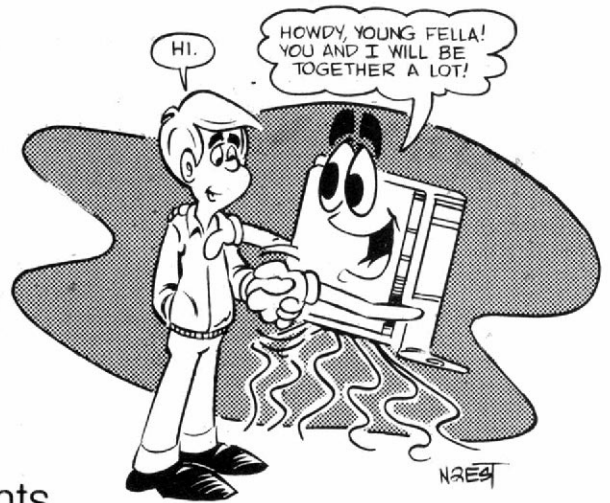


• *First Steps In Radio*

An Introduction to Coils and Transformers



Part 5: This time, we'll take a look at two useful and common components.

Coils are simply turns of wire wrapped around a form, while transformers change (transform) a voltage. What could be simpler?

By Doug DeMaw,* W1FB

Can we get by without coils and transformers in our Amateur Radio pastime? If we worked only with logic circuits and audio amplifiers, the answer might be "yes." But receivers, transmitters, antenna systems and most power supplies require some type of transformer and/or coil. Let's look at how coils and transformers fit into the overall scheme of things.

Meet the Coil

A fancier name for a coil is *inductor*. Each coil, depending on its diameter and the number of conductor turns it uses, has a property known as inductance. Inductance is defined as the "property of an electric circuit by virtue of which a varying current induces an electromotive force in that circuit or in a neighboring circuit."

The basic unit of inductance is the henry, abbreviated H. Our radio math can be carried out much more conveniently if we work with small fractions of the henry, such as the millihenry (mH) or microhenry (μ H). A mH is 1/1000 of a henry, or 10^{-3} henry. A μ H is 10^{-6} henry and a nanohenry (nH) is 10^{-9} henry. Inductance values of 1 H or greater are common only in audio and power-supply circuits. It is important to familiarize yourself with these various expressions of the henry, since you will encounter them often.

Types of Coils

Most of the large coils are wound on in-

ulating cylindrical forms. Some are self-supporting, or "air wound." Generally, the conductor is large-diameter copper wire, but some very large coils are fashioned from copper tubing. Large conductors are needed to create a self-supporting coil.

Other large coils are semi air wound; that is, they have high-grade insulating material in the form of ribs that are spaced 90 degrees apart, parallel to the axis of the coil. The coil turns are essentially air wound between the four ribs (see Fig. 1). Two

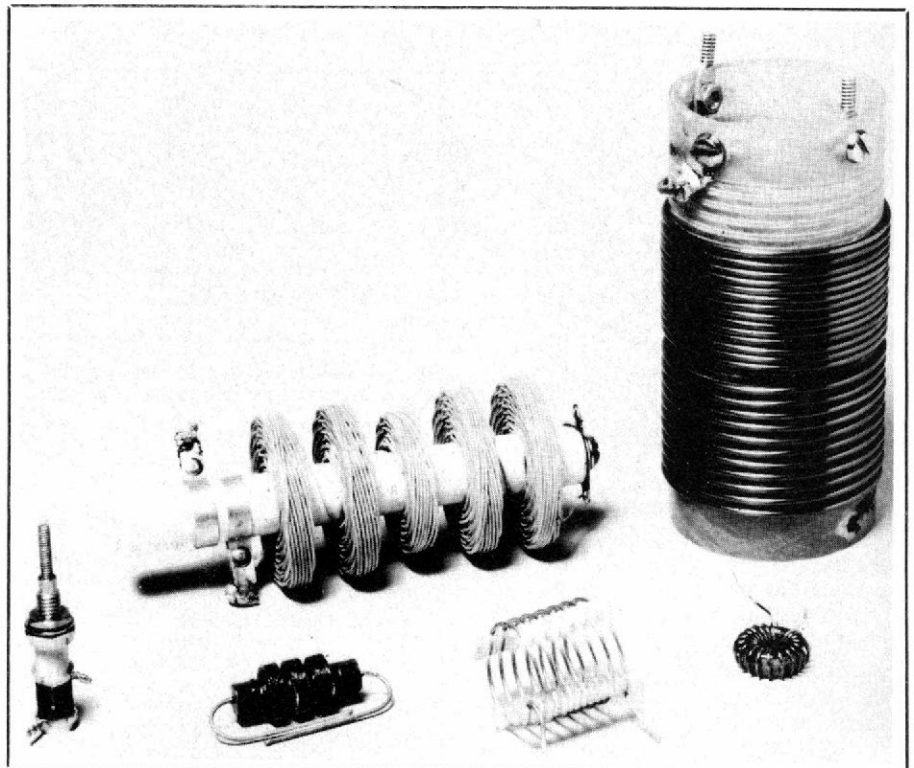


Fig. 1 — A variety of coils. Clockwise, from the left, are: a slug-tuned coil with the adjustment screw visible at its top, a high-power RF choke for transmitters, a homemade coil wound on a cylindrical insulating form, a small toroidal coil, an air-wound Miniductor coil and a small RF choke.

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firms make coils of this type (Barker & Williamson Miniductors® and Poly Coils Co.).

Most of the smaller coils we will use are wound on some type of insulating form, and the wire gauge is small — usually no. 20 to, say, no. 40 gauge. Small coils are suitable in low-power circuits, but large air-wound inductors are the rule when working with high power. Today's miniature coils are wound on high-quality plastic, ceramic or phenolic forms. The coils may have only a single layer (solenoidal) of wire, or many layers may be stacked atop one another to obtain high values of inductance. The wire used in these little coils must be insulated to prevent the turns from shorting to the adjacent ones. Most large air-wound coils use bare wire for the conductors.

Another common style of inductor is the toroid. The coil is wound on a toroidal core, which is doughnut-shaped. Fig. 1 shows such a coil. The toroidal core may be made from ferrite or powdered-iron material. The exact nature of the particular core (there are many types) will determine the final inductance value for a given number of turns. This magnetic core material will always yield a higher-inductance coil than we would obtain when using an equal number of turns on a standard insulating form, or if our coil happened to be an air-wound type.

Similarly, many small coils contain a movable iron or ferrite core (slug). The slug provides a range of inductance for a specified number of turns of wire. These slug-tuned inductors are very convenient when we need to adjust the inductance for a critical value in our circuits. You will often hear an amateur say that he or she "tweaked" a circuit for correct performance. Generally, this means that the ham adjusted the slug in a coil, or perhaps adjusted a trimmer capacitor.

Some adjustable coils contain brass slugs. These are used chiefly at very high frequencies (VHF). The brass core has the opposite effect of powdered iron or ferrite: it *decreases* the inductance of a coil.

We should be aware that there is also a style of coil contained within an enclosure made from ferrite material. The coil is wound on an insulating form or bobbin, and the halves of the core material are bolted together (or cemented) over the bobbin. These units are called *cup cores* or *pot cores* (see Fig. 2). The core halves increase the coil inductance, just as an iron or ferrite slug does in a slug-tuned coil. The advantage of the pot-core inductor (or transformer) is that the outer shell provides a shield, just as would be true if a plain coil was mounted within a metal enclosure. The shielding is helpful when we want to isolate our coil from adjacent circuit elements.

No matter what form a single inductor has, it is a coil. You will hear about radio-frequency (RF) chokes. They are simply

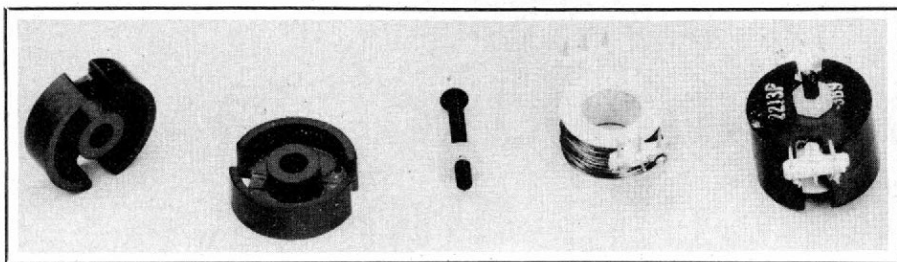


Fig. 2 — A pot-core or cup-core assembly. To the left is a break-down view of the core halves and the insulating bobbin that contains the coil winding. The unit at the right is a completed pot-core coil with the core halves bolted together.

coils used for a specific purpose. You may also hear of coils being called *reactors*. In essence, these terms indicate that we're using the "same players in different games."

Some Common Coil Applications

First, let's look at the coil symbols we are going to find in schematic diagrams. Memorize these, for you will be using them many times. The common designations are given in Fig. 3.

Thus far we've talked a lot about coils, but haven't shown examples of their use. Let's contrive an imaginary circuit for the purpose of illustration. Fig. 4 shows a suitable example in schematic form. Here we have a two-stage transistorized code transmitter. Q1 is the oscillator, and it creates our signal when the telegraph key is closed at J1. Y1 is the quartz crystal that

determines our transmitter frequency. In the collector circuit of Q1, we find an RF choke (a coil) labeled RFC1. All coils are for use in alternating-current (ac) circuits: Remember that radio-frequency (RF) energy is also a form of ac. There is no such thing as a direct-current (dc) transformer. So, RFC1 is used in Fig. 4 to permit the flow of dc to the collector of Q1 while preventing, or choking, the flow of RF energy back into the +12-V voltage line. The RF choke has a value of 1 mH.

If we look to the right in Fig. 4, we will note another coil, L1. It is used to tune the output of the crystal-oscillator stage to the frequency of the crystal — 3.7 MHz. C1 is used with L1 to achieve this requirement. When the combination of C1 and L1 is tuned to 3.7 MHz, we have what is known as a *resonant* circuit, or we might say the circuit is tuned to *resonance*. We can see

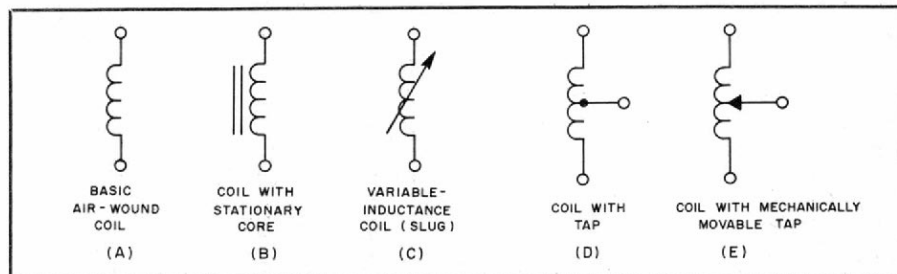


Fig. 3 — Various common symbols for coils. The example at E is for a coil with manual taps such as terminals and clip leads, or a coil with a movable contact, such as a roller inductor has.

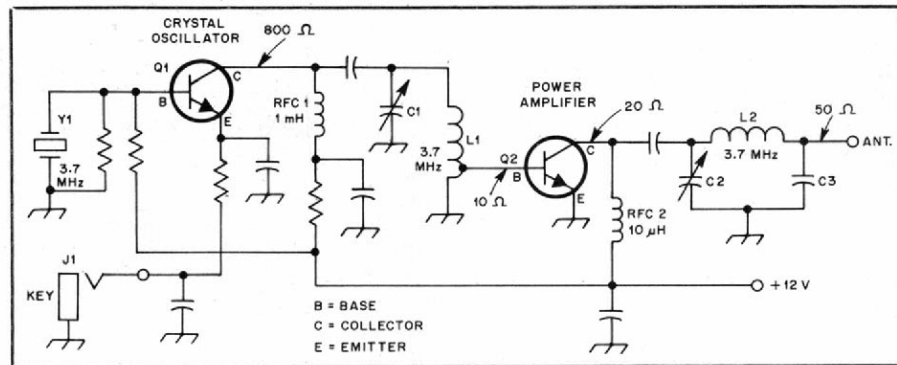


Fig. 4 — Circuit example of a transmitter that uses four styles of coil. See text for details.

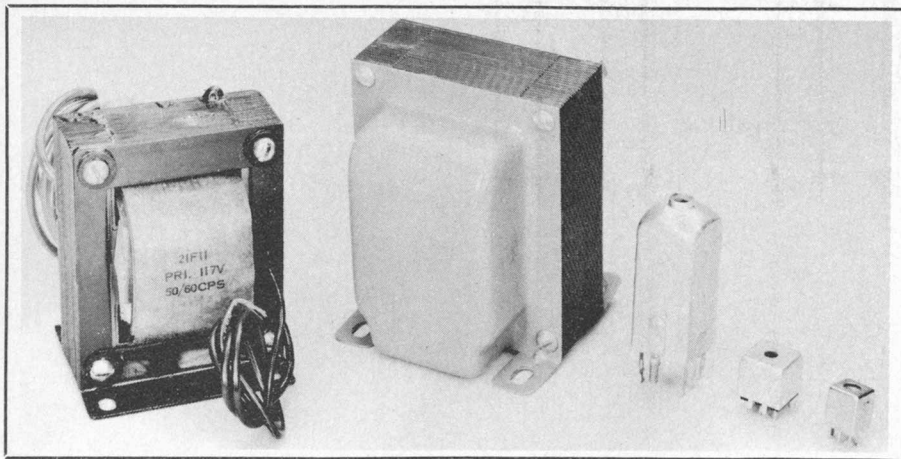


Fig. 5 — Various transformers. The one at the left is called an “open frame” or unshielded type. Next is a shielded power transformer, which is enclosed in a metal shell or case. To the right of this transformer are three styles of shielded RF transformers for use in transmitters or receivers.

that L1 serves a different purpose than does RFC1, but both are coils. L1 must have a specific value of inductance, and C1 must be set for a particular capacitance value in order to tune the circuit to 3.7 MHz. Not just any coil and capacitor combination can provide the desired resonance.

Moving to the right of our diagram once more, observe the placement of RFC2. It functions in a like manner to RFC1 — keeping the RF energy where we want it to be while permitting dc to reach the collector of Q2. In this example, we have an RF choke in the microhenry (μH) range. The reason for RFC2 having much less inductance than RFC1 is not important now. Later in our beginner’s course we will learn more about such matters. You will recall that $10\ \mu\text{H}$ is 1/100th of a millihenry (mH).

At the far right in Fig. 4 we have L2. It is a coil also, but in this application it serves two purposes: It is tuned to resonance by means of C2 while acting as an impedance-matching network. Our circuit example shows that the collector of Q2 looks like 20 ohms to the circuit that follows it. But, the antenna presents a 50-ohm impedance. If we are to have maximum power transfer from Q2 to the antenna, we must match the impedances of the two devices. By selecting the proper values for C2, C3 and L2 we can reach this goal.

So, we have seen three important uses for coils in Fig. 4. I should mention also that the tap on L1 (near ground) is selected to provide another impedance match. This time, we are matching the 800-ohm collector of Q1 to the 10-ohm base of Q2. The coil, L1, actually functions as a transformer under such a condition. The impedances presented by the various elements of a transistor are determined for the most part by the operating voltage and current common to the transistor. The values listed in Fig. 4 are by no means specific.

Enter the World of Transformers

From a physical point of view, a

transformer is simply two or more coils wound on a magnetic core. The word “transformer” means the component can be used to transform one ac voltage to another (higher or lower than the source voltage). It also is used to transform one impedance to another, or to match unlike impedances.

A specific definition of a transformer is “a device consisting of a winding with tap or taps, or two or more coupled windings, with or without a magnetic core, for introducing mutual coupling between electric circuits.” Transformers that have no magnetic core material are used at radio frequencies, but many RF transformers do contain core material. Conversely, coreless transformers are not suitable for use at audio frequencies and lower. Fig. 5 shows a variety of transformers as assembled units. The larger the size, the greater the power-handling ability of the device.

Transformer Applications

I’m sure you are aware of the large transformers found on utility-company poles throughout your area. These “pole pigs,” as some amateurs call them, are used to reduce the potential on the power line before it is routed to the consumer. The power lines that crisscross the country carry thousands of volts. It would be unsafe and impractical to route so high a potential into our homes. Therefore, the existing power-line voltage is dropped to 234 V for entry into our homes.

You will also find power transformers in your TV set, hi-fi gear and ham radio equipment. These are used in the equipment power supplies to change the 117-V ac-line level to some higher or lower voltage. The voltage chosen depends on the requirements of your equipment. After the voltage is lowered or raised by the transformer, it is converted to dc voltage by means of *rectifiers* (usually semiconductor diodes). Then, the not-so-pure dc voltage is filtered to remove any ac

energy that may still be present after rectification.

Various types of transformers are shown schematically in Fig. 6. Illustration A shows the basic arrangement for a transformer that has two windings — a primary and a secondary, as we call them. The two parallel lines between the windings signify that a magnetic core exists. It might be made of iron, powdered iron or ferrite material, depending on the application. Voltage is specified in Fig. 6 as E, and it can be of any frequency in the ac range. The proper core material must be used for the frequency of operation if the transformer is to function correctly, however.

Next, let’s consider the transformer of Fig. 6B. It is similar to the one shown at A, except that it steps down the voltage we might apply to the primary winding. The ratio of the turns of the windings determines what the transformer output voltage will be. The smaller the number of secondary turns, the lower the output voltage.

Fig. 6C shows a transformer with a number of taps on the secondary winding. Under this arrangement, we may have a variety of secondary voltages available. The location of the tap, respective to the number of turns for both windings, will determine the output voltage. Fig. 6E shows a unit that can achieve the same results, except that separate windings are used to obtain the different output voltages.

At Fig. 6D we have a tuned transformer. This is a common type that we will encounter in working with RF circuits. Because the transformer primary winding and capacitor C form a resonant circuit at a desired frequency, we are actually dealing with what is called a *narrow-band transformer*. Untuned transformers respond to a broad range of frequencies, so they are known as *broadband transformers*. The core material in the transformer of Fig. 6D is adjustable within the coil winding. This slug enables us to tune the transformer precisely to the operating frequency. For RF work, the core will be made of powdered iron or ferrite.

Finally, we see an audio transformer at Fig. 6F. It is similar to the transformers shown at A and B, except that we have a center tap in the primary winding. This allows us to provide what is known as “push-pull” operation for the two output tubes or transistors in the audio amplifier. In other words, we will achieve a desired balanced condition for the amplifier devices.

Audio transformers are used also to ensure an impedance match between the amplifier output and the load, which in our example is an 8-ohm speaker. The impedance transformation is related to the turns ratio of the windings. It is the square of the turns ratio. Hence, a turns ratio of 3:1 will yield an impedance ratio of 9:1. Conversely, a 12:1 impedance ratio will be

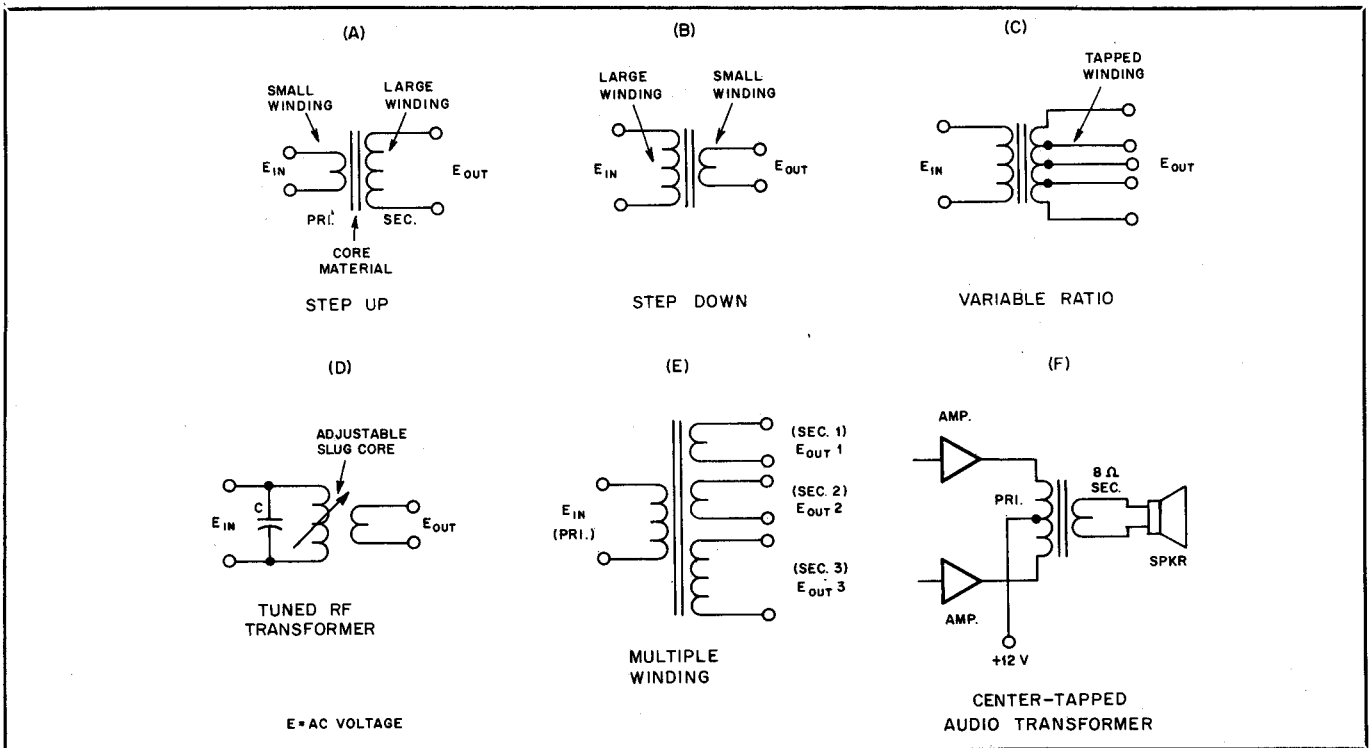


Fig. 6 — Schematic representations of a number of common transformers. These are discussed in the text.

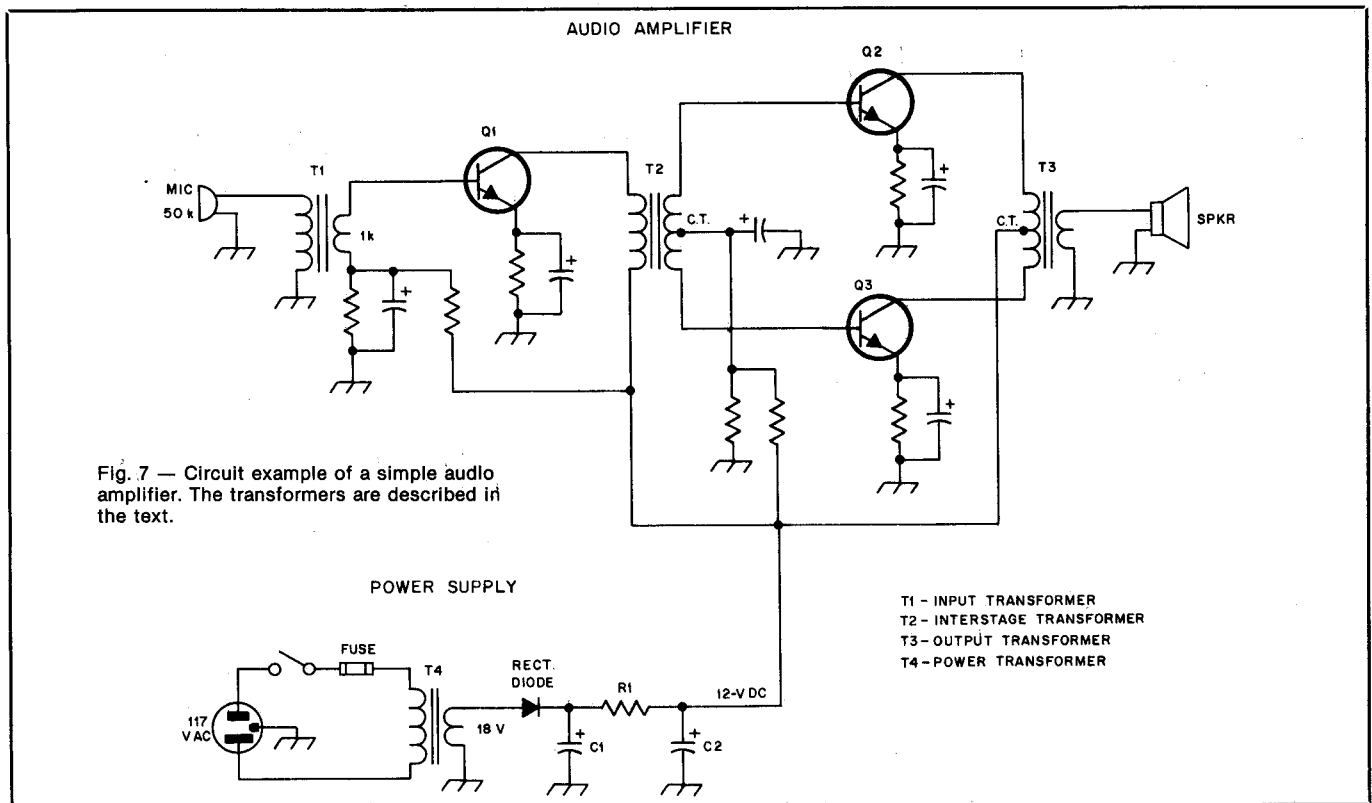


Fig. 7 — Circuit example of a simple audio amplifier. The transformers are described in the text.

had when the turns ratio is 3.46:1. The transformer voltage ratio, however, is the same as the turns ratio. Memorize these facts for later use.

Fig. 7 shows a hypothetical audio-

amplifier circuit in which some transformers are used. You will note that we have a power supply in our circuit. It also uses a transformer, T4. It steps the voltage down from 117 to a more

manageable 18. The diode rectifier converts the ac voltage to dc voltage. The remaining unwanted ac energy is filtered out of the +12-V line by means of C1, C2 and R1. T4 also isolates us from the 117-V wall

outlet, helping to prevent shock hazards.

Transformer T1 is used to match the high impedance of our microphone to the low impedance of the Q1 transistor input. So, we can think of T1 as a matching transformer, or an input matching transformer. T2, on the other hand, is an interstage transformer with a center-tapped secondary winding. The split winding enables us to supply audio energy in push-pull (balanced) to the push-pull output transistors. It can be used also to match the output impedance of Q1 to the input impedance of Q2 and Q3 if the proper turns ratio is chosen.

The output transformer, T3, functions as does the example of Fig. 6F, which we have already discussed. We have not assigned parts values to any of the circuit components, since this is purely an imaginary circuit. In reality, most modern audio amplifiers that use transistors do not employ audio transformers, but they were standard fare in the vacuum-tube days and during the early days of transistors.

Coil and Transformer Power Capability

The greater the power a transformer must accommodate (watts = E multiplied by I, where E is voltage and I is current), the larger the wire size and the greater the core area. The core material plays an important role in the power rating too, as some materials are more efficient than others. The large wire is needed to reduce the resistance (and heating) of the windings. Also, the greater the winding resistance, the higher the transformer losses. An ideal transformer would be cool to the touch after many hours of operation, but this is seldom the case. Most transformers in power supplies are warm or quite warm to the touch after they have been on for a period of time. This heat causes wasted power and reduced efficiency.

Glossary

henry — basic unit of inductance. Abbreviations are H: henry; mH: millihenry; μ H: microhenry; nH: nanohenry.

inductance — a property of an electric circuit by which voltage is induced in it by varying current in the circuit itself or a neighboring circuit.

inductor — a coil or transformer winding, with or without a magnetic core, for introducing inductance into an electric circuit.

magnetic core — one of various materials, such as iron, brass, powdered iron or ferrite, contained within a coil or transformer winding to increase the inductance over that which would exist with no core material. It concentrates an induced magnetic field in a transformer or coil.

potential — the relative voltage or voltage level in an electric circuit.

reactor — a device used for introducing reactance in a circuit. An inductive reactor, or inductance. Coils and transformer windings exhibit reactance, hence can

be referred to as reactors.

rectifier — a device used to convert ac to dc. Semiconductor or tube types of diodes are used for this purpose.

resonance — a point at which a coil and capacitor combination are set for the same or zero reactance at a chosen frequency. A condition under which the coil and capacitor are adjusted so as to be tuned to a specific, chosen frequency. The circuit is then said to be "resonant."

shielding — the use of metal or other conductive material to prevent magnetic or capacitive coupling between circuit elements. A shield is an electrical barrier for ac energy.

signal — ac or dc current varied according to the information it carries.

quartz crystal — a mineral that resonates at a precise frequency according to how it is cut.

toroid — doughnut-shaped device, such as a toroidal core for coils and transformers.

Coils that must handle RF power also can become warm. To reduce resistive losses, it is wise to use large-diameter wire for such coils. High-quality insulation should always be used in coils and transformers to prevent arcing between the windings, and to minimize losses.

Let's Summarize

What have we learned? First, that coils can take many shapes. They can be built for fixed values of inductance, or they can be made variable by using a movable slug inside them. They are used in all manner of radio circuits and at many power levels. Coils are also known as inductors, and they may be wound on magnetic cores or can be built as "air-wound" units with no core.

Transformers are used from the power-

line frequencies (50 or 60 Hz), through audio frequencies, and into the high RF range. They can be narrow band or broad-band, and they may also have cores or no cores. They are used not only to step up or step down a specific voltage level, but may serve as impedance-matching devices between components of unlike characteristics. The impedance ratio of transformers is the square of the voltage or turns ratio and vice versa.

Coils and transformers are among the common radio parts we will be working with during our amateur careers. Detailed information about them can be found in the *Radio Amateur's Handbook* and other ARRL books.

Next, we'll take a look at still another electronics component. See you then. 