is the most common method used for transformers in power supply circuits, as shown in FIGURE 10.

The 117V on the primary winding is the voltage coming from the wall socket. The secondary voltages shown are those which will be found if 117V is applied to the primary.

The use of the voltage ratio, instead of the turns ratio, is very practical when troubleshooting.

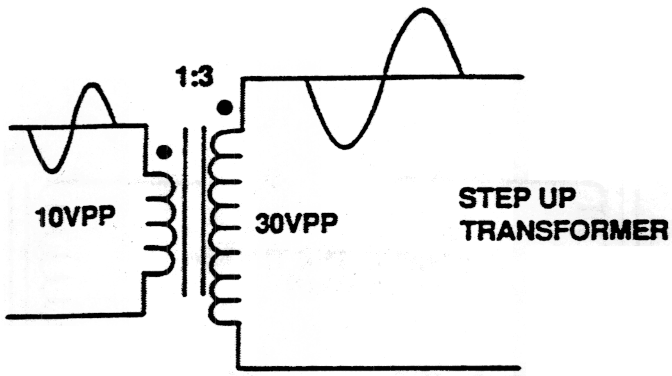

FIGURE 11

The primary is usually drawn on the left, with the secondary on the right, as shown in FIGURE 11. Note that the winding ratio and the voltages of this transformer increases from primary to secondary. This is called "stepping up"; therefore, the transformer is called a "step-up" transformer.

Compare the turns ratio and the voltage ratio of the transformer. In what way are the two ratios related?

They are directly related. As you increase turns, you increase voltage by the same amount. It is the turns ratio which causes the voltage change.

If there were the same number of turns in each winding, what would be the turns ratio, and what would be the output voltage with a 10 volt input?

With the same number of turns, the turns ratio would be one-to-one, and the output voltage would be the same as the input: 10 volts. Transformers having the same number of turns in the primary and secondary windings are normally used for "isolation" purposes. Isolation means that there are no physical electrical connections in the circuit.

Calculate the turns ratio from the primary to each of the three secondaries of the transformer in FIGURE 12.

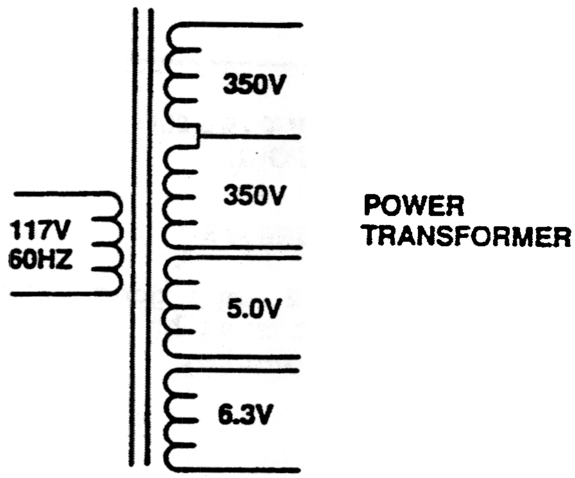

FIGURE 12

Using the voltages shown, you would divide 117v into 700v for the high voltage secondary, giving a turns ratio of approximately 1 to 6.

Dividing the 6.3v into 117v gives a turns ratio of 18.6 to 1.

Note that this is stepping down.

Dividing the 5v into 117v gives a turn ratio of 23.4 to 1. This is another step-down transformer secondary.

The basis for all calculations is the power in the primary (Pp) is equal to the power in the secondary (Ps). Power (P) is equal to voltage (E) times current (I) or P = EI. Thus, $E_P I_P = E_S I_S$.

Earlier in this subject, we said that we would consider a transformer to be 100% efficient. P-in will equal P-out. If you put 10 watts in, you would get 10 watts out. Although there are some losses in the transformer, they are too small for you to measure in a properly designed circuit.

If the voltage is stepped up by a transformer, the current must be stepped down by the same amount, because the input and output power is the same.

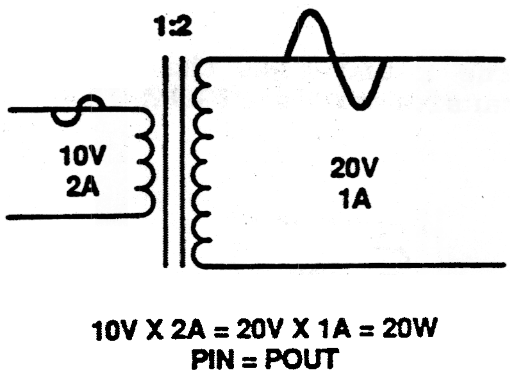

FIGURE 13

In FIGURE 13, if 10 volts at 2 amps goes into a transformer, and the output is 20 volts, the current must be 1 amp. The output power is the same as the input power of 20 watts.

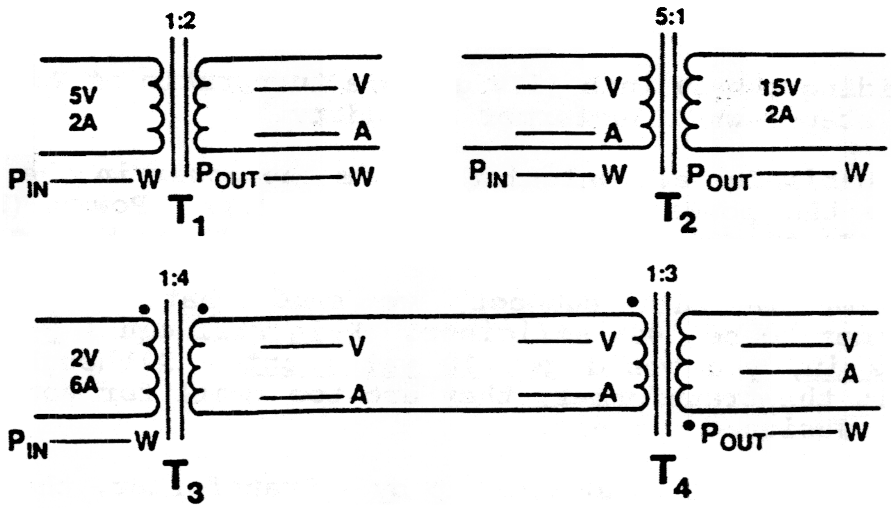

FIGURE 14

As a check-up, calculate the output voltage and current in the three drawings shown.

You should have calculated the following. Transformer "T1", being a 1 to 2 step-up transformer, would have an output of 10v at 1 amp. Remember, as voltage goes up, current goes down. The term "step-up" refers only to the voltage change. Current is stepped down in a voltage step-up transformer.

Transformer "T2", which is a step-down transformer, drops the voltage to 3 volts and raises the current to 10 amps.

The bottom view shows two transformers hooked together, with the output of the first becoming the input to the second. Both are step-up transformers. The first one raises the voltage to 8 volts. The second multiplies the 8 volts by 3 to give a final output of 24 volts.

The total step-up is found by multiplying the two ratios. That is, 4 times 3 is 12. So the total is 1 to 12, and the output voltage will be 12 times the input voltage, or 24 volts. Current is stepped down by twelve (12), and is one-half (.5) amp.

There are many different types of transformer. We will discuss only a few of them. Discussed here are some various frequency and special purpose type transformers.

The transformer construction varies with the frequency of the AC to be used.

Electrical power is transmitted at very low frequencies. Typical power frequencies are 50hz, 60hz and 400hz.

The standard power frequency in the United States is 60hz. Many European countries use 50hz. Military portable power generators often use the higher frequency of 400Hz instead of 60Hz because the increase in frequency permits the use of smaller transformers and other components.

The audio transformer normally operates between 100 hertz and 5 kilohertz and uses and iron core. The low power permits smaller wires and smaller transformers.

Above 10Khz, transformer efficiency decreases. Higher frequencies (20KHz and above), are called "radio frequency" and are usually abbreviated as "RF".

Because RF energy is easily coupled between windings, the iron core is not needed. In fact, the iron core would interfere with, and absorb, the RF energy.

Are power transformers considered to be audio or RF transformers?

Power transformers are audio transformers. They handle very low frequencies, therefore they require an iron core and fall in the audio range.

What is the main difference between power and audio transformers?

The main difference is size. Power transformers must handle higher currents and voltages, and operate at the lower end of the audio frequency range. This requires large iron cores, large wiring, and heavy insulation.

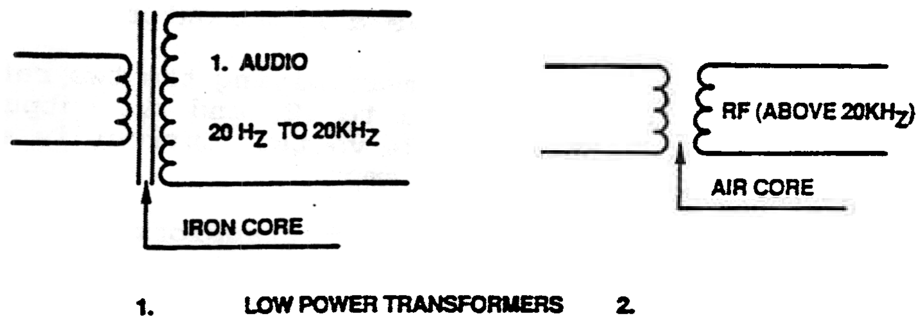

FIGURE 15

Audio and RF transformers handle AC which is usually at very low current values, compared to power transformers. AC waveforms in such circuits are often referred to as "signals" because their purpose is to transmit information, rather than power.

The frequency of sound vibrations falls between twenty and twenty thousand hertz. Transformers designed for handling AC signals in sound systems are called "audio" transformers.

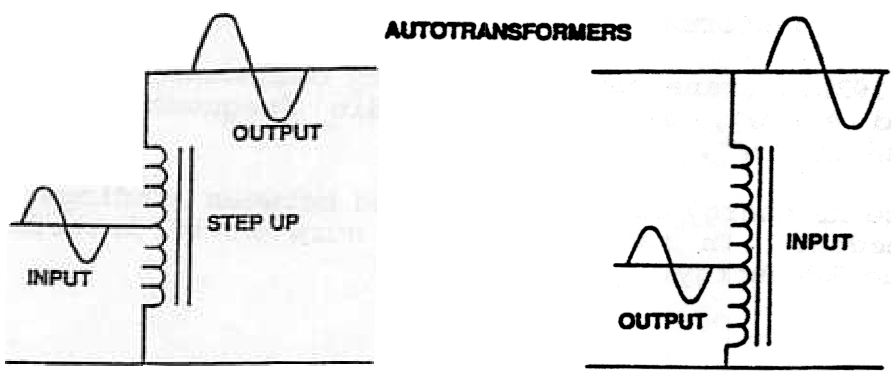

FIGURE 16

Now we will look at autotransformers shown in FIGURE 16. They have only one winding and connecting wires for the primary and the secondary. Note that both the primary and secondary currents flow through the same wire.

Autotransformers are cheaper to make. The reason is that they have only one winding, and a smaller core. The only requirement for transformer action is the wire connections.

There is one major disadvantage of the autotransformer when in use. There is no isolation between the circuit and the line. A serious shock hazard exists with such transformers.

The name "autotransformer" comes from the automatic voltage regulation which these transformers provide. As previously stated, the primary and secondary currents run through the same wire in part of the winding.

Despite changes in load current, these opposing currents strike a balance which causes a stable output voltage to exist. They are used in such AC circuits as sewing machines and electric train controls.

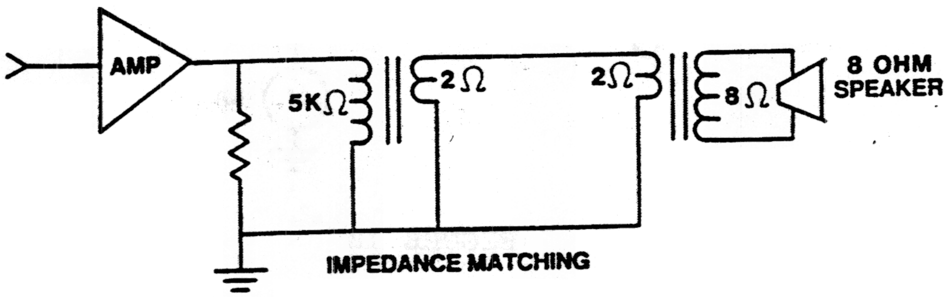

FIGURE 17

Another important use of transformers is for impedance matching, shown in FIGURE 17. It is important that the output impedance of one circuit be the same as the input impedance of the next circuit. Where this does not occur, power will be lost.

Transformers are often used to match impedance between two circuits. This allows for maximum power to be transferred from one circuit to another.

Compare this analogy by thinking of a common stereo system in your home. The schematic symbol for the amplifier is shown to have an impedance of 80K ohms at the output. This goes to the large primary winding of the transformer.

By using a step-down transformer, a secondary winding can be wound with only a few turns to match the required 8 ohm input impedance of the speaker.

What would be the effect of connecting an 8 ohm speaker directly to an amplifier having an output impedance of 80,000 ohms?

The impedance mismatch would create sound distortion. You probably would get no sound from the speaker. The low voice coil impedance could also load down the amplifier, and cause damage to the amplifier.

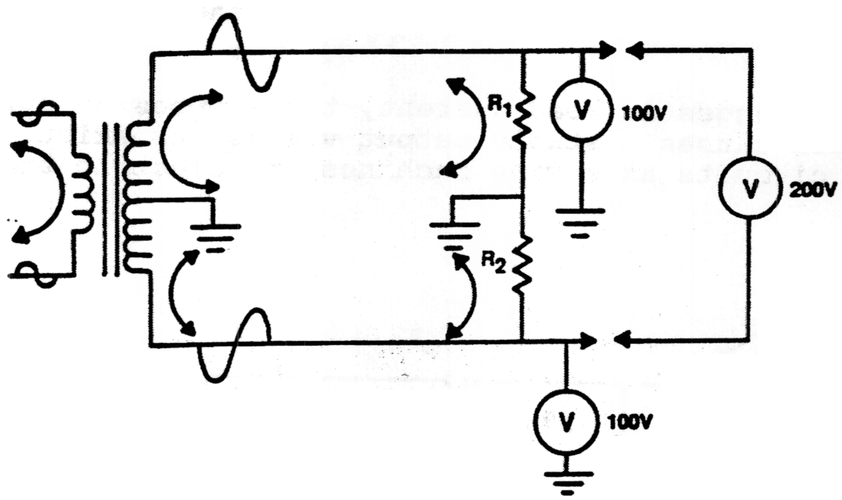

FIGURE 18

A center-tapped secondary creates two separate AC circuits in FIGURE 18, as if there were two separate secondary windings. The current flows back and forth in the two circuits independently. The AC sine waves in the two circuits are 180 degrees out of phase with each other.

If the center-tapped and external circuit, represented by two resistors, are connected to ground, you would have two separate AC voltages with reference to ground, from one winding.

Because the two half-windings are in series with each other, the voltage across both windings is double the voltage across either one.

FIGURE 19 shows a type of transformer used often in power supplies and certain types of amplifiers.

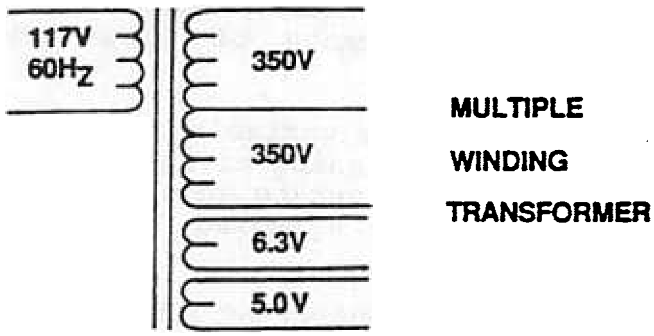

FIGURE 19

FIGURE 19 shows a multiple winding transformer. The primary has 117VAC applied. The secondary windings provide four different AC voltages which are available for different types of AC circuitry. Note, that there is available 700 volts, 350 volts, 6.3 volts, 5 volts, at the output windings.

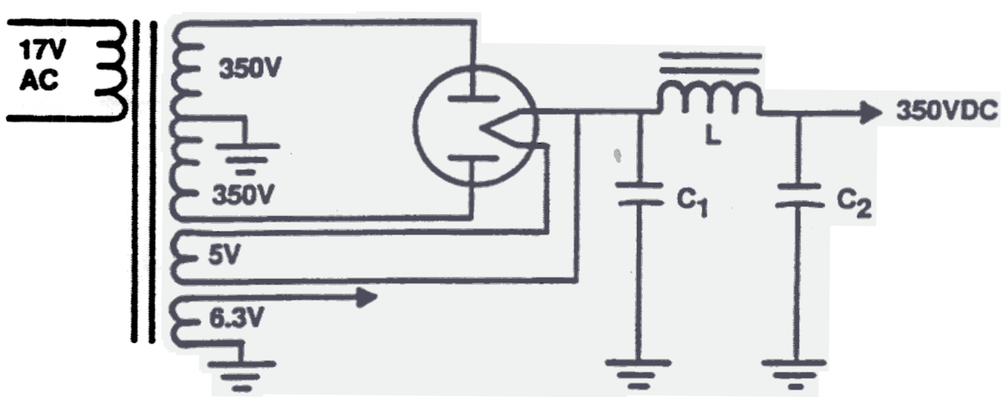

FIGURE 20

FIGURE 20 shows one type of a multiple winding power supply, demonstrating how a multiple winding transformer can be used.

The high voltage 700V winding goes to the plates of two vacuum tubes. The vacuum tubes turn the AC into DC.

The tubes require five volts AC to heat their filaments. The 6.3v AC winding is for the filaments of other tubes, relays and/or accessories.

In FIGURE 21, adjusting the variable resistor for zero resistance will short out the secondary winding of the transformer, and short out the output signal. It is important to understand that the input signal on the primary will also be affected by a change in the output resistance.

The resistance across the output of a transformer is referred to as the "load." The current being drawn from the circuit by the output signal on the primary will also be affected by a change in the output resistance.

Power is transferred across a transformer in the form of both current and voltage. Therefore, a change in either the voltage or current on one side of a transformer will affect the voltage and current on the other side.

TRANSFORMER LOADING

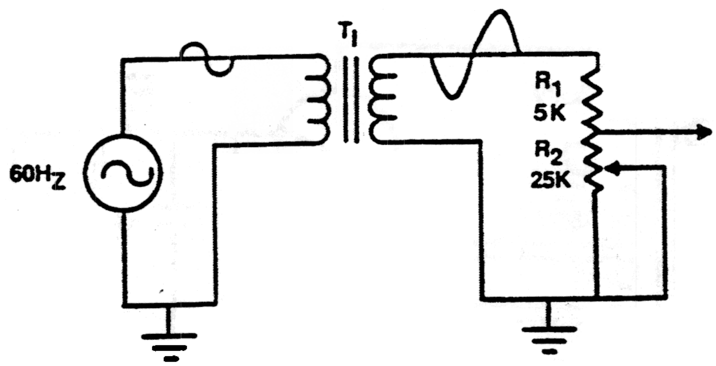

FIGURE 21

To summarize transformers and transformers action, the two basic ideas introduced are those of SELF INDUCTION AND MUTUAL INDUCTION.

Self induction means the flux lines cut the inductor coils producing counterelectromotive force as would be the case in the autotransformer.

Mutual induction in one coil induces a voltage in another coil by its flux lines cutting the windings of the second coil.

The coil generating the flux lines is the PRIMARY (P). The coil in which the flux lines are inducing a voltage is the SECONDARY (S).

The primary could be wound on a core. The core could be material from iron to air.

The lower frequencies would need to have an iron core. Higher frequencies would need a core of less permeability.

The phase relationships could be made in phase or 180 degrees out of phase by reversing the winding process on the secondary.

The ratio could be controlled between the primary and secondary by the number of turns.

The power in the primary is always equal to the power in the secondary.

When the voltage is stepped up, the current is stepped down.

The transformer provides isolation.

The autotransformer does not provide isolation.