Electronics
Radio
Television
Radar

UNITED ELECTRONICS LABORATORIES
LOUISVILLE KENTUCKY

REVISED 1967

IRON CORE COILS AND TRANSFORMERS

ASSIGNMENT 17

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IRON-CORE COILS AND TRANSFORMERS

Coils are used in electronics circuits in either of two main applications. In one of these applications, coils are used with capacitors to provide tuned circuits so that the circuits will respond to one desired frequency only. This tuning process will be studied in a future assignment. The coils used in these tuned circuits are usually of the air-core type, which were discussed in the last assignment, or of the special powdered-iron core type which will be described later in this assignment. The other main application for a coil is its use as a choke. Chokes used for radio frequencies are usually air-core coils, but those used for audio frequencies, and power frequencies, are always iron-core coils.

The reactance of a coil (its opposition to the flow of an a-c current) depends on both the inductance of the coil (in henries) and the frequency at which the coil is operated. The reactance, in ohms, can be found by the formula:

$$X_L = 2 \pi f L = 2 \times 3.14 \times f L = 6.28 f L$$

Suppose we have a coil that has an inductance of 1 henry ($L = 1$).

The reactance to direct current (frequency = zero hertz, or zero cycles per second) will be $X_L = 6.28 \times 0 \times 1 = 0$ ohms.

The reactance at 10 hertz ($f = 10$) will be $X_L = 6.28 \times 10 \times 1 = 62.8$ ohms.

The reactance at 10,000 hertz will be $X_L = 6.28 \times 10{,}000 \times 1 = 62{,}800$ ohms.

We see that the opposition to the flow of current depends on the frequency. A choke coil will offer little or no opposition to the flow of direct current and alternating currents of low frequencies. It will block or "choke" the flow of high-frequency currents.

In order for a "choke" to be effective at low frequencies, such as at the frequency of 120 hertz which is often found in the power supplies of electronic equipment, the inductance value is several henries. The chokes used in power supplies, called **filter chokes**, usually have inductance values ranging from 10 henries to 100 henries. Thirty henries is a very common value found in this application. Figure 1(A) illustrates a typical iron-core choke of this value. Figure 1(B) illustrates the physical construction of this choke. To insure a good magnetic path for all of the magnetic lines of force, the coil is usually wound on the middle "leg" of a three legged core. Chokes are wound with enameled copper wire to prevent adjacent turns from shorting. To prevent adjacent layers from shorting, the layers are usually separated by a sheet of insulating paper or cloth. The same insulating material is used to insulate the winding from the core.

The core of chokes is not made from solid iron or steel, but is made up of thin sheets, called **laminations**. This is done to reduce losses and will be discussed in detail later in this assignment. The shape of an individual sheet or lamination of the core is shown in Figure 1(C). When the choke is manufactured, the coil is pre-wound and then placed on the center leg of the core which is formed by stacking together the required number of the thin E-shaped laminations. Then the same number of the "cross-bar" laminations are stacked together and placed across the three "legs" of the core to form the arrangement shown in Figure 1(B). A thin frame is then placed around the edge of the core to hold it together, and the tips of this frame are bent at right angles to the core and punched with mounting holes to form the completed choke as shown in Figure 1(A). The laminations used in the core assembly are normally made from **silicon steel** or, as it is sometimes called, **transformer steel.**

Remember: Iron-core chokes are used in audio-frequency circuits and in power supply filter circuits.

Transformers

Transformers find many applications in electronics circuits. For example, there are power transformers, RF transformers, AF transformers, impedance matching or output transformers, etc. Regardless of the application, all transformers operate on just one basic principle. This is the principle of **mutual-induction.**

It will be recalled that in the assignment on air-core coils the principle of **self-induction** was explained. It was pointed out that when a moving magnetic field, caused by a changing current in a coil, cut the turns of wire or conductors in that coil, a voltage was induced into the coil. This was called **self-induction**, since the changing magnetic field produced a voltage in the coil which was producing the magnetic field.

In the process of **mutual-induction**, a changing magnetic field in one coil induces an emf (voltage) in **another** coil.

To fully understand this principle, examine Figure 2. This is a very simple form of a transformer. In this figure, the a-c generator, or oscillator, is forcing current through the coil. We know that the current in the coil will produce a magnetic field. Since the coil is connected to an oscillator, the current through the coil will move first in one direction, then in the opposite direction. The magnetic field in and around the coil will build up first in one direction, then in the opposite direction. As the field builds up, it will expand and "sweep across" the wire. A voltage will be **induced** in the wire. As the field collapses, it will sweep back across the wire and a voltage will be induced in the opposite direction.

During the next half cycle, the field will expand and collapse again. Voltage will be induced in the wire during this half cycle also.

If the oscillator output is 10 volts a-c, the voltmeter, V_1, will read 10 volts. The amount of induced voltage in the wire (read by voltmeter V_2) will depend on the amount of magnetic field sweeping across the wire. The important thing to notice is that the changing magnetic field in one circuit (the coil circuit), is producing a voltage in another circuit (the wire). The only connection between these two circuits is the magnetic field.

In a transformer, the circuit into which the energy is fed from an external source is called the **primary circuit,** or **primary** winding. In Figure 2, the coil is the **primary** of the transformer, since energy is fed into it from the oscillator. The conductor, or coil, in which a voltage is **induced** is called the **secondary** winding of a transformer. In Figure 2, the piece of wire is the **secondary** of the transformer.

In the transformer shown in Figure 2, we might possibly read as much as .1 volt with voltmeter V_2.

What could be done to increase the voltage read by voltmeter, V_2? There are four things we can do. Read the next few paragraphs with care. They will give you a good working knowledge of transformer action.

The first thing we might do to increase the reading of V_2 is obvious. We could increase the oscillator voltage. This would increase the current in the **primary** (coil). The primary winding would then produce a stronger magnetic field. This stronger magnetic field would induce a higher voltage in the **secondary** (wire).

We might next try to hold the wire closer to the primary coil. This would permit a larger portion of the magnetic field to sweep across the wire. See Figure 3(A). This would reduce the **flux leakage.** In Figure 2, only a few of the magnetic flux lines set up by the primary winding cut the secondary. These un-used flux lines do not enter into the transformer action. This is called **flux leakage.**

The next thing we might try would be to wind our secondary wire in the form of a coil. If, as in Figure 2, we had .1 volt induced in one secondary wire, we should have .1 volt induced in each turn of the secondary winding. In Figure 3(B), the secondary is in the form of a three turn coil. The voltage V_2 will be approximately three times as large as with the single wire, or .3 volt.

Finally, in order to increase the strength of the magnetic field in and around the secondary coil, we might introduce an iron core. The magnetic iron core would provide a good path for the magnetic field. The iron core should be in the form of a closed loop passing through the center of both the primary and secondary coils. Almost every bit of the magnetic field produced by the primary will be in this good magnetic path right through the center of the secondary. We say, in electronic terms, that we have very good magnetic "linkage" if all the magnetic field links with the secondary. See Figure 3(C). The addition of the magnetic core has done two things. It has greatly increased the amount of magnetic field present, and it has reduced the flux leakage. The voltage read by V_2 in this case, would probably be about 6 volts (assuming five turns on the primary and three turns on the secondary).

The core material used in iron-core transformers is also in the form of thin sheets or laminations usually shaped as illustrated in Figure 1(C). However, the core is assembled in a different fashion than in the case of an iron-core choke. The core is assembled around the pre-wound coil by placing alternate laminations in the opposite direction. To illustrate, the first lamination of the transformer core is placed as shown in Figure 1(C). The second lamination is placed "upside down" to the first lamination; that is, the open ends of the E-shaped piece are placed down. The third lamination is placed as the first, the fourth is placed as the second, etc. In this manner the core is assembled "around" the coil. In most iron-core transformers, the primary winding and the secondary winding, or windings, are wound one on top of the other, and insulated from each other, to form an arrangement similar in appearance to the winding of the choke of Figure 1. However, for simplicity, we will show the primary and secondary windings as separate coils in the following illustrations.

The four points that have been outlined are now repeated. They are important since, if you understand them, you will be able to work intelligently with transformers.

A. An increase in the a-c voltage applied to the primary will result in an increase in the a-c voltage induced in the secondary.

B. Increasing the coupling (placing the secondary in a position where it will be linked by a greater portion of the magnetic field) will increase the voltage induced in the secondary.

C. Increasing the number of turns in the secondary will increase the total voltage induced in the secondary.

D. A magnetic core linking both the primary and secondary coils will make the coupling almost perfect. It will give maximum magnetic linkage and maximum secondary voltage for a given number of turns in the secondary.

Suppose we have the primary of a transformer connected to a battery. Will the voltmeter V_2 register any voltage? Refer to Figure 4. When we first close the switch the needle of the voltmeter will "kick" a little. During the very short length of time required for the magnetic field to build up, a voltage will be induced in the secondary winding. After the primary current and the magnetic field reach a **steady** value, we will have **absolutely no voltage** induced in the secondary. The voltmeter V_2 will read zero. We need an **alternating** primary current producing a **changing** magnetic field in order to operate the transformer.

This illustrates a very important point. Transformers **will not operate** with pure d-c applied to the primary. As a matter of fact, if pure d-c is applied to the primary of most transformers, they will burn out, due to the fact that the only factor to limit the current flow will be the resistance of the wire. This is usually a low value of resistance so the current which will flow is high. The heat produced by the high current will be great ($P = I^2R$) and will cause the copper wire to melt or "burn out".

The Relationship of Primary Voltage to Secondary Voltage

It has been shown that an increase in the number of turns in the secondary will give an increase in the total induced secondary voltage. It can be shown experimentally that in an iron-core transformer (all the magnetic field linking with the secondary), the secondary voltage will depend only on the primary voltage and the ratio of the number of turns in the secondary to the number of turns in the primary. This can be stated in the following formula:

$$E_s = E_p \times \frac{N_s}{N_p}$$

Where: E_s = secondary voltage
E_p = primary voltage
N_s = number of secondary turns
N_p = number of primary turns.

To illustrate the use of this formula, let us find the secondary voltage of each transformer shown in Figure 5. The primary winding is connected to a 110-volt 60-hertz a-c source. The number of turns in each of the windings is shown in Figure 5.

In the transformer shown in Figure 5(A), the primary voltage E_p is 110 volts, the number of primary turns N_p is 5000, and the number of secondary turns N_s is 5000. To find the secondary voltage, we put these known values in the formula:

$$E_s = E_p \times \frac{N_s}{N_p}$$

$$E_s = 110 \times \frac{\cancel{5000}}{\cancel{5000}}$$

$$E_s = 110 \times 1 = 110 \text{ volts.}$$

This shows that, if the primary turns and the secondary turns are equal in number, the secondary voltage will be equal to the primary voltage.

In the transformer shown in Figure 5(B):

$$E_p = 110, \quad N_p = 5000, \quad N_s = 500$$

$$E_s = E_p \times \frac{N_s}{N_p}$$

$$E_s = 110 \times \frac{\overset{1}{\cancel{500}}}{\underset{10}{\cancel{5000}}}$$

$$E_s = 110 \times \frac{1}{10} = 11 \text{ volts.}$$

In the transformer shown in Figure 5(C):

$$E_p = 110, \quad N_p = 500, \quad N_s = 1000$$

$$E_s = E_p \times \frac{N_s}{N_p}$$

$$E_s = 110 \times \frac{\overset{2}{\cancel{1000}}}{\underset{1}{\cancel{500}}} = 220 \text{ volts.}$$

In the transformer shown in Figure 5(d):

$$E_p = 110, \quad N_p = 5000, \quad N_s = 450$$

$$E_s = E_p \times \frac{N_s}{N_p}$$

$$E_s = 110 \times \frac{\overset{9}{\cancel{450}}}{\underset{100}{\cancel{5000}}} = 9.9 \text{ volts.}$$

A transformer, such as the one in Figure 5(C), is called a step-up transformer, since the secondary voltage is a higher value than the primary voltage (or has been stepped-up).

Transformers, such as Figure 5(B) and 5(D), are called step-down transformers, since the secondary voltage is lower than the primary voltage.

Directly below each of the transformers in Figure 5 is the ratio of the number of primary turns to the number of secondary turns. A ratio is merely a fraction. In these examples, it is obtained by placing the number of primary turns **over** the number of secondary turns, and then reducing this fraction to its lowest terms. In the transformer shown in Figure 5(A), this ratio (called the **turns ratio**) is 1 or as a ratio is often written 1 : 1. This is obtained by placing the primary turns (5000) over the secondary turns (5000) and reducing the fraction to its lowest terms.

$$\frac{\overset{1}{\cancel{5000}}}{\underset{1}{\cancel{5000}}} = \frac{1}{1}.$$

Notice that the ratio of primary voltage to secondary voltage is exactly the same, $\frac{1}{1}$. The turns ratio for each of the other transformers is also given. Check each to prove to yourself that the voltage ratio of a transformer is equal to the turns ratio.

Suppose we have a 5 volt a-c supply and we want to "transform" this to 50 volts a-c. We can use a transformer to step-up this 5 volts to 50 volts. We will need ten times as many turns on the secondary as we have on the primary. If the primary winding has 100 turns we will need 100 × 10 or 1000 turns on the secondary winding.

In the last example, we boosted 5 volts a-c to 50 volts a-c. Suppose we want to boost the 5 volts a-c to 110 volts a-c. The secondary voltage will be 110/5 or 22 times the primary voltage. We will need 22 times as many turns on the secondary as on the primary. If there are 100 turns on the primary, there will have to be 100 × 22 or 2200 turns on the secondary.

This transformer will transform 5 volts a-c to 110 volts a-c. Can we operate a 50 watt, 110 volt light bulb from the 110 volt transformer secondary? Yes, provided the copper windings and iron core are of sufficient size to handle 50 watts of power. Remember also that there is only one place this 50 watts of power can come from—**the primary.** All of the energy in the secondary was induced by the changing magnetic field. This field was produced by the primary. Therefore, the secondary power is supplied by the primary through the medium of the magnetic field. In this example, the 5 volt a-c supply must be able to deliver 50 watts of power. It is never possible to get more power from the secondary than is fed into the primary.

What current will there be in the secondary winding and in the 50 watt 110 volt light bulb?

$P = E \times I$. Solving for I, we obtain:

$$\frac{P}{E} = \frac{\cancel{E} \times I}{\cancel{E}}, \quad \frac{P}{E} = I \text{ or}$$

$$I = \frac{P}{E} = \frac{50}{110} = .454 \text{ amperes.}$$

What current will the 5 volt a-c supply have to deliver to feed 50 watts into the primary?

$$I = \frac{P}{E} = \frac{50}{5} = 10 \text{ amperes.}$$

Although we obtained 22 times as much voltage from the secondary, we had to supply 22 times as much current to the primary ($.454 \times 22 = 10$ amperes).

Just remember this: Transformers are marvelous in many respects, but they are not going to manufacture any power. If we step-up the voltage 22 times, we will have only one twenty-second (1/22) as much current in the secondary.

To further demonstrate this principle, study the following problem.

A transformer has 100 turns on the primary and 500 turns on the secondary. The secondary is connected to a load (resistor). The primary current is 10 amperes and the primary voltage is 1 volt a-c. What is the secondary voltage and secondary current?

There are five times as many turns on the secondary as on the primary. The secondary voltage will be 5 times as large as the primary voltage.

$$E_s \text{ (secondary voltage)} = 1 \times \frac{500}{100} = 5 \text{ volts.}$$

We obtained five times as much voltage in the secondary. We will have one fifth as much current in the secondary.

$$I_s \text{ (secondary current)} = 10 \times \frac{1}{5} = 2 \text{ amperes.}$$

How much power is being fed into the primary winding?

$P = E_p \times I_p = 1 \times 10 = 10$ watts.

How much power is being delivered by the secondary winding?

$P = E_s \times I_s = 5 \times 2 = 10$ watts.

To increase the amount of power which a transformer can handle, larger wire must be used for the windings, and a larger core must be used.

These calculations for secondary voltage and current will apply only to iron-core transformers. It is difficult to calculate the ratios of voltages and currents in air-core transformers. In air-core transformers the magnetic linkage (or magnetic coupling) is difficult to determine. The performance of air-core transformers can best be determined experimentally.

It is possible to construct transformers which have one primary winding and several secondary windings. The schematic diagram of such a transformer is shown in Figure 6. In such a transformer, the turns ratio for a desired voltage step-up or step-down between the primary and each secondary is the same as if there were three separate transformers. For example, in Figure 6, the voltage of secondary number 1 will be twice the primary voltage, secondary number 2 will have half as much voltage as the primary voltage, and secondary number 3 will have one tenth as much voltage as the primary. In such a transformer the power which is handled by the primary winding is **the sum** of all of the secondary powers.

In some transformers, one or more of the windings may be center-tapped. The best way to think of center taps is as follows: Figure 7(A) shows a transformer with 1100 turns on the 110-volt a-c primary. There are two 3 volt secondary windings each with 30 turns. If we connect the two secondary windings in series we will have 6 volts available. Suppose we still need 3 volts for some other purpose. We can bring out a lead from the junction or center and use this "center tap" along with either of the other leads to obtain 3 volts. This is shown in Figure 7(B).

Another type of transformer which is sometimes used is the **auto-transformer.** The circuit of an **auto-transformer** is shown in Figure 8. In Figure 8(A) the transformer is connected as a step-up transformer, and in Figure 8(B) the transformer is connected as a step-down transformer. The main difference between auto-transformers and other types is the fact that part of the primary and secondary turns are common to both windings. In the circuit shown in Figure 8(A), the energy is fed into the transformer at the points labeled **primary,** and taken out at the points labeled **secondary.** There are more turns on the secondary than on the primary, so the voltage will be higher. In Figure 8(B), there are more turns on the primary than on the secondary so the transformer will act as a step-down transformer.

Applications of Iron-Core Transformers

There are four main applications of iron-core transformers.

One of these is as the **power transformer** in electronics equipment. Most types of electronics equipment, operating from the 110 volt a-c lines, employ transformers to change the 110 volts to voltages suitable for the operation of transistor or vacuum-tube circuits. Figure 9 shows an iron-core transformer that can be used to obtain 400 volts a-c for operation of the power supply in an electronics unit. There are two secondary windings. The small secondary winding is used to obtain 6 volts a-c for operating the heaters in the vacuum-tubes.

Check to see if the proper ratios of secondary to primary turns are indicated in this diagram in order to obtain the 400 volts and 6 volts from the two secondary windings.

The purpose of this transformer is two-fold. The low voltage secondary winding is used to supply power to heat the "heaters" of the vacuum tubes. The output of the high voltage winding is normally **rectified** or changed into d-c by vacuum tubes or solid-state rectifiers. This d-c voltage is then used to supply the "B" voltage for the other tubes in the equipment. Power transformers are available in almost any desired ratings, as far as output voltages and power handling capacity are concerned, for use in all kinds of electronics equipment.

The second main use for transformers occurs when we wish to feed power from one part of an electronics circuit to another without any direct electrical connection. In a power transformer the main purpose was to change voltages. Notice also, however, that there is no direct electrical connection between the primary and secondary (except in auto-transformers). In some circuits the transformer's main use will be to isolate one circuit from another as far as direct electrical connections are concerned.

Such transformers are called **isolating** transformers and usually have a 1 to 1 turns ratio.

The third application is really another instance of isolating two circuits electrically. In Figure 10(A), the primary of a transformer is fed from a battery and oscillator in series. Figure 10(B) shows a graph of the voltage applied to the primary winding. During the time interval, from A to B on this graph, we see the voltage which would be applied if the oscillator were not in the circuit. During the time interval from B to C, we see what happens when the positive alternation is being produced by the oscillator. The oscillator voltage adds to the battery voltage during this period. The voltage applied to the transformer reaches a maximum value of 150 volts. During the time interval, from C to D, the oscillator voltage opposes the battery voltage, and the voltage applied to the transformer reaches a minimum of 50 volts. This is, of course, a pulsating d-c voltage. If this voltage is applied to the primary of the transformer, a pulsating d-c current will flow. Only the **changing** part of this current will induce a voltage in the secondary winding. This changing amount of current is produced by the pulsating voltage which varies from 100 to 150, back to 100, then to 50 and back to 100 again. This change is just the same as would be produced by the oscillator acting alone, without the battery. Thus, the effect produced in the secondary (the induced secondary voltage) is determined by the oscillator voltage, and is independent of the d-c voltage in the primary circuit. The battery will cause d-c to flow through the primary, but this current will not produce a voltage in the secondary. The transformer separates the a-c from the d-c. The effects of the a-c are felt in the secondary, but the d-c produces no voltage in the secondary.

In the explanation of the operation of a transistor in a preceding assignment, it was stated that a pulsating d-c current flows in the collector circuit. If the pulsating d-c current flows through the primary of a transformer, an a-c voltage will appear across the secondary winding. A circuit showing this is given in Figure 11. A small a-c signal is applied to the base of the transistor. This causes a pulsating d-c current to flow through the primary of the transformer. The transformer secondary is affected by the changing part of the pulsating current only, and an a-c voltage is induced into the secondary winding. The d-c **stays** in the primary winding circuit. The transformer has separated the a-c part of the pulsating signal from the d-c part.

The fourth application is one that involves a knowledge of maximum power transfer. You will often see a small transformer mounted on the back of a loudspeaker. This is called an **output transformer,** or impedance matching transformer. It takes power to operate a loud-speaker. The more power we can obtain at the speaker itself, the more volume we can produce. You will study the "impedance matching" properties of transformers in a later assignment. We will discuss this only briefly at this time.

Suppose you have an oscillator that has an output of 1 volt at 1000 hertz. The oscillator has an internal resistance of say, 100 ohms. You want to hear this 1000 hertz note with a loud-speaker. The oscillator can deliver maximum power to the speaker if the speaker coil has 100 ohms also. Suppose the speaker coil is only 5 ohms. If we connect the speaker directly to the oscillator most of the power in the circuit will be used in the 100 ohms **inside** the oscillator.

We can remedy the situation by using a transformer between the oscillator and loud-speaker. We should select a transformer with a 100 ohm primary and a 5 ohm secondary. The 100 ohm oscillator would then be able to drive maximum power into the 100 ohm primary, and the 5 ohm secondary would be able to drive maximum power into the 5 ohm load speaker. (The "ohms" we spoke of would have to include both resistance and reactance.) Transformers used for "matching impedance" are called **matching** transformers.

So far, we have found that:

Voltage will be induced in the secondary of a transformer only while the magnetic field is changing. Transformers will not operate with direct current.

The amount of voltage induced in the secondary depends on the primary voltage, the ratio of the turns in the two windings, and the amount of magnetic field that is linking the two coils.

In air-core transformers this linkage is poor. At best, only a small portion of the total magnetic field will sweep across the secondary winding. In iron-core transformers this linkage is nearly perfect.

Why should air-core transformers have any place in electronics circuits? The magnetic linkage is poor. We cannot calculate the performance of an air-core transformer with any degree of accuracy. Only very small amounts of power can be handled by air-core transformers.

Iron-core transformers would be used exclusively if it were practical.

Power transformers (operating at 60 hertz) function very satisfactorily. The Impedance Matching Transformers used with loud-speakers operate very satisfactorily. These transformers handle power at audio frequencies (frequencies within the range of the human ear) from perhaps 20 to 20,000 hertz.

These transformers have iron cores. They are able to handle relatively large amounts of power. Most important of all, notice that these iron-core transformers are operating at relatively low-frequencies.

There are several reasons why we will not use iron-core transformers at radio frequencies. These reasons all add up to the same thing—inefficiency.

Transformer Losses

Suppose we have an iron-core transformer and we try to operate it at say 1,000,000 hertz.

To begin with, we will have a hard time trying to produce much current in the primary. The primary (a coil of wire wound around an iron core) will tend to act as a choke coil. It will have a high reactance in ohms at 1 megahertz (1,000,000 hertz, or 1,000,000 cycles per second).

Suppose, that by applying a large RF voltage we obtain a fair amount of current in the primary. The magnetic field in the core will be varying at the rate of 1,000,000 hertz. At these high frequencies, most of the power fed into the primary will never reach the secondary winding. Almost all the power will be lost in the core materials.

These core losses at high frequencies take the form of Hysteresis losses and Eddy current losses.

Hysteresis losses—We are dealing with alternating currents. The magnetic field in the core is built up first in one direction and then in the other. A certain amount of friction must be overcome each time the tiny "atom magnets" are lined up. With a primary current of 1,000,000 hertz, this friction must be overcome 2,000,000 times a second. The opposition offered to being aligned, by the "atomic magnets", produces heat in the core material. This heat is produced by power obtained from the primary, and since it serves no useful purpose, is a loss. This loss, produced by the opposition of the core material to being aligned magnetically, is called **hysteresis loss.**

The hysteresis losses may be reduced by using special alloy steels for core materials. Silicon steels are commonly used as transformer core material, because these materials have relatively low hysteresis losses as they are alternately magnetized and demagnetized. The use of these special steels effectively reduces the hysteresis losses at the power frequencies and at audio frequencies, but at radio frequencies the hysteresis losses would still be excessive.

Eddy Current losses—We know that the changing magnetic field will induce voltages in any conductor which it cuts, or sweeps across. If a complete path is provided by this **secondary** conductor, current will flow through it. The lower the resistance of the secondary conductor, and its circuit, the higher the resulting current will be. The iron core is an electrical conductor. The changing magnetic field induces voltages into the iron core itself, and undesirable currents will flow in the core material. The tiny circulating, or eddy, currents flow at right angles to the magnetic field. See Figure 12. These eddy currents will also cause the core material to overheat, they contribute nothing to the secondary winding, and are therefore losses. The higher the frequency, the greater the eddy current losses become.

Eddy current losses can be reduced by building up the core with a stack of thin sheets or laminations. These sheets are electrically insulated from each other and therefore the path offered to these circulating currents is a high resistance path and the currents will be small. This reduces the losses. Figure 13 shows the construction of a laminated core. This is also illustrated in Figure 1(B). If a laminated core is used at radio frequencies, the eddy current losses will still be excessive.

A relatively recent development permits the use of cores in transformers operating at radio frequencies. Such transformers use what are called **powdered-iron cores.** An exceptionally high grade core material is used to keep hysteresis losses at a minimum. The core material is finely divided and bonded together with a non-conducting cement. Thus, each small particle of core material is separated from the remainder of the core by insulating material. This reduces the eddy current path to an absolute minimum. Powdered-iron-core coils are superior to air-core coils when used at the lower radio frequencies, because the use of the core will give a higher reactance for a given amount of wire, and a higher Q results (Remember $Q = \frac{2\pi f L}{R}$).

Another loss which is present in all transformers is called **copper loss.** This is the loss that reults from current flowing through the resistance of the primary and secondary windings. These windings are made of copper, and will therefore have some resistance. These losses will be found by the formula $P = I^2R$, where R is the resistance of the winding. The **copper losses** can be reduced by using larger conductors for the primary and secondary windings.

Another loss which will be found in transformers has already been mentioned, **flux leakage.** If the magnetic linkage is less than perfect, some of the magnetic field produced by the primary is following a path other than through the secondary winding. This stray or leakage field can induce voltages and eddy currents while sweeping across metal shielding, chassis, etc. These leakage losses are usually negligible except for high frequency air-core transformers.

After seeing all of these transformer losses itemized, you may think that transformers are inefficient devices but such is **not** the case. Most iron-core transformers are about 95% efficient. That is, the power delivered to the load is about 95% of the power delivered to the primary.

Examine Figure 14 carefully to see the important part played by transformers in a radio circuit. This is a block diagram of a vacuum-tube superheterodyne receiver. The symbol near each transformer and choke block indicates whether it is an air-core or iron-core component. The IF transformers operate at a radio frequency of about 456 kHz.

Color Code for Transformer Leads

A standard color code has been adopted for transformer leads. The color of the leads indicates the winding to which they connect. Figure 15 shows the color code for a typical power transformer. By color code, the windings can be identified very easily. For example, the red leads connect to the high voltage secondary winding, and the red and yellow striped lead is the center tap of this winding.

Summary

Let us summarize the material covered in this assignment. Try to retain a clear mental picture of the action which takes place in chokes and transformers.

In choke coils, the reactance, or $X_L = 6.28\ fL$.

Audio frequency chokes and transformers always have iron cores.

Radio frequency chokes and transformers usually have air cores.

Powdered iron cores are sometimes used in radio frequency chokes and transformers.

In iron-core transformers the secondary voltage is determined by the primary voltage and the number of turns in the primary and secondary windings. A transformer does not generate power. The secondary power can never be greater than the primary power. If the secondary voltage is higher than the primary voltage, the secondary current will be lower than the primary current.

The four transformer losses are:

(a) Hysteresis losses—These losses are due to friction within the core as it is magnetized and demagnetized. Specialized transformer steels are available that have relatively low hysteresis losses.

(b) Eddy current losses—These are losses due to circulating currents in the iron or steel core. They can be reduced by building the core of thin laminated sheets of metal, or by making the core of powdered iron for high frequency transformers.

(c) Copper losses—These losses occur in the windings and are due to the current passing through the resistance of the primary and secondary windings.

(d) Flux leakage—This loss is due to some of the flux from the primary failing to cut secondary turns.

Iron-core transformers can handle large amounts of power; air-core transformers can handle only small amounts of power.

Iron-core transformers have an efficiency of approximately 95%.

Transformers will not operate with pure d-c applied. If pulsating d-c is applied to the primary of a transformer, only the a-c component appears across the secondary winding.

Energy is fed into the primary winding of a transformer. Energy is taken out of the secondary winding of a transformer.

"How To Pronounce . . ."

(Note: the accent falls on the part shown in CAPITAL letters.)

hysteresis	(his-turr-EE-siss)	silicon	(SILL-ih-konn)
impedance	(imm-PEED-ance)	superheterodyne	(super-HETT-roe-dine)
isolating	(eye-soe-LATE-ing)		

ASSIGNMENT 17

Test Questions

Use a multiple-choice answer sheet for your answers to this assignment.

The questions on this test are of the multiple-choice type. In each case four answers will be given, one of which is the correct answer. To indicate your choice of the correct answer, **mark out** the letter opposite the question number on the answer sheet which corrresponds to the correct answer. For example, if you feel that answer (A) is correct for Question No. 1, indicate your preference on the answer sheet as follows:

1. (A) (B) (C) (D)

Submit your answers to this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

1. A power transformer in an electronics amplifier unit has ten leads, color coded as follows: Black, black, red, red, yellow, yellow, green, green, red and yellow, and yellow and blue. The transformer probably has:

+TAP +TAP on YELLOW

(A) A primary, a high voltage secondary, and two filament windings.

(B) A primary, two high voltage secondaries, and two filament windings.

(C) A primary, a high voltage secondary, and three filament windings.

(D) A primary, and three center tapped secondary windings.

2. To find the turns ratio which a transformer should have to change 110 volts to 10 volts, we use the formula:

(A) $E_p \times E_s = N_p \times N_s$

(B) $\frac{E_p}{E_s} = N_p \times N_s$

(C) $\frac{E_p}{E_s} = \frac{N_s}{N_p}$

(D) $\frac{E_p}{E_s} = \frac{N_p}{N_s}$

3. The transformer of Question 2 is normally called:

(A) A step-up transformer.

(B) A step-down transformer.

(C) A current transformer.

(D) A power transformer.

4. Suppose we have an air-core transformer which consists of both primary and secondary windings wound on the same round cardboard form.

To increase the secondary voltage, we would:

(A) Make the secondary of larger size wire.
(B) Reduce the number of turns in the secondary.
[✓ (C)] Move the secondary closer to the primary.
(D) Move the secondary farther from the primary.

5. Cores of iron-core transformers are normally made from thin sheets of iron because:

[✓ (A)] This construction reduces eddy currents in the core.
(B) This construction increases eddy currents in the core.
(C) This construction reduces the weight of the transformer.
(D) This construction reduces the cost of the transformer.

6. The type of core used for an R-F choke is:

(A) A solid iron core.
(B) A laminated iron core.
[✓ (C)] An air core.
(D) A steel core.

7. If 110 volts is applied to the 1000 turns primary of an iron-core transformer, the voltage developed across a 3000 turn secondary will be:

(A) 336 volts
(B) 36.6 volts
[✓ (C)] 330 volts
(D) 33 volts

8. If 30 milliamperes of current flows in the secondary of the transformer of Question 7, the primary current will be:

(A) 10 mA.
(B) .1 amp.
[✓ (C)] 90 mA.
(D) .9 amp.

9. If pulsating d-c is applied to the primary of a transformer, what will we have in the secondary? Select the correct answer.

(A) No voltage.
(B) Pulsating d-c.
(C) Pure d-c voltage.
[✓ (D)] An a-c voltage.

10. A transformer is to be operated from 110-V a-c. It is desired to obtain 440 volts from it. If the primary winding has 2000 turns, the secondary winding should have:

[✓ (A)] 8,000 turns.
(B) 5,000 turns.
(C) 800 turns.
(D) 500 turns.

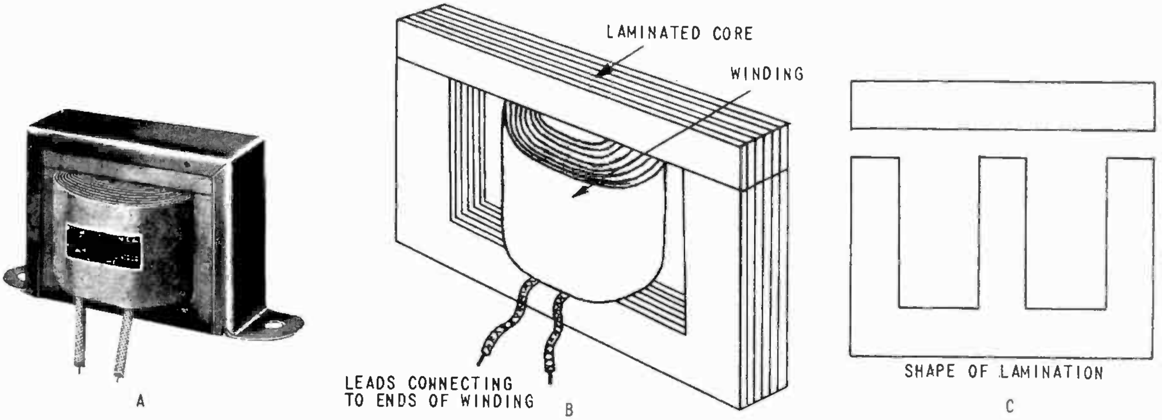


FIGURE 1

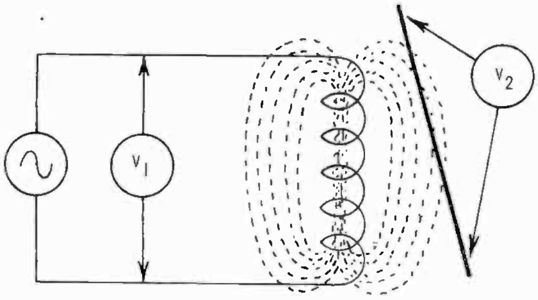
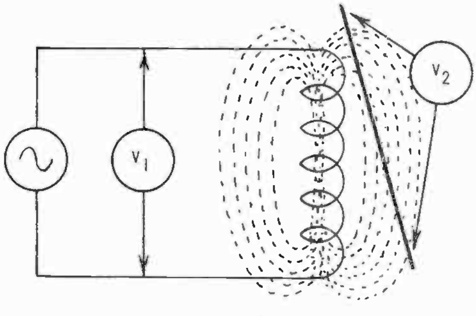
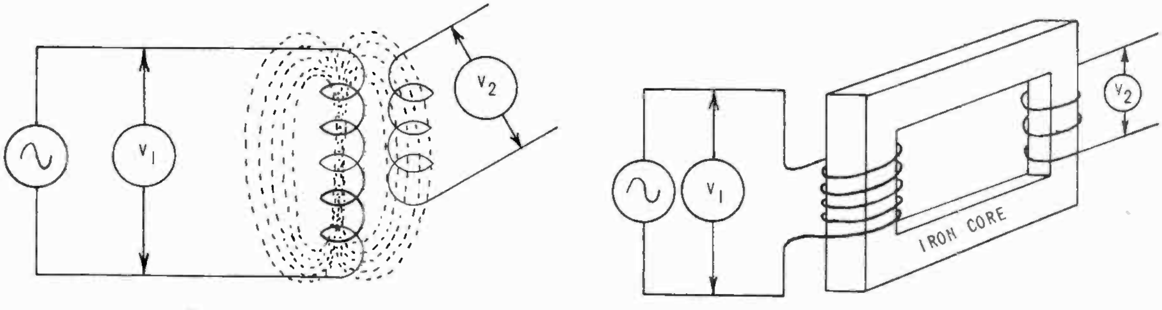


FIGURE 2



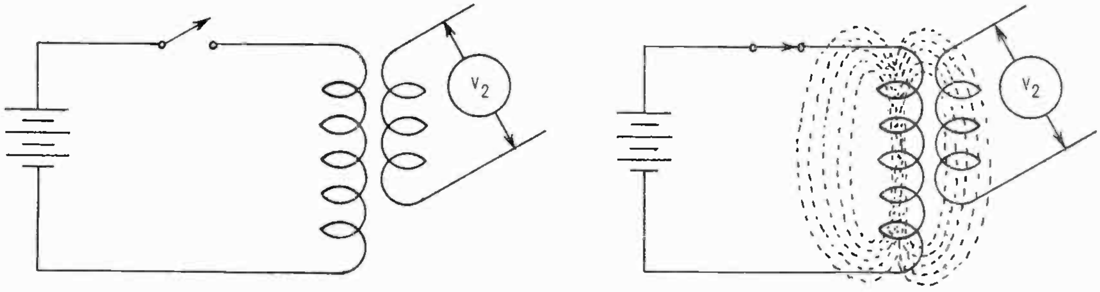
A



B

FIGURE 3

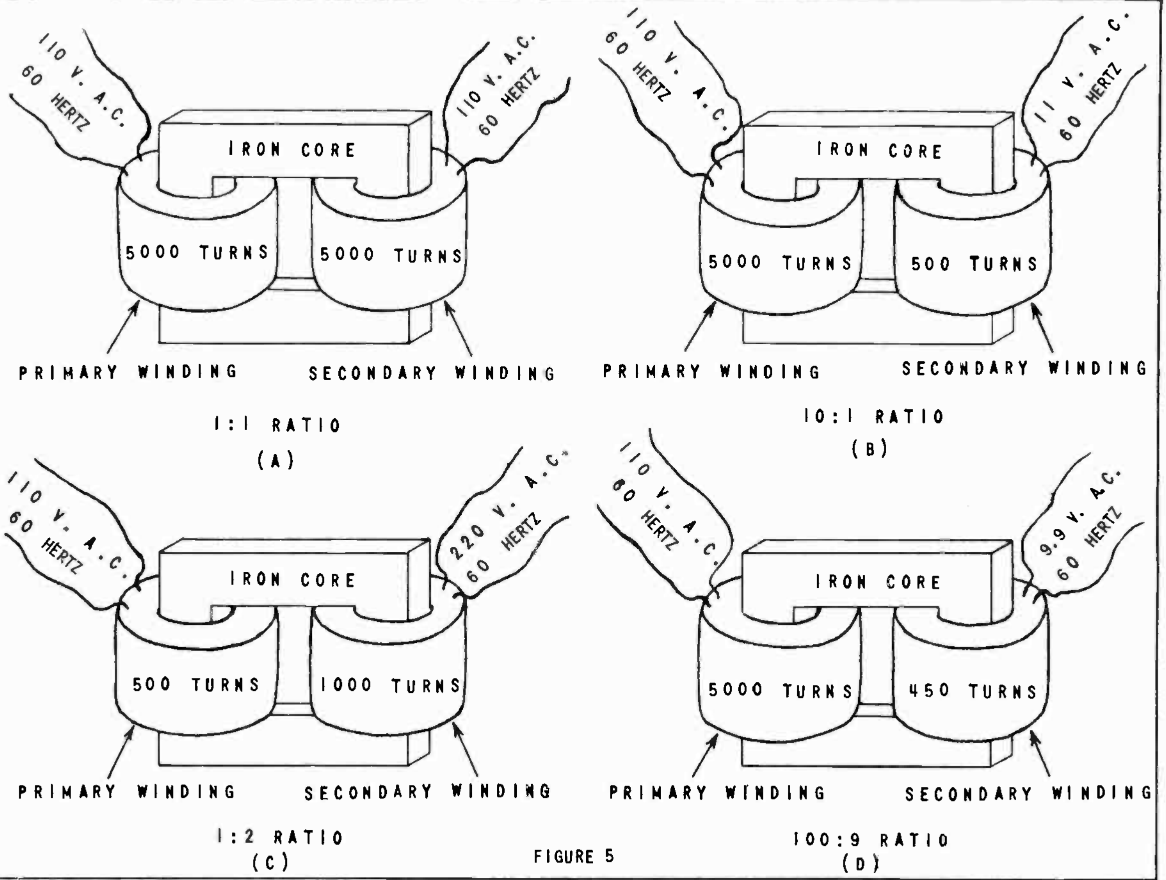
C



A

FIGURE 4

B



1:1 RATIO
(A)

10:1 RATIO
(B)

1:2 RATIO
(C)

100:9 RATIO
(D)

FIGURE 5

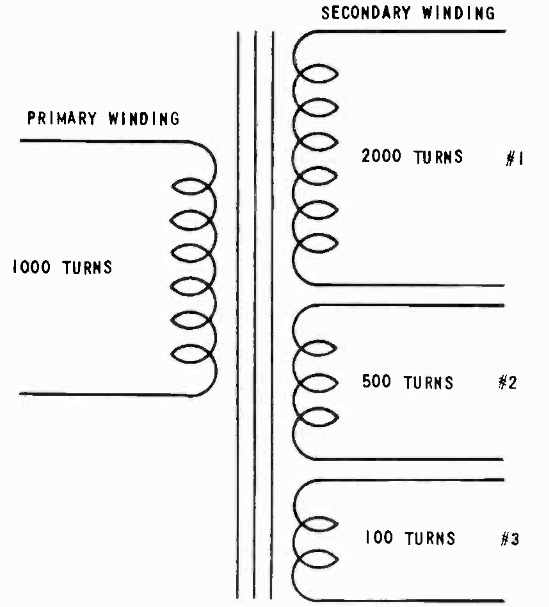
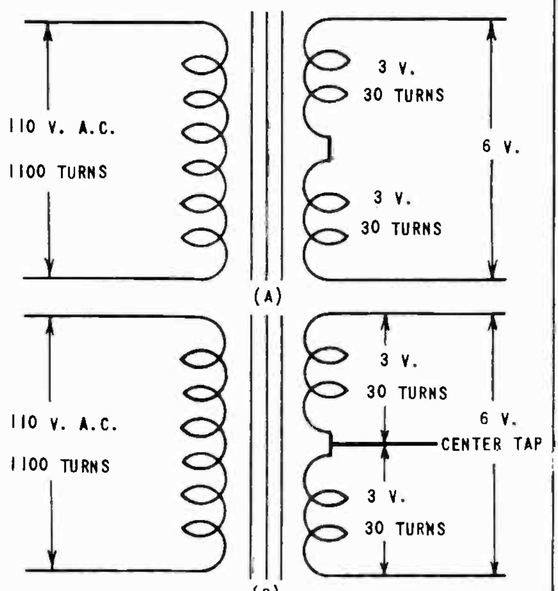


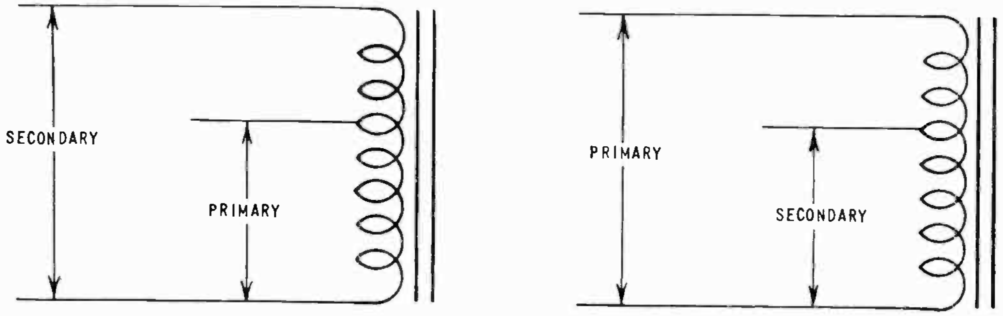
FIGURE 6



(A)

(B)

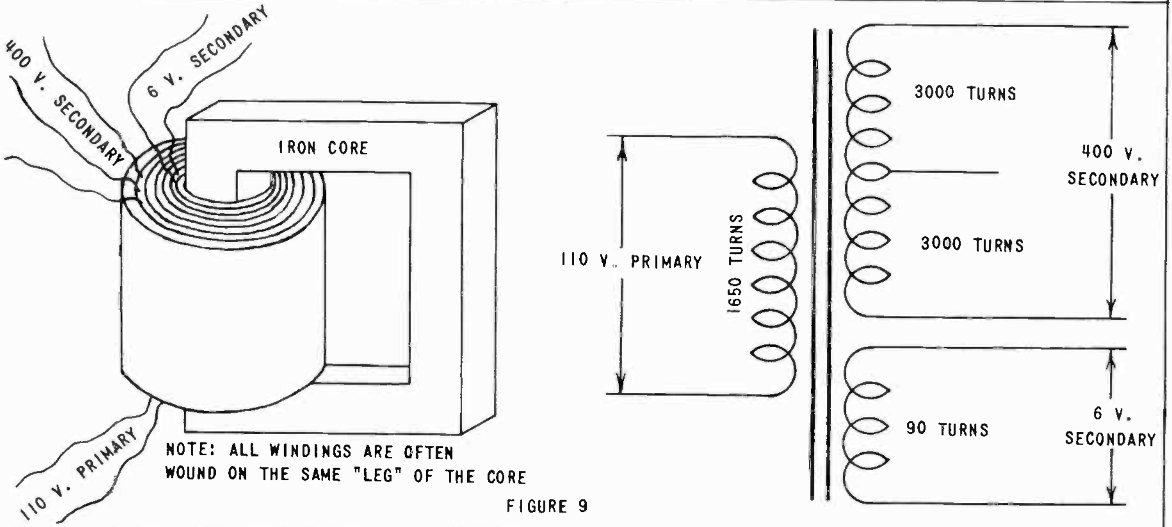
FIGURE 7



(A)

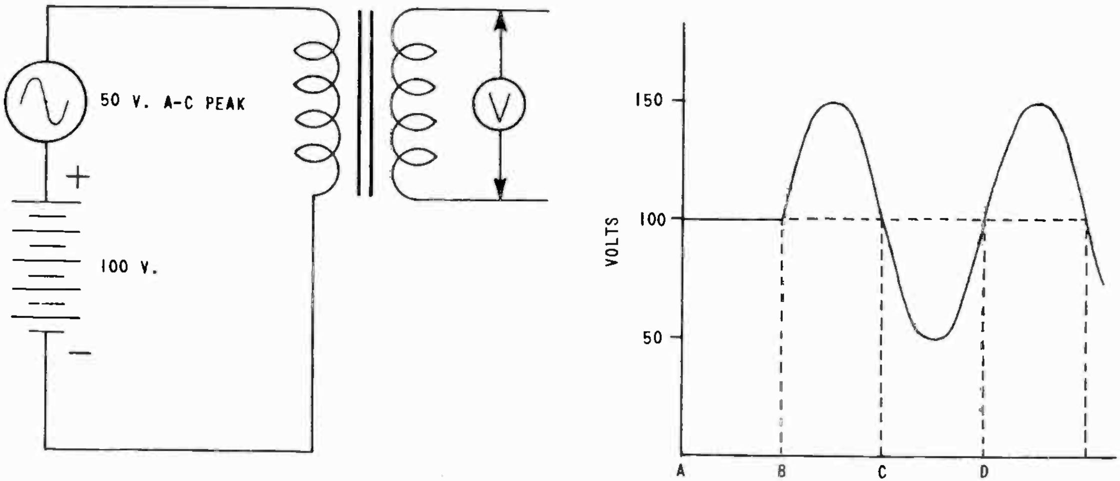
(B)

FIGURE 8



NOTE: ALL WINDINGS ARE OFTEN WOUND ON THE SAME "LEG" OF THE CORE

FIGURE 9



(A)

(B)

FIGURE 10

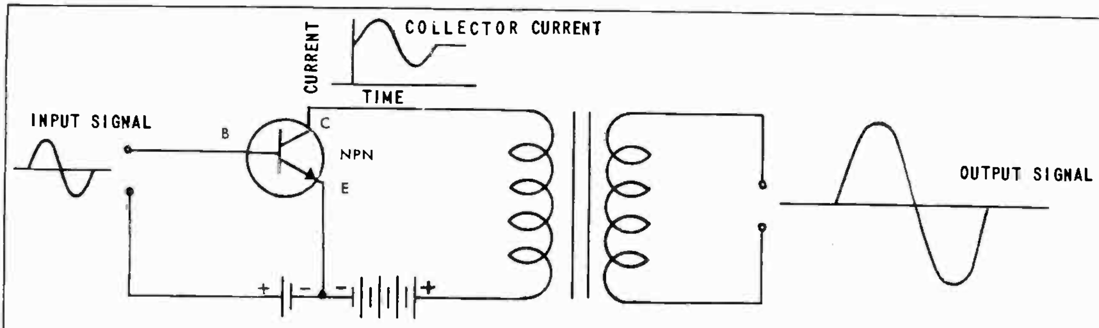


FIGURE 11

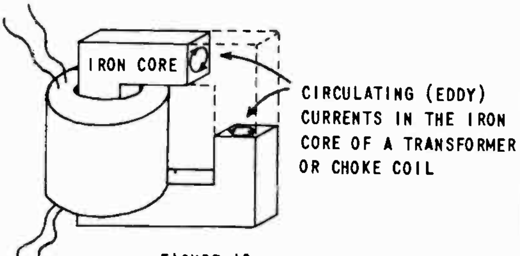
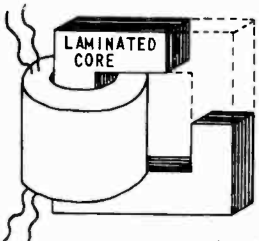


FIGURE 12



EDDY-CURRENTS ARE RELATIVELY SMALL IN THIS LAMINATED CORE. THE PATHS FOR EDDY CURRENTS HAVE BEEN BROKEN UP BY THE INSULATION BETWEEN THE SHEETS OF STEEL.

FIGURE 13

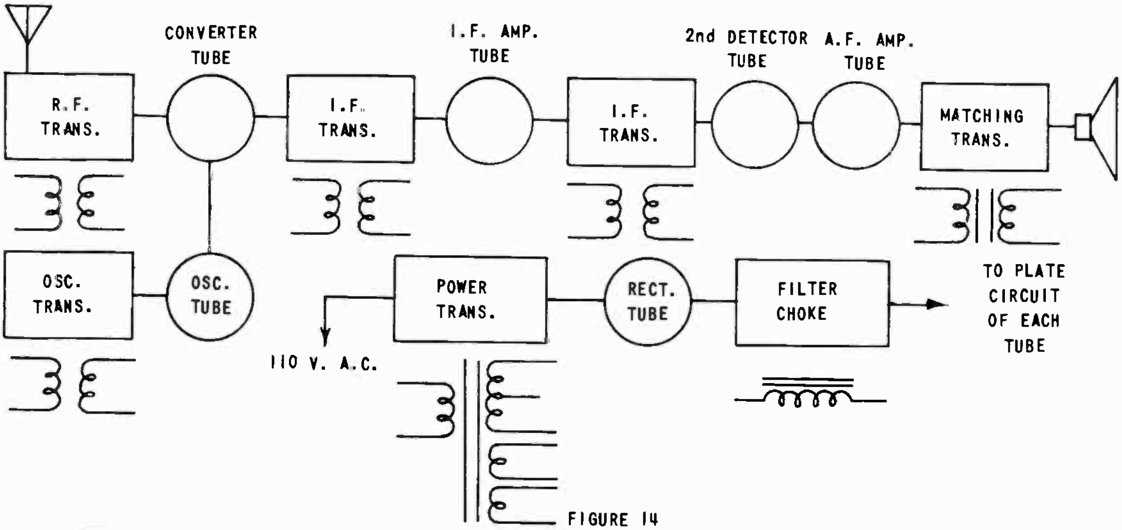


FIGURE 14

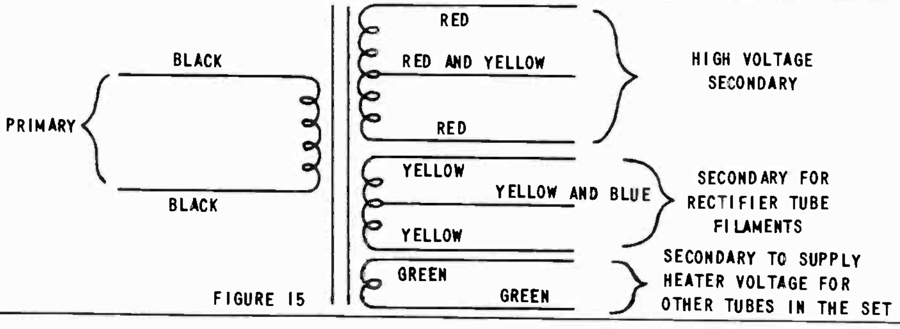


FIGURE 15