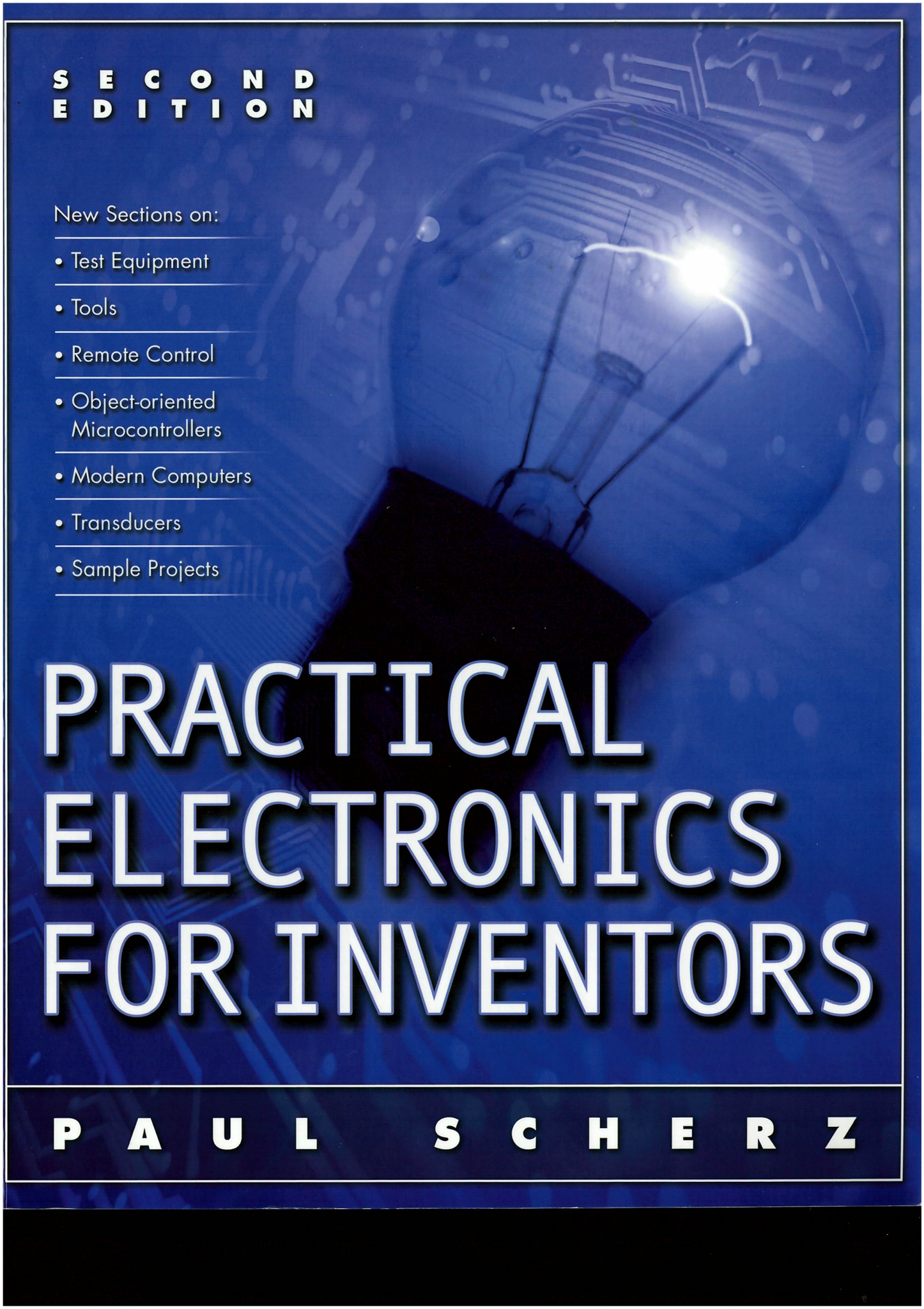
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PRACTICAL ELECTRONICS FOR INVENTORS

PAUL SCHERZ



Practical Electronics for Inventors

Second Edition

Paul Scherz

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1234567890 QPD QPD 019876

ISBN-13: 978-0-07-145281-6
ISBN-10: 0-07-145281-8

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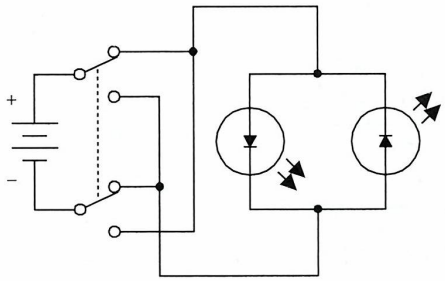
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Current-Flow Reversal



A DPDT switch, shown here, can be used to reverse the direction of current flow. When the switch is thrown up, current will flow throw the left light-emitting diode (LED). When the switch is thrown down, current will flow throw the right LED. (LEDs only allow current to flow in one direction.)

FIGURE 3.40

Multiple Selection Control of a Voltage-Sensitive Device via a Two-Wire Line

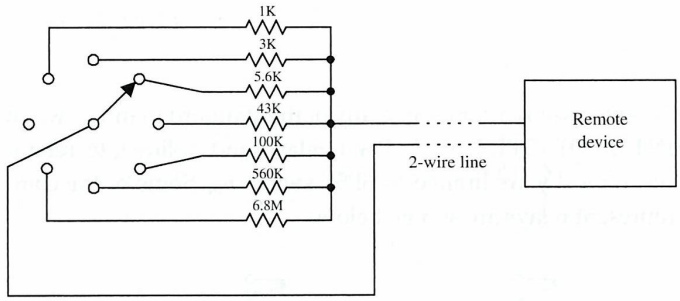


FIGURE 3.41

Say you want to control a remote device by means of a two-wire line. Let's also assume that the remote device has seven different operational settings. One way of controlling the device would be to design the device in such a way that if an individual resistor within the device circuit were to be altered, a new function would be enacted. The resistor may be part of a voltage divider, may be attached in some way to a series of window comparators (see op amps), or may have an analog-to-digital converter interface. After figuring out what valued resistor enacts each new function, choose the appropriate valued resistors and place them together with a rotary switch. Controlling the remote device becomes a simple matter of turning the rotary switch to select the appropriate resistor.

3.4 Relays

Relays are electrically actuated switches. The three basic kinds of relays include mechanical relays, reed relays, and solid-state relays. For a typical mechanical relay, a current sent through a coil magnet acts to pull a flexible, spring-loaded conductive plate from one switch contact to another. Reed relays consist of a pair of reeds (thin, flexible metal strips) that collapse whenever a current is sent through an encapsulating wire coil. A solid-state relay is a device that can be made to switch states by applying external voltages across *n*-type and *p*-type semiconductive junctions (see Chap. 4). In general, mechanical relays are designed for high currents (typically 2 to 15 A) and relatively slow switching (typically 10 to 100 ms). Reed relays are designed for moderate currents (typically 500 mA to 1 A) and moderately fast switching (0.2 to 2 ms). Solid-state relays, on the other hand, come with a wide range of current ratings (a few microamps for low-powered packages up to 100 A for high-power packages) and have extremely fast switching speeds (typically 1 to 100 ns). Some limitations of both reed relays and solid-state relays include limited switching arrangements (type of switch section) and a tendency to become damaged by surges in power.

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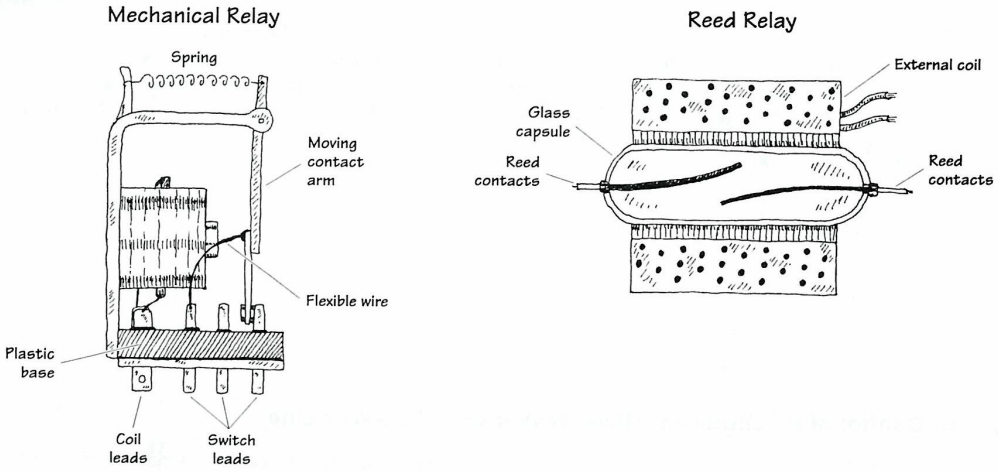


FIGURE 3.42

A mechanical relay's switch section comes in many of the standard manual switch arrangements (e.g., SPST, SPDT, DPDT, etc.). Reed relays and solid-state relays, unlike mechanical relays, typically are limited to SPST switching. Some of the common symbols used to represent relays are shown below.

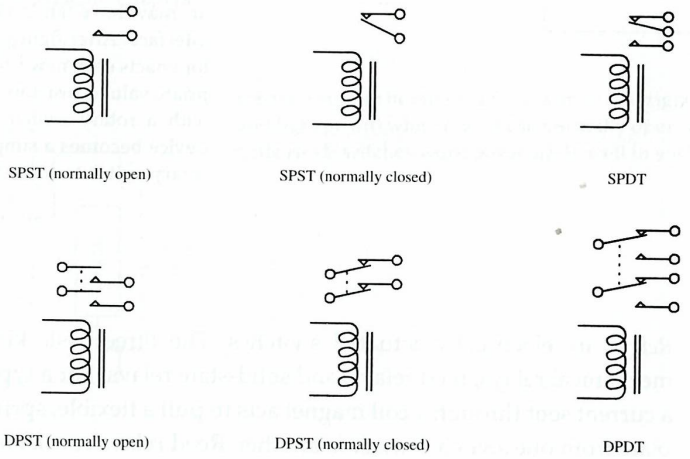


FIGURE 3.43

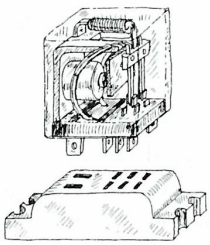
The voltage used to activate a given relay may be either dc or ac. For, example, when an ac current is fed through a mechanical relay with an ac coil, the flexible-metal conductive plate is pulled toward one switch contact and is held in place as long as the current is applied, regardless of the alternating current. If a dc coil is supplied by an alternating current, its metal plate will flip back and forth as the polarity of the applied current changes.

Mechanical relays also come with a latching feature that gives them a kind of memory. When one control pulse is applied to a *latching relay*, its switch closes. Even when the control pulse is removed, the switch remains in the closed state. To open the switch, a separate control pulse must be applied.

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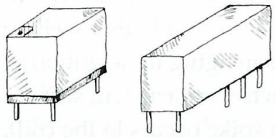
3.4.1 Specific Kinds of Relays

Subminiature Relays



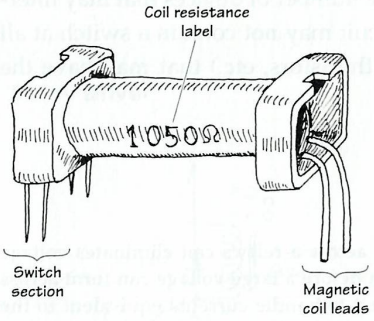
Typical mechanical relays are designed for switching relatively large currents. They come with either dc or ac coils. Dc-actuated relays typically come with excitation-voltage ratings of 6, 12, and 24 V dc, with coil resistances (coil ohms) of about 40, 160, and 650 Ω, respectively. Ac-actuated relays typically come with excitation-voltage ratings of 110 and 240 V ac, with coil resistances of about 3400 and 13600 Ω, respectively. Switching speeds range from about 10 to 100 ms, and current ratings range from about 2 to 15 A.

Miniature Relays



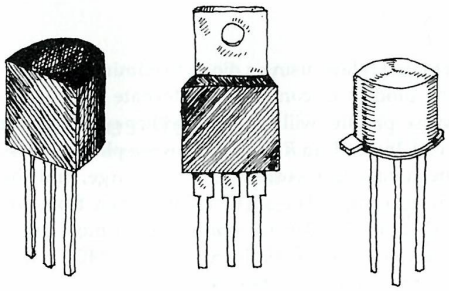
Miniature relays are similar to subminiature relays, but they are designed for greater sensitivity and lower-level currents. They are almost exclusively actuated by dc voltages but may be designed to switch ac currents. They come with excitation voltages of 5, 6, 12, and 24 V dc, with coil resistances from 50 to 3000 Ω.

Reed Relays



Two thin metal strips, or reeds, act as movable contacts. The reeds are placed in a glass-encapsulated container that is surrounded by a coil magnet. When current is sent through the outer coil, the reeds are forced together, thus closing the switch. The low mass of the reeds allows for quick switching, typically around 0.2 to 2 ms. These relays come with dry or mercury-wetted contacts. They are dc-actuated and are designed to switch lower-level currents, and come with excitation voltages of 5, 6, 12, and 24 V dc, with coil resistances around 250 to 2000 Ω. Leads are made for PCB mounting.

Solid-State Relays



These relays are made from semiconductor materials. Solid-state relays include transistors (FETs, BJTs) and thyristors (SCRs, triacs, diacs, etc.). Solid-state relays do not have a problem with contact wear and have phenomenal switching speeds. However, these devices typically have high "on" resistances, require a bit more fine tuning, and are much less resistant to overloads when compared with electromechanical relays. Solid-state devices will be covered later in this book.

FIGURE 3.44

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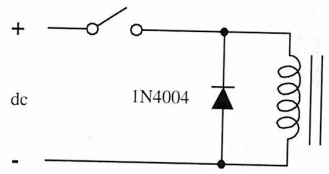
3.4.2 A Few Notes about Relays

To make a relay change states, the voltage across the leads of its magnetic coil should be at least within ±25 percent of the relay's specified control-voltage rating. Too much voltage may damage or destroy the magnetic coil, whereas too little voltage may not be enough to "trip" the relay or may cause the relay to act erratically (flip back and forth).

The coil of a relay acts as an inductor. Now, inductors do not like sudden changes in current. If the flow of current through a coil is suddenly interrupted, say, a switch is opened, the coil will respond by producing a sudden, very large voltage across its leads, causing a large surge of current through it. Physically speaking, this phenomenon is a result of a collapsing magnetic field within the coil as the current is terminated abruptly. [Mathematically, this can be understood by noticing how a large change in current (dI/dt) affects the voltage across a coil ($V = LdI/dt$).] Surges in current that result from inductive behavior can create menacing voltage spikes (as high as 1000 V) that can have some nasty effects on neighboring devices within the circuit (e.g., switches may get zapped, transistors may get zapped, individuals touching switches may get zapped, etc.). Not only are these spikes damaging to neighboring devices, they are also damaging to the relay's switch contacts (contacts will suffer a "hard hit" from the flexible-metal conductive plate when a spike occurs in the coil).

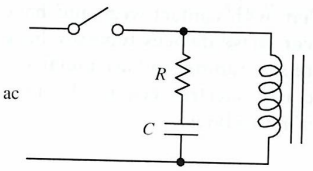
The trick to getting rid of spikes is to use what are called *transient suppressors*. You can buy these devices in prepackaged form, or you can make them yourself. The following are a few simple, homemade transient suppressors that can be used with relay coils or any other kind of coil (e.g., transformer coils). Notably, the switch incorporated within the networks below is only one of a number of devices that may interrupt the current flow through a coil. In fact, a circuit may not contain a switch at all but may contain other devices (e.g., transistors, thyristors, etc.) that may have the same current-interrupting effect.

DC-Driven Coil



Placing a diode in reverse bias across a relay's coil eliminates voltage spikes by going into conduction before a large voltage can form across the coil. The diode must be rated to handle currents equivalent to the maximum current that would have been flowing through the coil before the current supply was interrupted. A good general-purpose diode that works well for just such applications is the 1N4004 diode.

AC-Driven Coil



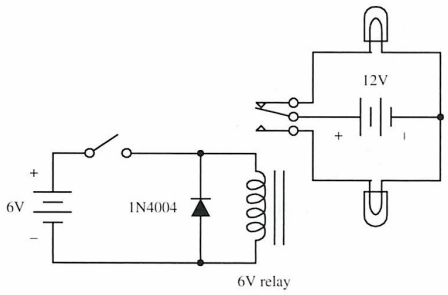
When dealing with ac-actuated relays, using a diode to eliminate voltage spikes will not work—the diode will conduct on alternate half-cycles. Using two diodes in reverse parallel will not work either—the current will never make it to the coil. Instead, an *RC* series network placed across the coil can be used. The capacitor absorbs excessive charge, and the resistor helps control the discharge. For small loads driven from the power line, setting $R = 100\ \Omega$ and $C = 0.05\ \mu F$ works fine for most cases. (Note: There are special devices, such as bidirectional TVs, MOVs, and MTLVs, that are designed for dc transients. See Sec. 4.5.)

FIGURE 3.45

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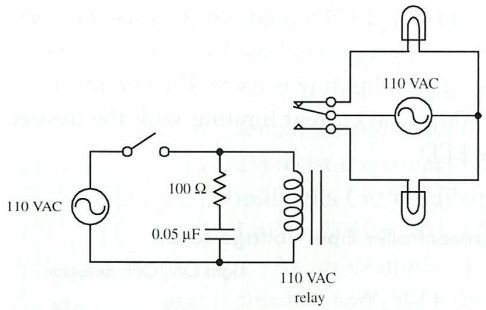
3.4.3 Some Simple Relay Circuits

DC-Actuated Switch



Here, a dc-powered SPDT relay is used to relay current to one of two light bulbs. When the switch in the control circuit is opened, the relay coil receives no current; hence the relay is relaxed, and current is routed to the upper bulb. When the switch in the control circuit is closed, the relay coil receives current and pulls the flexible-metal conductive plate downward, thus routing current to the lower bulb. The diode acts as a transient suppressor. Note that all components must be selected according to current and voltage ratings.

AC-Actuated Switch



Here, an ac-actuated relay is used to switch ac current to one of two ac-rated light bulbs. The behavior in this circuit is essentially the same as in the preceding circuit. However, currents and voltages are all ac, and an *RC* network is used as a transient suppressor. Make sure that resistor and capacitor are rated for a potential transient current that is as large as the typical coil current. The capacitor must be rated for ac line voltage. A discrete transient suppressor (e.g., bipolar TVs or MOV) can take the place of an RC network.

Relay Driver

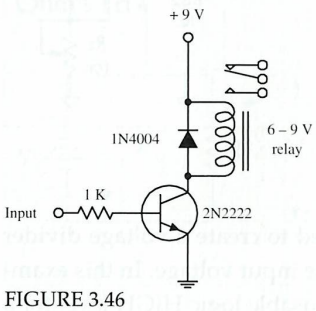


FIGURE 3.46

If a relay is to be driven by an arbitrary control voltage, this circuit can be used. The *npn* bipolar transistor acts as a current-flow control valve. With no voltage or input current applied to the transistor's base lead, the transistor's collector-to-emitter channel is closed, hence blocking current flow through the relay's coil. However, if a sufficiently large voltage and input current are applied to transistor's base lead, the transistor's collector-to-emitter channel opens, allowing current to flow through the relay's coil.

3.5 Resistors

There are various kinds of resistors available today. There are fixed resistors, variable resistors, digitally adjustable resistors, fusible resistors, photoresistors, and various resistor arrays (networks). Figure 3.47 shows schematic symbols and pictures of some of the most common types.

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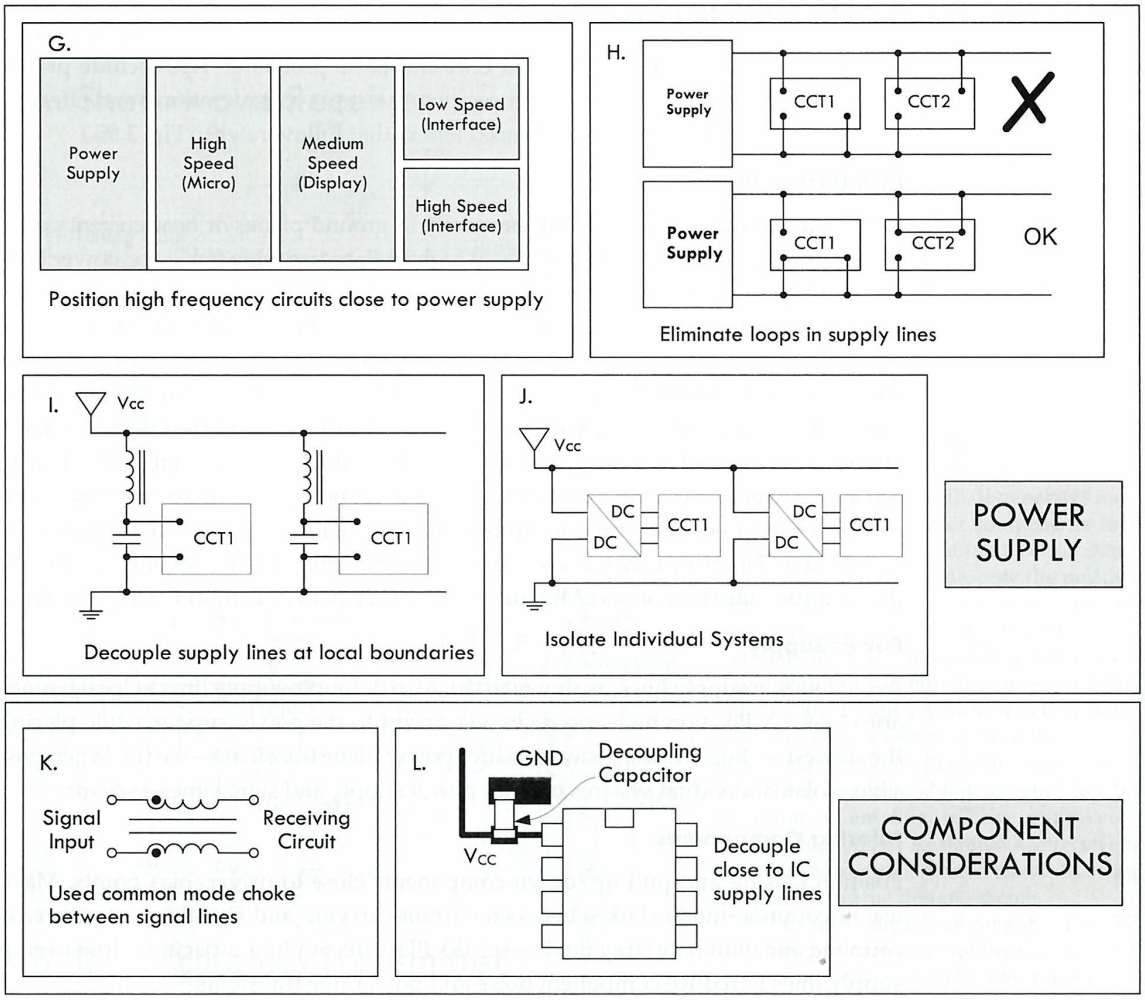


FIGURE 3.95 *(Continued)*

These tips where adapted from an Engineering Note, "Electro-Magnetic Interference and Electro-Magnetic Compatibility (EMI/EMC)" written by David B. Fancher, Inductive Products Division, Vishay Dale.

3.8 Transformers

3.8.1 Basic Operations

A basic transformer is a two-port (four-terminal) device capable of transforming an ac input voltage into a higher or lower ac output voltage. Transformers are not designed to raise or lower dc voltages, however, since the conversion mechanism relies on a changing magnetic field generated by a changing current. A typical transformer consists of two or more insulated wire coils that share a common laminated iron core. One of the coils is called the primary (containing N_P turns), while the other coil is called the secondary (containing N_S turns). A simplistic representation of a transformer is shown in Fig. 3.96, along with its schematic symbol.

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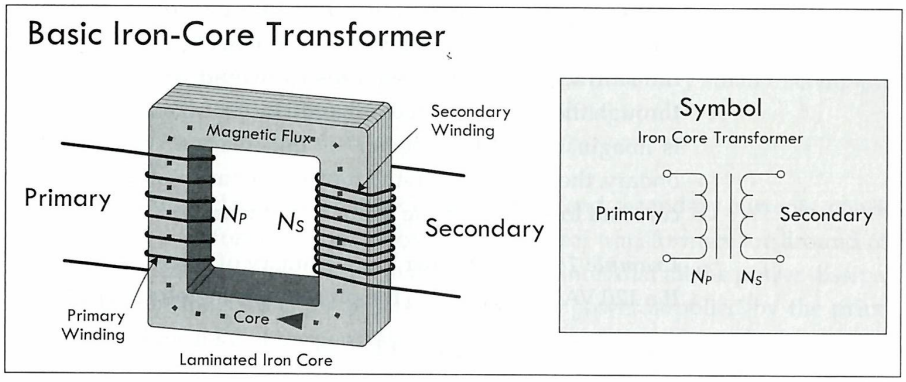


FIGURE 3.96

When an ac voltage is applied across the primary coil of the transformer, an alternating magnetic flux $\Phi_M = \int(V_{IN}/N_P)dt$ emanates from the primary, propagates through the iron-laminated core, and passes through the secondary coil. (The iron core increases the inductance, and the laminations decrease power-consuming eddy currents.) According to Faraday's law of induction, the changing magnetic flux induces a voltage of $V_S = N_S d\Phi_M/dt$, assuming there is perfect magnetic flux coupling (coefficient of coupling $k = 1$). Combining the primary flux equation with the secondary induced voltage equation results in the following useful expression:

$$V_S = V_P\left(\frac{N_S}{N_P}\right) \qquad \text{(3.1) Transformer voltage ratio}$$

This equation says that if the number of turns in the primary coil is larger than the number of turns in the secondary coil, the secondary voltage will be smaller than the primary voltage. Conversely, if the number of turns in the primary coil is less than the number of turns in the secondary, the secondary voltage will be larger than the primary.

When a source voltage is applied across a transformer's primary terminals while the secondary terminals are open-circuited (see Fig. 3.97), the source treats the transformer as if it were a simple inductor with an impedance of $Z_P = j\omega L_P = \omega L \angle 90°$, where L_P represents the inductance of the primary coil. This means that the primary current will lag the voltage (source voltage) by 90°, and the primary current will be equal to V_P/Z_P, according to Ohm's law. At the same time, a voltage of $(N_S/N_P)V_P$ will be present across the secondary and will be in phase with the primary voltage or 180° out of phase, depending on the secondary coil winding direction or depending on which secondary coil end you choose as a reference (more on this in a moment).

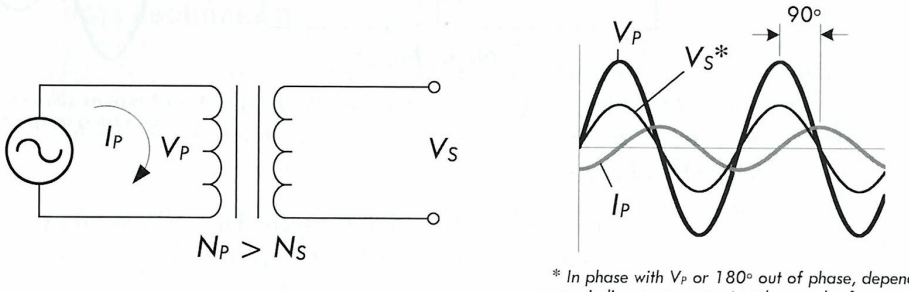


FIGURE 3.97

* *In phase with V_P or 180° out of phase, depending on winding arragnement and ground reference.*

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When there is no load attached to the secondary of a transformer, the current within the primary is called the magnetizing current of the transformer. An ideal transformer, with no internal losses, would consume no power, since the current through the primary inductor would be 90° out of phase with the voltage (in $P = IV$, I is imaginary and the "power" is imaginary or reactive). With no load in the secondary, the only losses in the transformer are associated with those losses in the iron core and losses within the primary coil wire itself.

Example 1: A transformer has a primary of 200 turns and a secondary of 1200 turns. If a 120 VAC is applied to the primary, what voltage appears across the secondary?

Answer: Rearranging Eq. 3.1,

$$V_S = V_P\left(\frac{N_S}{N_P}\right) = 120\text{ VAC}\left(\frac{1200\text{ turns}}{200\text{ turns}}\right) = 720\text{ VAC}$$

This is an example of a step-up transformer, since the secondary voltage is higher than the primary voltage.

Example 2: Using the same transformer from Example 1, flip it around so the secondary now acts as the primary. What will be the new secondary voltage?

Answer:

$$V_S = V_P\left(\frac{N_S}{N_P}\right) = 120\text{ VAC}\left(\frac{200\text{ turns}}{1200\text{ turns}}\right) = 20\text{ VAC}$$

This is an example of a step-down transformer, since the secondary voltage is lower than the primary voltage.

As you can see from the previous example, either winding of a transformer can be used as the primary, provided the windings have enough turns (enough inductance) to induce a voltage equal to the applied voltage without requiring an excessive current. The windings must also have insulation with a voltage rating sufficient for the voltage present.

Now let's take a look at what happens when you attach a load to the secondary, as shown in Fig. 3.98.

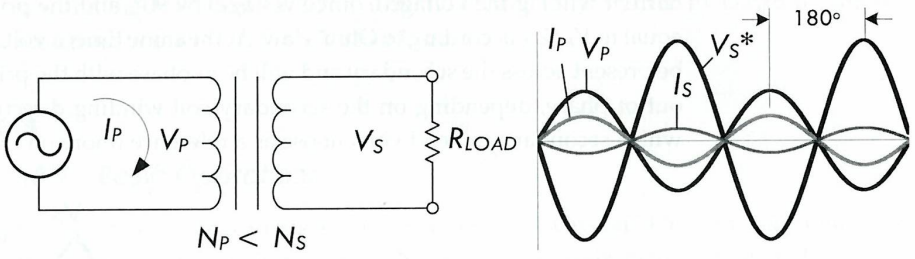


FIGURE 3.98

When a load is attached to the secondary, the secondary current sets up a magnetic field that opposes the field set up by the primary current. For the induced voltage in the primary to equal the applied voltage, the original field must be maintained. The primary must draw enough additional current to set up a field exactly equal and

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opposite to the field set up by the secondary current. At this point, for practical purposes, we assume that the entire primary current is a result of the secondary load. (This is close to true, since the magnetizing current will be very small in comparison with the primary load current at rated power output.)

Current Ratio

To figure out the relationship between the primary and secondary currents, consider that an ideal transformer is 100 percent efficient (real transformers are around 65 to 99 percent efficient, depending on make), and then infer that all the power dissipated by the load in the secondary will be equal to the power supplied by the primary source. With the help of the generalized power law, we get:

$$P_P = P_S$$
$$I_P V_P = I_S V_S$$

Plugging our transformer voltage equation (3.1) into the V_S term, we get:

$$I_P V_P = I_S\left(V_P \frac{N_S}{N_P}\right)$$

Eliminating the V_P from both sides, we get the following useful current relation:

$$I_P = I_S\left(\frac{N_S}{N_P}\right) \quad \text{(3.2) Ideal transformer current ratio}$$

Example 3: A transformer with a primary of 180 turns and a secondary with 1260 turns is delivering 0.10 A to a load. What is the primary current?

Answer: Rearranging Eq. 3.2 and solving for the primary current:

$$I_P = I_S\left(\frac{N_S}{N_P}\right) = 0.10\text{ A}\left(\frac{1260\text{ turns}}{180\text{ turns}}\right) = 0.7\text{ A}$$

Notice from the previous example that even though the secondary voltage is larger than the primary voltage, the secondary current is smaller than the primary current. The secondary current in an ideal transformer is 180° out of phase with the primary current, since the field in the secondary just offsets the field in the primary. The phase relationship between the currents in the windings holds true no matter what the phase difference between the current and the voltage of the secondary. In fact, the phase difference, if any, between voltage and current in the secondary will be reflected back to the primary as an identical phase difference. Note that phase, however, can be selected according to how you pull the secondary out—see the following note.

NOTE ABOUT PHASE

By now you may be a bit annoyed with the notion of phase. For example, to say that that the primary voltage is out of phase with the secondary by 180° is smack in the phase to relativity. Couldn't you simply wind the secondary winding in a different direction or, more easily, simply reverse the secondary leads to get an output that is within phase? The answer is yes. It is a relativity game with the transformer pins. Figure 3.99 shows two transformers that are identical in every way except for the winding direction of the secondary. The

(continued)

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winding A arrangement, when tested with a common ground and oscilloscope, yields in-phase voltages, while the winding in B yields voltage and currents that are 180° out of phase with the primary. To avoid confusion, a convention is used to keep track of the relative polarity between the leads. This convention makes use of what are called phase dots, which are a pair of dots: one placed on the primary side; the other placed on the secondary side. The similar placement of these dots next to the top ends of the primary and secondary windings tells you that whatever instantaneous voltage polarity is seen across the primary winding will be the same as that across the secondary winding. In other words, the phase shift from primary to secondary will be zero degrees. On the other hand, if dots on each winding of the transformer do not match up, the phase shift is 180° between primary and secondary. Of course, the dot convention only tells you which end of each winding is which, relative to the other winding(s). If you want to reverse the phase relationship, all you have to do is swap the winding connections.

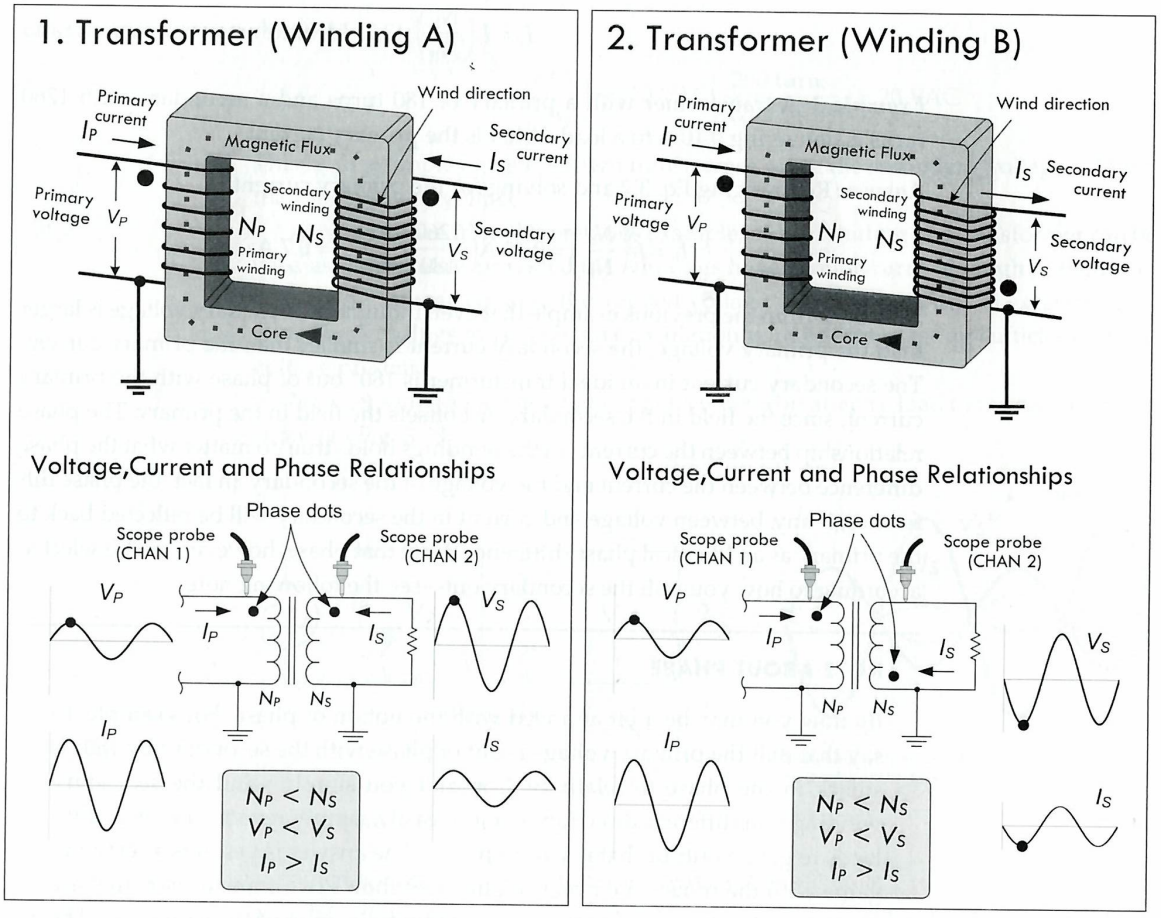


FIGURE 3.99

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Power Ratio

A moment ago, when deriving the transformer current equation, we assumed that the transfer of power from primary to secondary was 100 percent efficient. However, it is important to realize that there is always some power loss in the resistance of the coils and in the iron core of the transformer. This means that the power taken from the source is greater than the power used in the secondary. This can be stated by the following expression:

$$P_S = n \times P_P \qquad \text{(3.3) Efficiency factor}$$

where P_S is the power output from the secondary, P_P is the power input to primary, and n is the efficiency factor. The efficiency n is always less than 1. It is usually expressed as a percentage—for example, 0.75 represents an efficiency of 75 percent.

Example 4: What is the power input to the primary if a transformer has an efficiency of 75 percent and its full load output at the secondary is 100 W?

Answer: Rearranging Eq. 3.3,

$$P_P = \frac{P_S}{n} = \frac{100\text{ W}}{0.75} = 133\text{ W}$$

Transformers are typically designed to have highest efficiency at the manufacturer's rated outputs. Above or below the rated output, the efficiency drops. The amount of power a transformer can handle depends on its own losses (heating of wire and core, etc.). Exceeding the rated power of a transformer can lead to wire meltdown or insulation breakdown. Even when the load is purely reactive, the transformer will still be generating heat loss due to internal resistance of the coils and losses in the core. For this reason, manufacturers also specify a maximum volt-amp rating, or VA-rating, that should not be exceeded.

Impedance Ratio

Using ac Ohm's law, $I_P = V_P/Z_P$, and assuming an ideal transformer, where power from the primary is 100 percent transferred to secondary, we can come up with an equation relating the primary and secondary impedances:

$$P_P = P_S$$

$$I_P V_P = I_S V_S$$

$$\frac{V_P^2}{Z_P} = \frac{V_S^2}{Z_S} \rightarrow (\text{plug in } V_S = V_P(N_S/N_P) \rightarrow \frac{V_P^2}{Z_P} = \frac{V_P^2(N_S/N_P)^2}{Z_S}$$

Canceling the primary voltage terms, you get the following useful expression:

$$Z_P = Z_S\left(\frac{N_P}{N_S}\right)^2 \qquad \text{(3.4) Transformer impedance ratio}$$

where Z_P is the impedance looking into the primary terminal from the power source, and Z_S is the impedance of the load connected to the secondary. Figure 3.100 shows an equivalent circuit.

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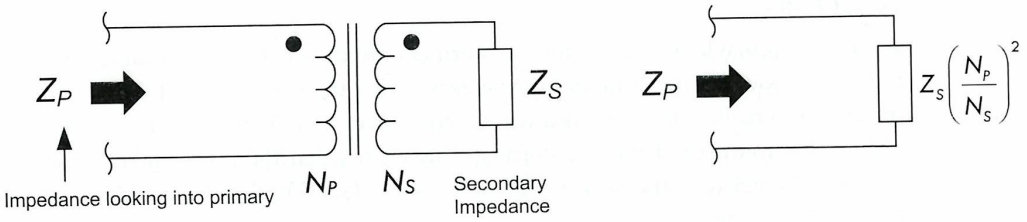


FIGURE 3.100

If the load impedance in the secondary increases, the impedance looking into the primary (from the source's point of view) will also increase in a manner that is proportional to the ratio of the turns squared.

Example 5: A transformer has a primary with 500 turns and a secondary with 1000 turns. What is the primary impedance if a 2000-Ω load impedance is attached to the secondary?

Answer: Using Eq. 3.4:

$$Z_P = 2000\ \Omega\left(\frac{500\ \text{turns}}{1000\ \text{turns}}\right)^2 = 2000\ \Omega(0.5)^2 = 500\ \Omega$$

As you can see, by selecting the proper turns ratio, the impedance of a fixed load can be transformed to any desired value (ideally). If transformer losses can be neglected, the transformed (reflected) impedance has the same phase angle as the actual load impedance. Hence, if the load is purely resistive, the load presented by the primary to the power source will also be pure resistance. If the load impedance is complex (e.g., inductance and capacitance are thrown in so that load current and voltage are out of phase with each other), then the primary voltage and current will show the same phase angle.

In electronics, there are many instances where circuits require a specific load resistance (or impedance) for optimum performance. The impedance of the actual load dissipating power may differ widely from the impedance of the source. In this case, a transformer can be used to change the actual load into an impedance of desired value. This is referred to as *impedance matching*. We can rearrange Eq. 3.4 and get:

$$\frac{N_P}{N_S} = \sqrt{\frac{Z_P}{Z_S}} \tag{3.5}$$

where N_P/N_S is the required turns ratio—primary to secondary, Z_P is the primary impedance required, and Z_S is the impedance of the load connected to the secondary.

Example 6: An amplifier circuit requires a 500-Ω load for optimum performance, but is to be connected to an 8.0-Ω speaker. What turns ratio, primary to secondary, is required in the coupling transformer?

Answer:

$$\frac{N_P}{N_S} = \sqrt{\frac{Z_P}{Z_S}} = \sqrt{\frac{500\ \Omega}{8\ \Omega}} = 8$$

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Hence, the primary must have eight times as many turns as the secondary.

Knowing what to set the primary count at depends on low internal losses and leakage current and making sure that the primary has enough inductance to operate with low magnetizing current at the voltage applied to the primary.

Example 7: What are the load impedances "seen" by the voltage sources in Fig. 3.101?

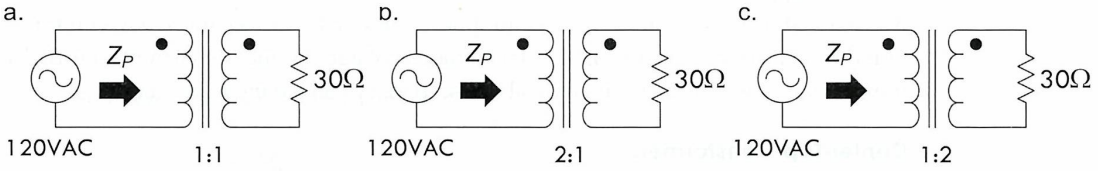


FIGURE 3.101

Answer: (a) 30 Ω, (b) 120 Ω, (c) 8 Ω.

Example 9: If a step-up transformer has a turns ratio of 1:3, what are the voltage ratio, current ratio, and impedance ratio? Assume ratios are given in the form "primary: secondary."

Answer: Voltage ratio is 1:3, current ratio is 3:1, impedance ratio is 1:9.

Transformer Gear Analogy

It is often helpful to think of transformers as gearboxes. For example, in the gearbox analogy in Fig. 3.101, the primary winding is analogous to the input shaft (where the motor is

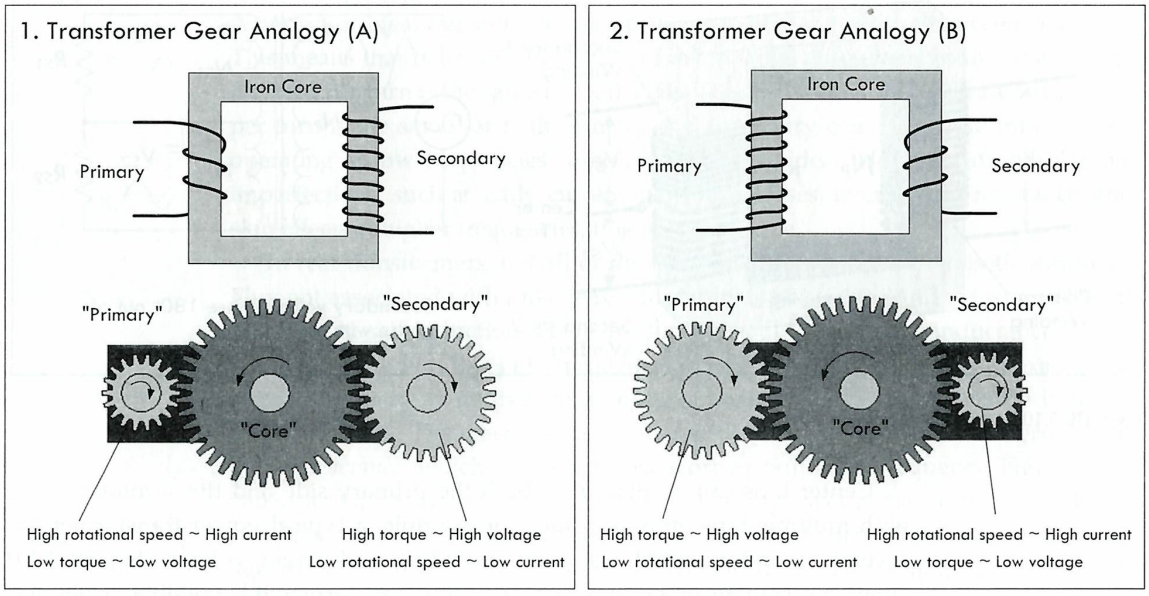


FIGURE 3.102

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attached) and the secondary winding is analogous to the output shaft. Current is equivalent to shaft speed (rmp) and voltage is equivalent to torque. In a gearbox, mechanical power (speed multiplied by torque) is constant (neglecting losses) and is equivalent to electrical power (voltage times current), which is also constant. The gear ratio is equivalent to the transformer step-up or step-down ratio. A step-up transformer acts like a reduction gear (in which mechanical power is transferred from a small, rapidly rotating gear to a large, slowly rotating gear): it trades current (speed) for voltage (torque), by transferring power from a primary coil to a secondary coil having more turns. A step-down transformer acts similarly to a multiplier gear (in which mechanical power is transferred from a large gear to a small gear): it trades voltage (torque) for current (speed), by transferring power from a primary coil to a secondary coil having fewer turns.

Center-Tap Transformers

Rarely do you see transformers in the real world with just four leads—two for the primary and two for the secondary. Many commercial transformers employ center taps. A center tap is simply an electrical connection that is made somewhere between the two ends of a transformer winding. By using a center tap, it is possible to utilize only a fraction of the winding voltage. For example, in Fig. 3.103, a transformer's secondary is center-tapped midway between its winding, yielding two output voltages V_{S1} and V_{S2}. If we place a ground reference on the center tap (it is treated now as a common), we see the voltages in terms of phase, as shown in the example circuit in Fig. 3.103. In this case, the two secondary voltages are equal because we assumed that the number of turns on either end of the center tap were the same. In general, the secondary voltages are determined by the turns ratio.

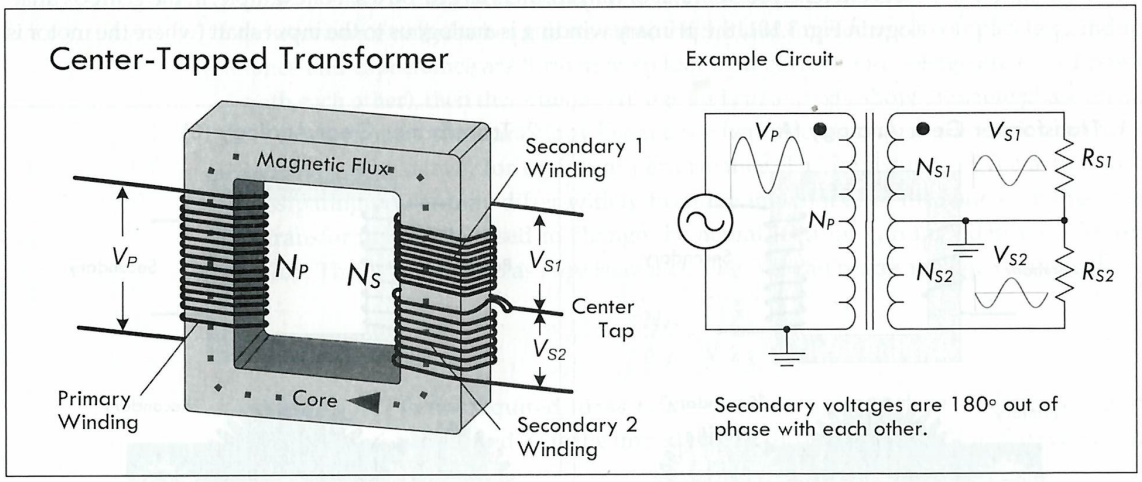


FIGURE 3.103

Center taps can be placed on both the primary side and the secondary side, with multiple taps on either side. For example, a typical power transformer has several secondary windings, each providing a different voltage. Figure 3.104 shows a schematic of a typical power supply transformer. It is possible to join pins with a jumper to get the desired voltage ratios across other pins. Manufacturers

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will provide you with the voltages between the various tap points, usually specifying CT as the center-tap voltage. Center taps provide flexibility in design and allow varying outputs, which you implement by incorporating switches, for example. We'll see how a center-tap transformer is used to split incoming 240 VAC for the main into two 120-VAC legs within the circuit breaker of your house, and we'll also discover how full-wave center-tap rectifier circuits are used in building dc power supplies.

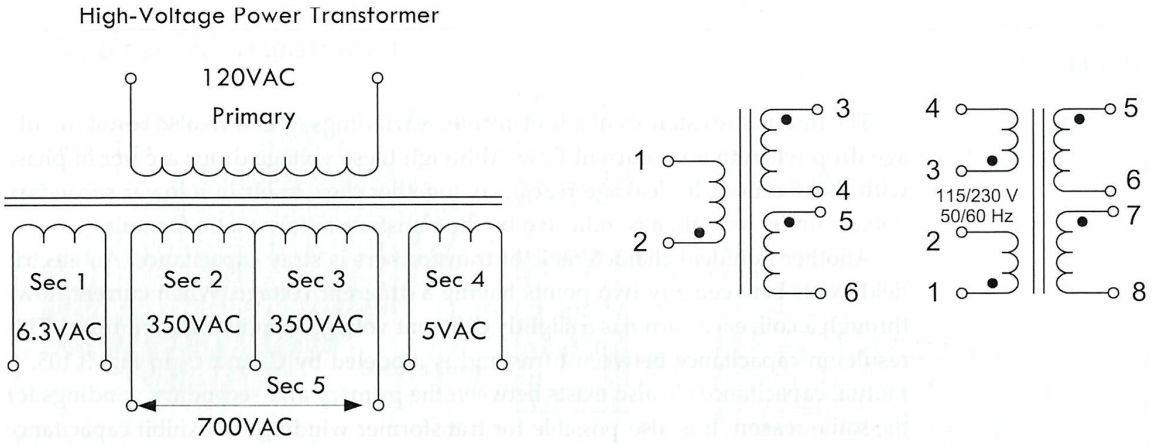


FIGURE 3.104

Real Transformer Characteristics

A perfect or ideal transformer has a primary-to-secondary coupling coefficient of 1. This means that both coils link with all the magnetic flux lines, so that the voltage induced per turn is the same for both coils. This also means that the induced voltage per turn is the same for both primary and secondary coils. Iron core transformers operating at low frequencies come close to being ideal. However, due to various imperfections, such as eddy current, hysteresis losses, internal coil resistance, and skin effects at higher frequencies, this isn't quite true.

In real transformers, not all of the magnetic flux is common to both windings. Flux not associated with linkage is referred to as *leakage flux* and is responsible for a voltage of self-induction. There are small amounts of leakage inductance associated with both windings of a transformer. Leakage inductance acts in exactly the same manner as an equivalent amount of ordinary inductance inserted in series with the circuit. The reactance associated with leakage inductance is referred to as *leakage reactance*, which varies with transformer build and frequency. Figure 3.105 shows a real-life model of a transformer including leakage reactances for both primary and secondary coils, namely, X_{L1} and X_{L2}. When current flows through a leakage reactance, there is an associated voltage drop. The voltage drop becomes greater with increasing current and increases as more power is taken from the secondary.

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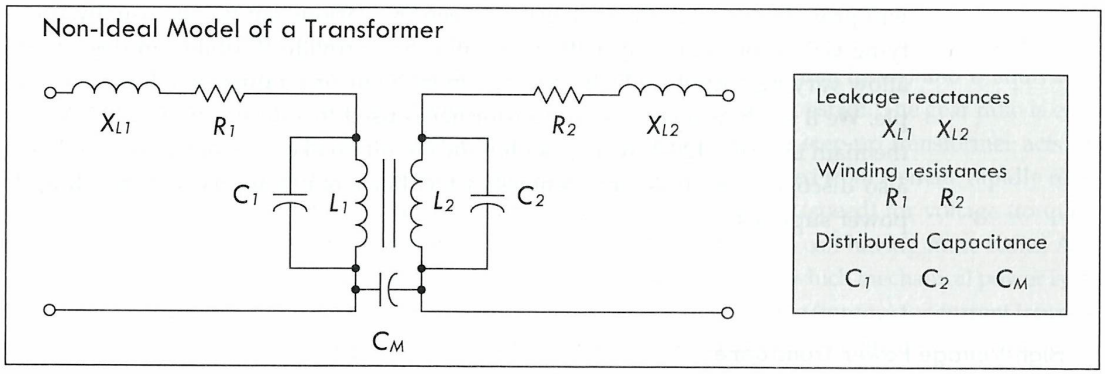


FIGURE 3.105

The internal resistances of a transformer's windings R_1 and R_2 also result in voltage drop when there is current flow. Although these voltage drops are not in phase with those caused by leakage reactance, together they result in a lower secondary voltage under load than is indicated by the transformer turns ratio formula.

Another nonideal characteristic of transformers is stray capacitance. An electric field exists between any two points having a different voltage. When current flows through a coil, each turn has a slightly different voltage than its adjacent turns. This results in capacitance between turns and is modeled by C_1 and C_2 in Fig. 3.105. A mutual capacitance C_M also exists between the primary and secondary windings for the same reason. It is also possible for transformer windings to exhibit capacitance relative to nearby metal, such as a chassis, shield, or even the core itself.

Stray capacitance tends to have little influence in power and audio transformers, but becomes influential as the frequencies increase. In RF applications where transformers are used, the stray capacitance can resonate with either the leakage reactance or, at lower frequencies, the winding reactances, especially under very light or zero-ohm loads. In the frequency region around resonance, transformers do not exhibit behavior as described by the previous transformer equations.

Iron core transformers also experience losses with hysteresis and eddy current, as was discussed in Chap. 2.24. These losses, which add to the required magnetizing current, are equivalent to adding a resistance in parallel to R_1 in Fig. 3.105.

TRANSFORMER PRECAUTIONS

There are three basic rules to observe when using a transformer. First, never apply a voltage that is greatly in excess of the transformer winding ratings. Second, never allow a significant direct current to flow through any winding not designed to handle it. Third, don't operate the transformer at a frequency outside the range specified by the manufacturer. Applying a voltage of, say, 120 VAC to a secondary in hopes of achieving 1200 VAC at the primary is a bad idea—expect smoke and combustion, accompanied by insulation failure. Similar results can be expected with excessive dc current through the primary. In terms of frequency, a 60-Hz transformer driven at 20 Hz will draw too much magnetizing current and will run dangerously hot.

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3.8.2 *Transformer Construction*

Cores

Transformers used for power and audio frequencies have cores made of many thin laminations of silicon steel. The laminations reduce eddy currents, as discussed in Sec. 2.24. A typical laminated core is made from E-shaped and I-shaped pieces, sandwiched together, as shown in Fig. 3.106. Transformers made from these cores are therefore often referred to as EI transformers.

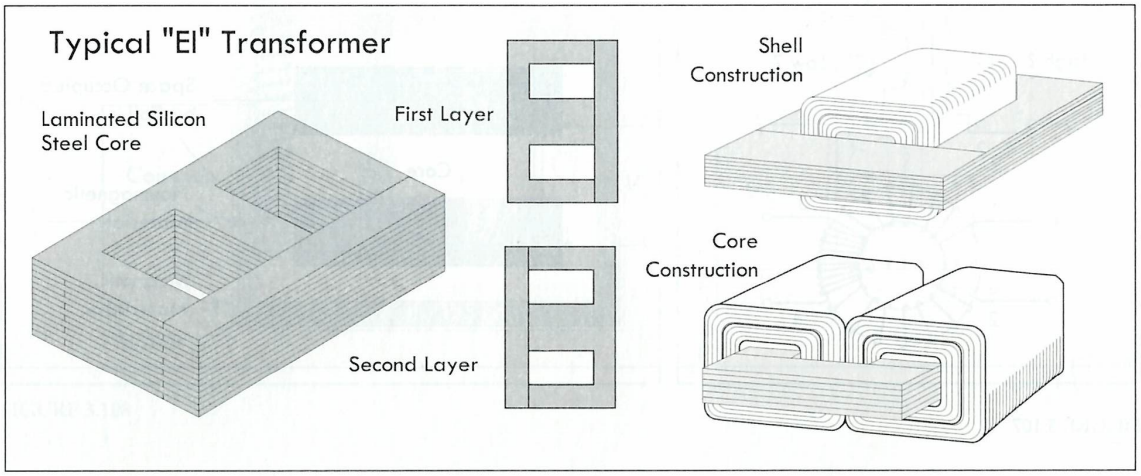


FIGURE 3.106

Two common core shapes in use are shown in Fig. 3.106. In the shell construction, both the primary and the secondary windings are wound around the same inner leg, while in the core construction, primary and secondary windings are wound on separate legs. The core construction is often implemented to minimize capacitive effects between primary and secondary windings, or when one winding is to be operated at very high voltage. The size, shape, and type of core material, as well as the frequency range, influence the required number of turns in each winding. In most transformers, the coils are wound in layers, with a sheet of special paper insulation placed between each layer. A thicker insulation is used between adjacent coils and between the core and the first coil.

Powdered iron cores, with their low eddy current characteristics, are used in transformers that operate above mains frequencies (60 Hz) up to several kilohertz. These cores have a very high permeability and thus provide decent stepping capability for their size. Transformers that are used in even higher-frequency applications, such as RF, often contain cores made from nonconductive magnetic ceramic materials or ferrites.

A common core shape for powdered iron and ferrite core transformers is the toroid, as shown in Fig. 3.107a. The closed ring shape of the toroid eliminates air gaps inherent in the construction of an EI core. The primary and secondary coils are often wound concentrically to cover the entire surface of the core. Ferrite cores are used at

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higher frequencies, typically between a few tens of kilohertz to a megahertz. In general, toroidal transformers are more efficient (around 95 percent) than cheaper laminated EI transformers; they are more compact (about half the size), weigh less (about half), have less mechanical hum (making them superior in audio applications), and have lower off-load losses (making them more efficient in standby circuits).

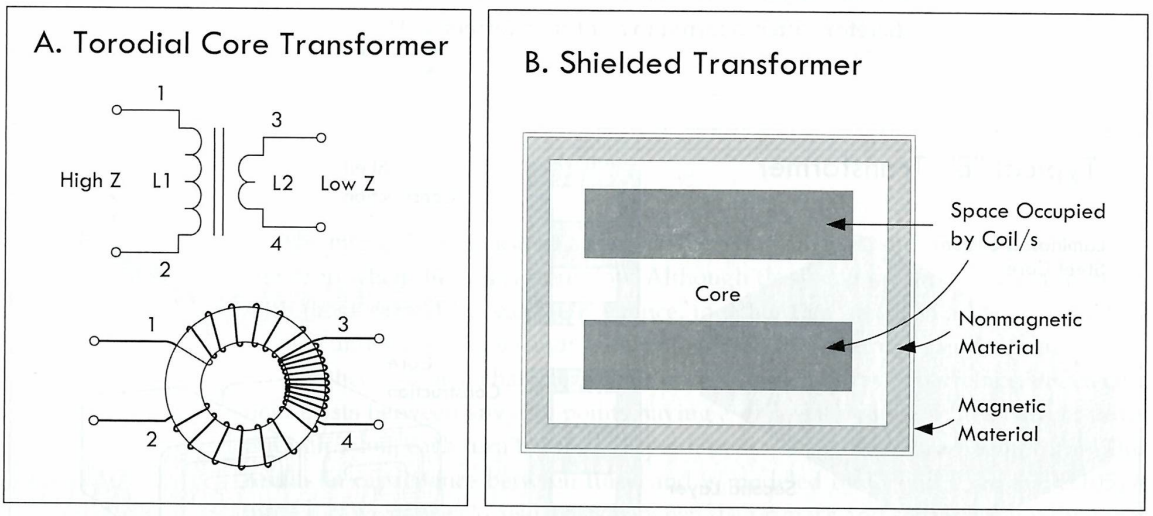


FIGURE 3.107

Shielding

To eliminate mutual capacitance between windings within a transformer, an electrostatic shield is often placed between the windings. Some transformers may incorporate a magnetic shield, as shown in Fig. 3.107b. The magnetic shield helps prevent outside magnetic fields (interference) from inducing currents within the inner windings. The shield also helps prevent the transformer from becoming an interference radiator itself.

Windings

For small-power and signal transformers, the windings are made from solid wire copper, insulated typically with enamel; sometimes additional insulation is used for safety. Larger-power transformers may be wound with copper or aluminum wire, or even strip conductors for very heavy current; in some cases multistrand conductors are used to reduce skin effect losses. High-frequency transformers operating in the kilohertz range often have windings made of Litz wire to minimize skin effects. For signal transformers, the windings may be arranged in a way to minimize leakage inductance and stray capacitance in order to improve high-frequency response.

3.8.3 Autotransformers and Variable Transformers

An autotransformer is similar to a standard transformer; however, it uses only one single coil and a center tap (or taps) to make primary and secondary connections. See

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Fig. 3.108. As with standard transformers, autotransformers can be used to step up or step down voltages, as well as match impedances; however, they will not provide electrical isolation like a standard transformer, since their primary and secondary are on the same coil—there is no electrical isolation between the two coils.

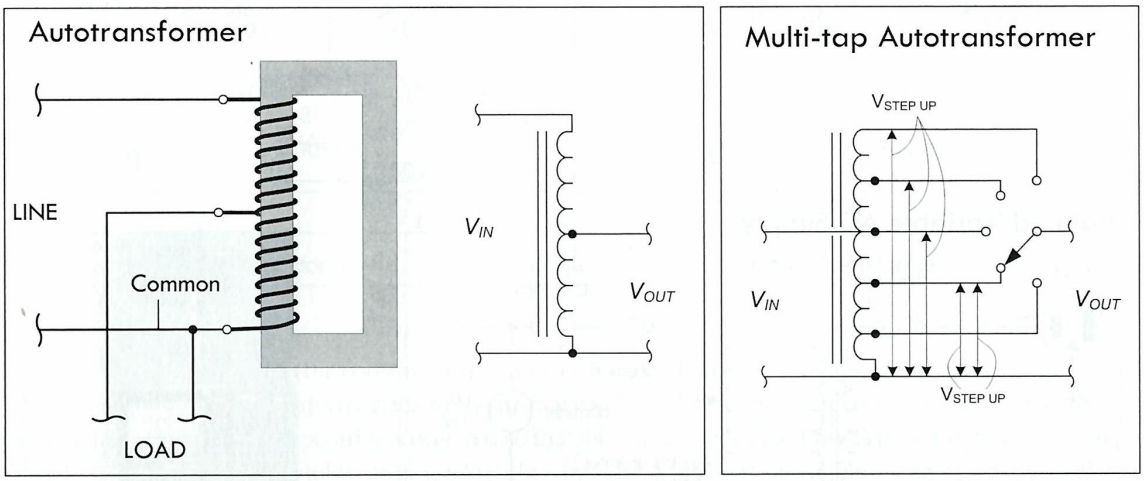


FIGURE 3.108

Although an autotransformer has only one winding, the laws of induction that were used with a standard transformer to step up and step down voltage can be applied just as well. This also applies to principles of current and impedance as a function of the number of winding turns. In Fig. 3.108, the current in the common winding is the difference between the line current (primary current) and the load current (secondary current), since these currents are out of phase. Hence, if the line and load currents are nearly equal, the common section of the winding may be wound with comparatively small wire. The line and load currents will be equal only when the primary (line) and secondary (load) voltages are close in magnitude.

Autotransformers are often used in impedance-matching applications. They are also frequently used for boosting or reducing the power-line voltage by relatively small amounts. Figure 3.108 shows a switch-stepped autotransformer whose output voltage can be set to any number of values determined by the switch contact position.

A variable transformer or Variac (commercial name) is similar to the switch-stepped autotransformer in Fig. 3.108; however, it has a continuous wiper action along a circular coil, as shown in Fig. 3.109. A Variac acts like an adjustable ac voltage source. Its primary is connected to the hot and neutral of the 120-V line voltage, while the secondary leads consist of the neutral and an adjustable wiper that moves along the single core winding.

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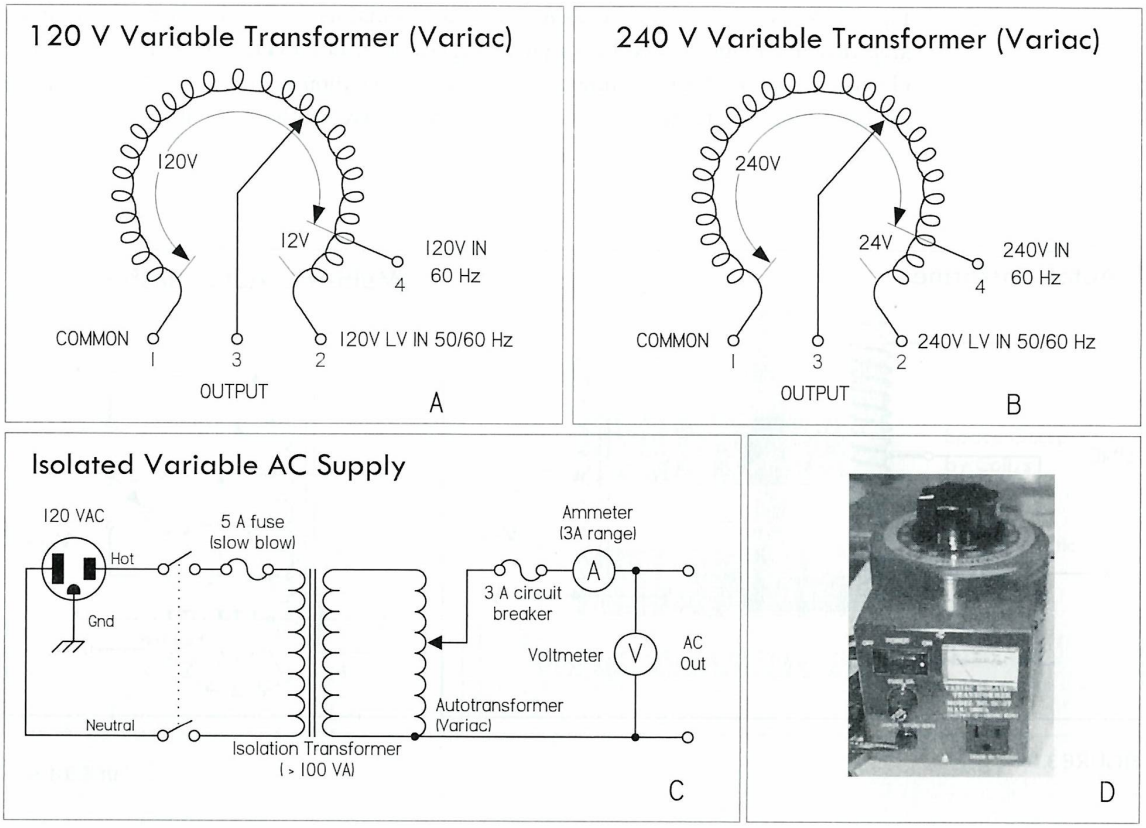


FIGURE 3.109 (a) Nonisolated 120-V Variac whose output voltage is varied by rotating a wiper. (b) Nonisolated 240-V Variac. (c) A homemade variable ac supply with isolation protection provided by means of an isolation transformer. (d) ac power supply that houses an isolation transformer, Variac, switch, fuse, ac outlet, and meter.

Being able to adjust the line voltage is a very useful trick when troubleshooting line-power equipment, where the fuse instantly blows at normal line voltage. Even without a fuse blowing, troubleshooting at around 85 V may reduce the fault current.

It is important to note that a Variac by itself does not provide isolation protection like a standard transformer, since the primary and secondary shared a common winding. It is therefore important, if you plan to work on ungrounded, "hot chassis" equipment, that you place an isolation transformer before the Variac—never after it. If you don't, shock hazards await. Figure 3.109c shows a schematic of such an arrangement. It includes a switch and fuse protection, as well as current and voltage meters, all of which create an adjustable, fully isolated ac power source.

To avoid the hassle of cascading a Variac and isolation transformer together, simply get an ac power supply that houses both elements together in one package—see Fig. 3.109d.

Boosting and Bucking

We just saw how autotransformers are used in applications requiring a slight boost or reduction in voltage to a load. It is possible to accomplish the same effect by using a normal (isolated) transformer with just the right primary/secondary turns ratio.

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There is still another alternative—use a step-down configuration with secondary winding connected in a series-aiding ("boosting") or series-opposing ("bucking") configuration, as shown in Fig. 3.110.

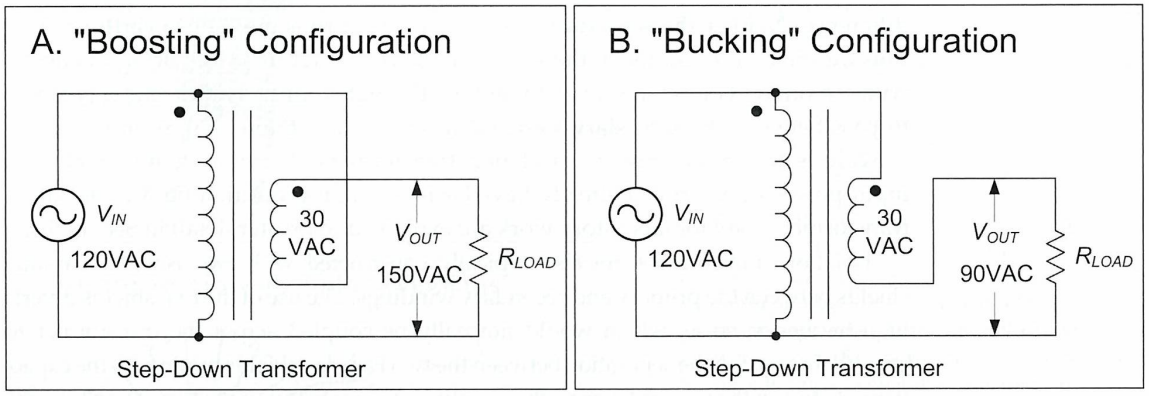


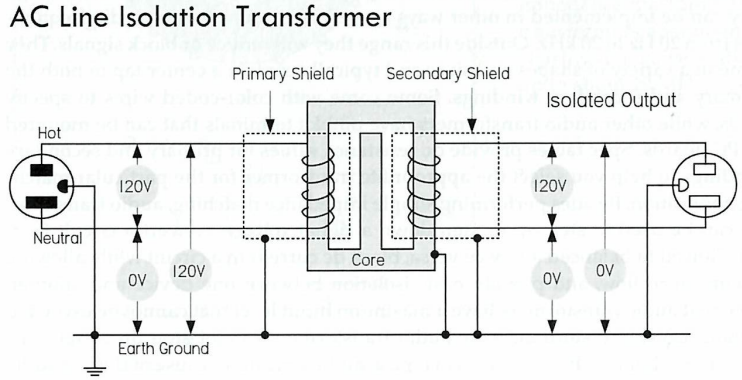
FIGURE 3.110

In the boosting configuration, the secondary coil's polarity is oriented so that its voltage directly adds to the primary voltage. In the bucking configuration, the secondary coil's polarity is oriented so that its voltage directly subtracts from the primary voltage. An autotransformer does the same job as the boosting and bucking functions displayed here, but using only a single winding, making it cheaper and lighter to manufacture.

3.8.4 Circuit Isolation and the Isolation Transformer

Transformers perform an important role in isolating one circuit from another. Figure 3.111 shows an example application that uses a transformer to isolate a load connected to an ac outlet. In this application, there is no need to step up or step down the voltage, so the transformer has a 1:1 winding ratio. Such a transformer is referred to as an *isolation transformer.* In Fig. 3.111, a mains isolation transformer is used to isolate a load from the source, as well as provide ground fault protection. An isolation transformer should be used whenever you work on nongrounded equipment, with no input isolation, such as switch-mode power supplies.

In your home wiring, the neutral (white) and the ground (green) connections are tied together at the main junction box, so they are basically at the same potential—



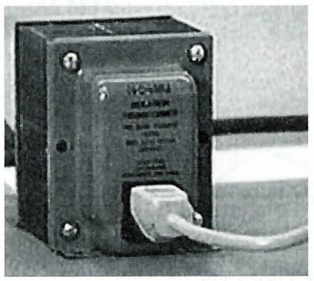


FIGURE 3.111

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0 V, or earth ground. If you accidentally touch the hot wire while being in contact with a grounded object, current will pass through your body and give you a potentially fatal shock. With an isolation transformer, the secondary winding leads act as a 120-V source and return, similar to the mains' hot and neutral, but with an important difference. Neither the secondary source nor return runs are tied to earth ground! This means that if you touch the secondary source or return while being in contact with a grounded object, no current will flow through your body. Current only wants to pass between the secondary source and return runs. (Note that all transformers provide isolation, not just line isolation transformers. Therefore, equipment with input power transformers already have basic isolation protection built in. Isolation transformers used for laboratory work are explained in greater detail in Sec. 14.5.12.)

Isolation transformers are also typically constructed with two isolated Faraday shields between the primary and secondary windings. The use of the two shields diverts high-frequency noise, which would normally be coupled across the transformer to ground. Increasing the separation between the two Faraday shields minimizes the capacitance between the two and, hence, the coupling of noise between the two. Therefore, the isolation transformer acts to clean up line power noise before being delivered to a circuit.

3.8.5 *Various Standard and Specialized Transformers*

Power Transformers

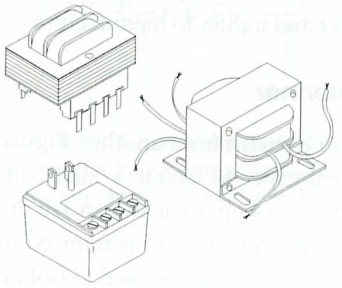


FIGURE 3.112

These transformers are used primarily to reduce line voltage. They come in a variety of different shapes, sizes, and primary and secondary winding ratios. They often come with taps and multiple secondary windings. Color-coded wires are frequently used to indicate primary and secondary leads (e.g., black wires for primary, green for secondary, and yellow for tap lead is one possibility). Other transformers use pins for primary, secondary, and tapped leads, allowing them to be mounted on a PC board. You can also find transformers in wall-mount packages that plug directly into an ac outlet, with screw-in terminals as secondary and tapped leads.

Audio Transformers

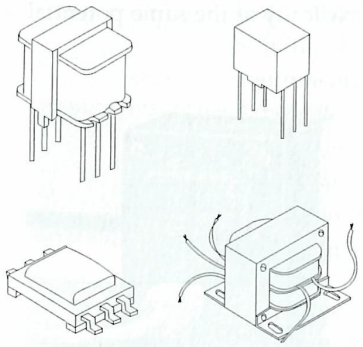


FIGURE 3.113

Audio transformers are used primarily to match impedances between audio devices (e.g., between microphone and amplifier or amplifier and speaker), though they can be implemented in other ways as well. They work best at audio frequencies from 20 Hz to 20 kHz. Outside this range they will reduce or block signals. They come in a variety of shapes and sizes and typically contain a center tap in both the primary and secondary windings. Some come with color-coded wires to specify leads, while other audio transformers have pinlike terminals that can be mounted on PC boards. Spec tables provide dc resistance values for primary and secondary windings to help you select the appropriate transformer for the particular matching application. Besides performing simple impedance matching, audio transformers can be used to step up or step down a signal voltage, convert a circuit from unbalanced to balanced and vice versa, block dc current in a circuit while allowing ac current to flow, and provide basic isolation between one device and another. Note that audio transformers have a maximum input level that cannot be exceeded without causing distortion. Also, audio transformers cannot step up a signal by more than about 25 dB when used in typical audio circuits. Because of this, an audio transformer cannot be substituted for a microphone preamp. If more than 25 dB of gain is required, an active preamp must be used instead of a transformer.

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Air Core RF Transformers

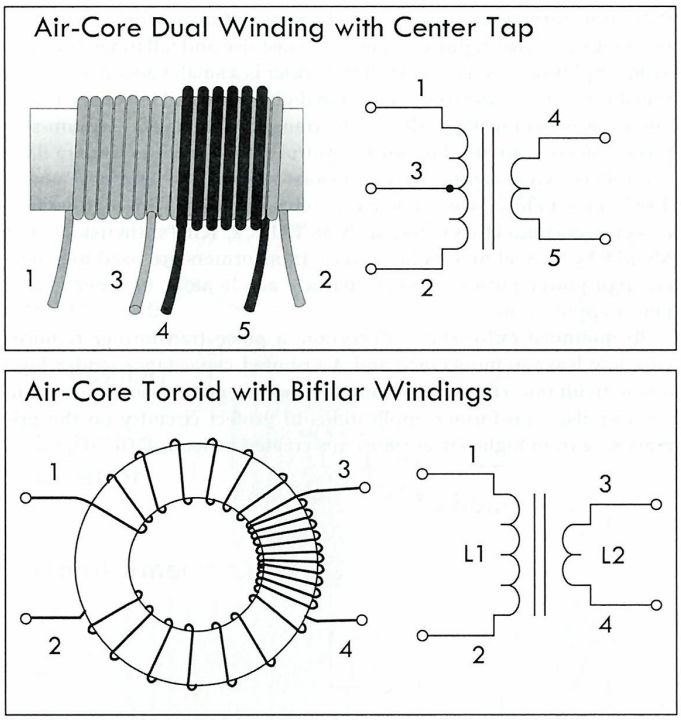


FIGURE 3.114

Air core transformers are special devices used in radio-frequency circuits. (They are used for RF coupling, such as antenna tuning and impedance matching.) Unlike steel or ferrite core transformers, the core is made from a nonmagnetic form, usually a hollow tube of plastic. The degree of coupling between windings in an air core transformer is much less than that of a steel core transformer; however, there are no losses associated with eddy currents, hysteresis, saturation, and so on, as is the case with magnetic cores. This becomes critically important in RF applications—at high frequencies, steel core transformers experience significant losses. Toroidal air core transformers aren't common nowadays, except in VHF (very high frequency) work. Today, special coupling networks and RF powdered-iron and ferrite toroids have generally replaced air cores, except in situations where the circuit handles very high power or the coils must be very temperature stable.

Ferrite and Powdered-Iron Toroidal Transformers

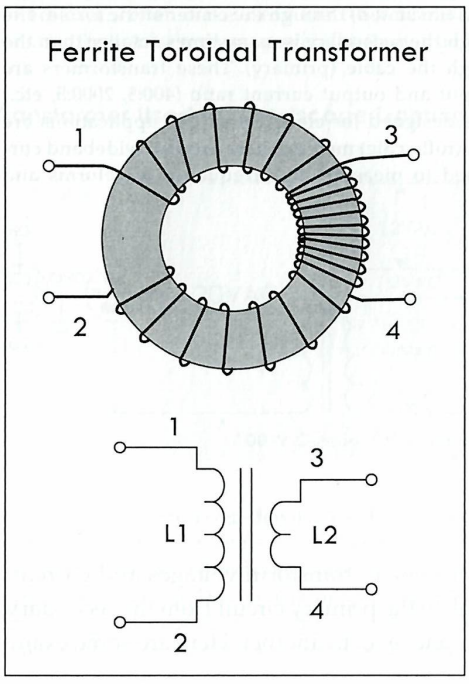


FIGURE 3.115

Toroidal ferrite and powdered-iron transformers are used from a few hundred hertz well into the UHF spectrum. The principal advantage of this type of core is self-shielding and low losses due to eddy currents. The permeability/size ratio is also very large, making them compact devices requiring fewer coil turns than traditional transformers. The most common ferrite toroid transformer is the conventional broadband transformer. Broadband transformers provide dc isolation between the primary and secondary circuits. The primary of a step-down impedance transformer is wound to occupy the entire core, with the secondary wound over the primary, as shown in Fig. 3.115. This style of transformer is frequently used in impedance matching. In standard broadcast radio receivers, these transformers operate in a frequency range from 530 to 1550 kHz. In shortwave receivers, RF transformers are subjected to frequencies up to about 20 MHz; in radar, it approaches upward of 200 MHz.

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Pulse and Small Signal Transformers

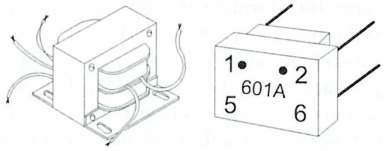


FIGURE 3.116

Pulse transformers are special transformers optimized for transmitting rectangular electrical pulses—ones with fast rise and fall times and constant amplitude. A small signal transformer is a small version of a pulse transformer. These devices are used in digital logic and telecom circuits, often for matching logic drivers to transmission lines. Medium-size power versions are used in power-control circuits such as camera flash controllers, while larger-power versions are used in electrical power distribution to interface low-voltage control circuitry with high-voltage power semiconductive gates, such as TRIACs, IGBTs, thyristors, and MOSFETs. Special high-voltage pulse transformers are used to generate high-power pulses for radar, particle accelerators, or other pulsed power applications.

To minimize pulse shape distortion, a pulse transformer requires very low leakage inductance and distributed capacitance, and a high open-circuit inductance. Low coupling capacitance is also important in power-pulse transformer applications to protect circuitry on the primary side from high-power transients created by load.

Current Transformers

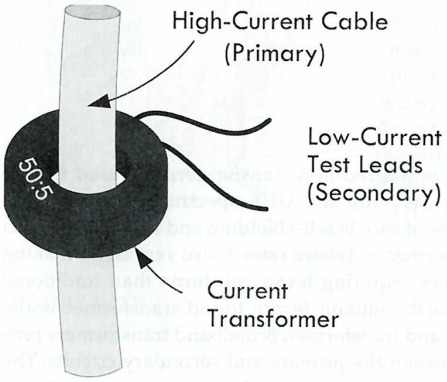


FIGURE 3.117

Current transformers are special devices used primarily to measure larger currents that would be too dangerous to measure with an ammeter. They are designed to provide a current in their secondary that is proportional to the current flowing in the primary. A typical current transformer resembles a toroidal core inductor with many secondary windings. The primary coil consists of simply passing a single cable-to-be-measured (insulated) through the center of the toroid. The output current through the secondary is many times smaller than the actual current through the cable (primary). These transformers are specified by their input and output current ratio (400:5, 2000:5, etc.) Current transformers designed for electrical supply applications are designed to drive 5-A (full-scale) meters. There are also wideband current transformers used to measure high-frequency waveforms and pulsed currents.

3.8.6 Transformer Applications

There are three principal uses for transformers: to transform voltages and currents from one level to another, to physically isolate the primary circuit from the secondary, and to transform circuit impedances from one level to another. Here are some examples in action.

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Center-Tap Pole Transformer

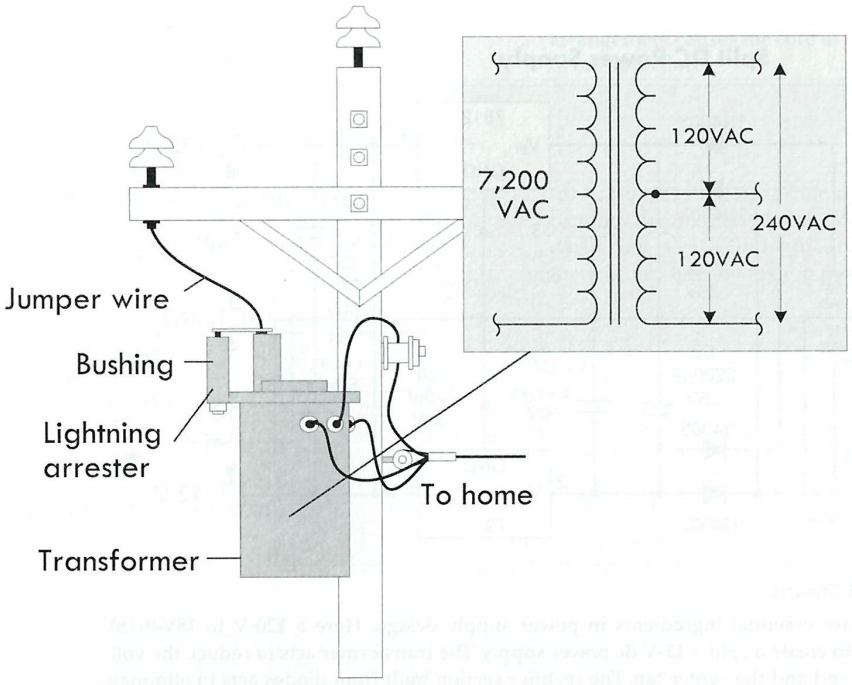


FIGURE 3.118 In the United States, main power lines carry ac voltages upward of several thousand volts. A center-tap pole transformer is used to step down the line voltage to 240 V. The tap then acts to break this voltage up into 120-V portions. Small appliances, such as TVs, lights, and hair dryers can use either the top line and the neutral line or the bottom line and the neutral line. (The neutral is grounded to a ground rod through a link between neutral and ground buses in the breaker box.) Larger appliances, such as stoves, refrigerators, and clothes dryers often make use of the 240-V terminals and often use the neutral terminal as well. See App. A for more on power distribution and home wiring.

Transformer Used for Landscape Lighting

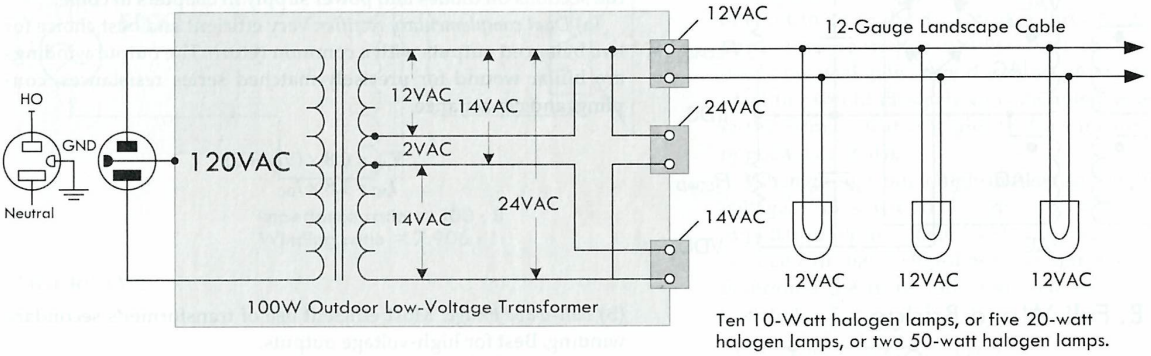


FIGURE 3.119 Here a step-down low-voltage transformer is used to drive quartz halogen landscape lamps. The lamps in this case don't care if the voltage is ac since the frequency (60 Hz) is too fast for there to be any noticeable variation in luminous output. Most commercial transformers used for landscape wiring, or for driving solenoid-powered sprinkler systems, will come with multiple outputs. This transformer provides 12-V, 24-V, and 14-V outputs. The 14-V output may be used to drive 12-V lamps if there is an anticipated voltage drop along long cable runs; the 24-V output may be used to drive 24-V devices. Note that the total load should not consume more power than the transformer's rated output capacity. For example, this 100-W transformer should not be used to drive more than, say, ten 10-watt lamps or five 20-watt lamps. Exceeding this will result in lamp dimming.

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Step-Down Transformer for DC Power Supply

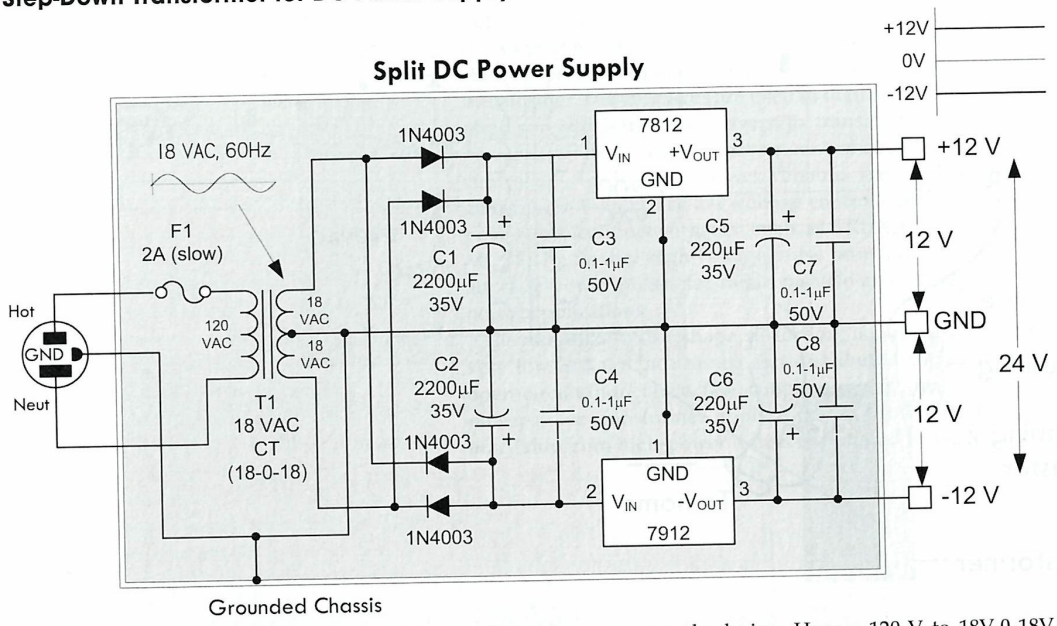


FIGURE 3.120 Transformers are essential ingredients in power supply design. Here a 120-V to 18V-0-18V center-tap transformer is used to create a split ±12-V dc power supply. The transformer acts to reduce the voltage to 18 VAC across each coil end and the center tap. The rectifier section built from diodes acts to eliminate negative swings in the upper positive section and eliminate positive swings in the lower section. Capacitors are thrown in to remove the pulsating dc and make the voltages appear dc. The regulators are used to set the dc voltages to exactly +12 V and −12 V. See Chap. 10 on power supplies for more details.

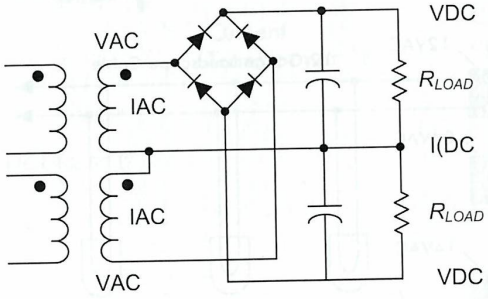
Various Transformer/Rectifier Arrangements

There are various ways in which to create dc power supplies. Figure 3.121 shows the four basic schemes used. Each scheme has its pros and cons, which are briefly described here and in greater detail in the sections on diodes and power supply in chapters to come.

(a) *Dual complementary rectifier:* Very efficient and best choice for two balanced outputs with a common return. The output windings are bifilar wound for precisely matched series resistances, coupling, and capacitance.

$$V_{AC} = 0.8 \times (V_{DC} + 2)$$
$$I_{AC} = 1.8 \times I_{DC}$$

A. Dual Complementary Rectifier



(b) *Full-wave bridge:* Most efficient use of transformer's secondary winding. Best for high-voltage outputs.

$$V_{AC} = 0.8 \times (V_{DC} + 2)$$
$$I_{AC} = 1.8 \times I_{DC}$$

B. Full-Wave Bridge

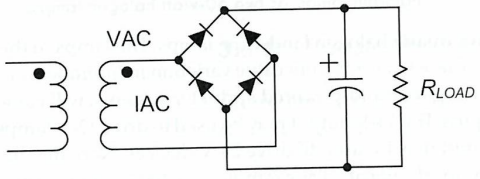
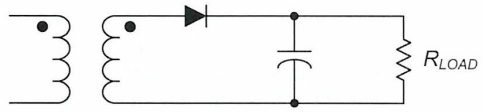


FIGURE 3.121

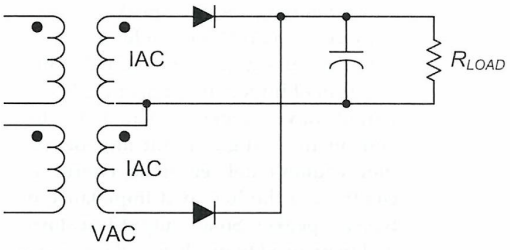
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C. Half-Wave Rectifier



(c) *Half-wave rectifier:* This design should be avoided for power supply design, as it is an inefficient use of the transformer. This arrangement causes the core to become polarized and to saturate in one direction.

D. Full-Wave Center Tap



(d) *Full-wave center tap:* While more efficient than the half-wave rectifier circuit, the full wave does not make full use of secondaries, but is good for high-current, low-voltage applications, as there is only one diode drop per positive half cycle.

$$V_{AC} = 1.7 \times (V_{DC} + 1)$$
$$I_{AC} = 1.2 \times I_{DC}$$

FIGURE 3.121 (*Continued*)

Audio Impedance Matching

A. Need for Matching Impedances

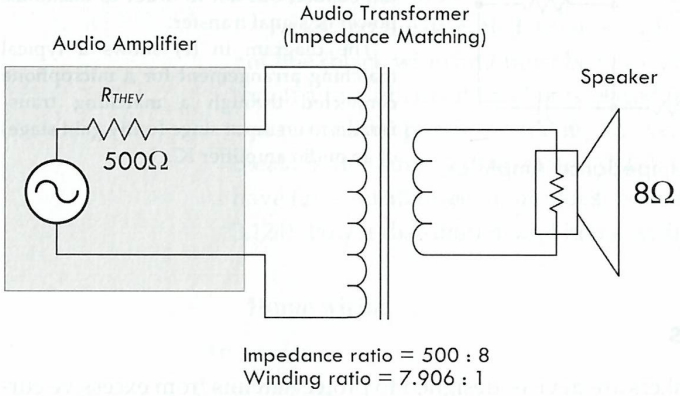


FIGURE 3.122

(a) Maximum power is transferred to a load if the load impedance is equal to the Thevenin impedance of the network supplying power. To supply maximum power transfer from the audio amplifier with an output impedance of 500 Ω to an 8-Ω speaker, we must properly match the load impedance with that of the output impedance (or Thevenin impedance) of the source. If we were not to match impedance and attempt to drive the 8-Ω speaker directly, the impedance mismatch would result in very poor (low peak power) performance. Also, the amplifier would dissipate considerable power in the form of heat as it tries to drive the low-impedance speaker.

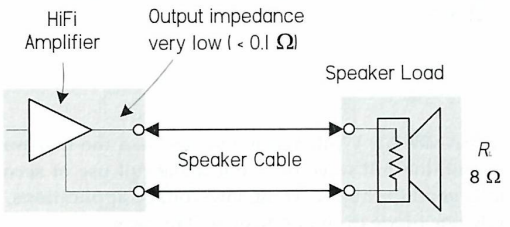
When going from a high-impedance (high-voltage, low-current) source to a low-impedance (low-voltage, high-current) load, we need to use a step-down transformer. To determine the turns ratio required, we refer back to Eq. 5:

$$\frac{N_P}{N_S} = \sqrt{\frac{Z_P}{Z_S}} = \sqrt{\frac{500\ \Omega}{8\ \Omega}} = 7.906$$

In other words, the required winding ratio is 7.906:1. With such a transformer in place, the speaker will load the amplifier to just the right degree, drawing power at the correct voltage and current levels for the most efficient power transfer to load.

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B. No Need for Matching



Virtually all audio power from amplifer is transferred into speaker.

(b) Note that most hi-fi amplifier and speaker systems have amplifiers with output impedances much lower than the speaker impedance. A typical speaker impedance is 8 Ω, for example, but most hi-fi amplifiers have an output impedance of 0.1 Ω or less. This not only ensures that most of the audio energy is transferred to the speaker, but also that the amplifier's low output impedance provides good electrical damping for the speaker's moving voice coil—giving higher fidelity.

Older valve amplifiers needed a different form of impedance matching, because output valves generally had fairly fixed and relatively high output impedance so they couldn't deliver audio energy efficiently into the low load impedance of a typical speaker. So an output transformer had to be used to produce a closer impedance match. The transformer stepped up the impedance of the speaker, so that it gave the output valve an effective load of a few thousand ohms; this was at least comparable to the valve's own output impedance, so only a small amount of energy was wasted as heat in the valve.

C. Microphone Input Transformer

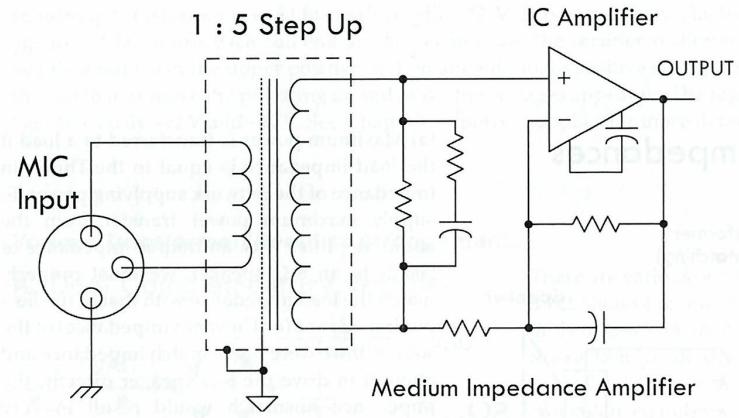


FIGURE 3.122 (*Continued*)

(c) The only area in audio where impedance matching (of a different kind) tends to be important is with transducers such as microphones, gramophone pickups, and tape heads. Here, the transducer often needs to be provided with particular load impedance, but not in order to maximize power or signal transfer.

The diagram in (c) shows a typical matching arrangement for a microphone connected through a matching transformer to an input stage (unity gain stage) of an audio amplifier IC.

3.9 Fuses and Circuit Breakers

Fuses and circuit breakers are devices designed to protect circuits from excessive current flows, which are often a result of large currents that result from shorts or sudden power surges. A fuse contains a narrow strip of metal that is designed to melt when current flow exceeds its current rating, thereby interrupting power to the circuit. Once a fuse blows (wire melts), it must be replaced with a new one. A circuit breaker is a mechanical device that can be reset after it "blows." It contains a spring-loaded contact that is latched into position against another contact. When the current flow exceeds a breaker's current rating, a bimetallic strip heats up and bends. As the strip bends, it "trips" the latch, and the spring pulls the contacts apart. To reset the breaker, a button or rockerlike switch is pressed to compress the spring and reset the latch.

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CHAPTER 6

Integrated Circuits

An *integrated circuit* (IC) is a miniaturized circuit that contains a number of resistors, capacitors, diodes, and transistors stuffed together on a single chip of silicon no bigger than your fingernail. The number of resistors, capacitors, diodes, and transistors within an IC may vary from just a few to hundreds of thousands in number. The trick to cramming everything into such a small package is to make all the components out of tiny *n*-type and *p*-type silicon structures that get imbedded into the silicon chip during the production phase. To connect the little transistors, resistors, capacitors, and diodes together, aluminum plating is applied along the surface of the chip. Here is a magnified cross-sectional view of an IC showing how the various components are embedded and linked together.

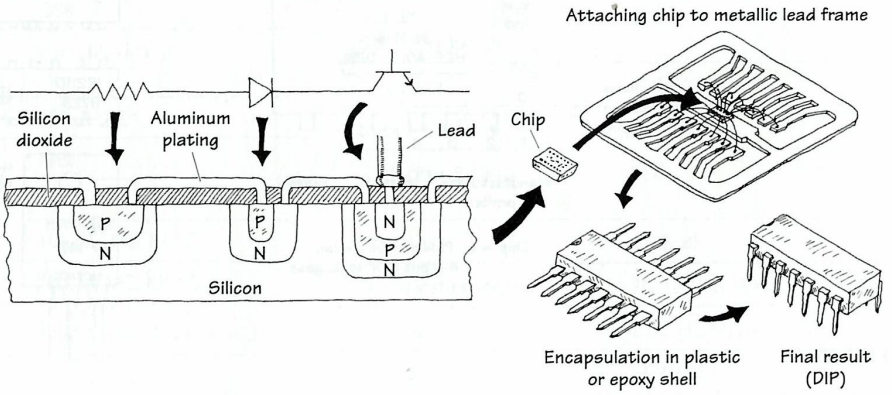


FIGURE 6.1

ICs come in either analog, digital, or analog/digital form. Analog (or linear) ICs produce, amplify, or respond to varying voltages. Digital (or logic) ICs respond to or produce signals having only high and low voltage states, whereas analog/digital ICs share properties common with both analog and digital ICs. Some common analog ICs include voltage regulators, operational amplifiers,

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comparators, timers, and oscillators. Common digital ICs include logic gates (e.g., AND, OR, NOR, etc.), flip-flops, memories, processors, binary counters, shift registers, multiplexers, encoders and decoders, etc. Analog/digital ICs may take on a number of different forms. For example, such an IC may be designed primarily as an analog timer but may contain a digital counter. Alternatively, the IC may be designed to read in digital information and then use this information to produce a linear output that can be used to drive, say, a stepper motor or LED display.

6.1 IC Packages

ICs are housed most frequently in dual in-line packages (DIPs). These packages consist of a plastic or ceramic box with metal pins sticking out of its sides. Each pin has a specific function and an identification number. The number 1 pin is located to the left of an index marker (see Fig. 6.2), while the succeeding pins are counted off in a counterclockwise direction. A manufacturer's logo, manufacturer's prefix, part number, and date code are almost always printed on an IC package. Other numbers and symbols found on ICs are often used to specify production process, temperature range, package type, etc. Here are a few deciphered ICs to get you going.

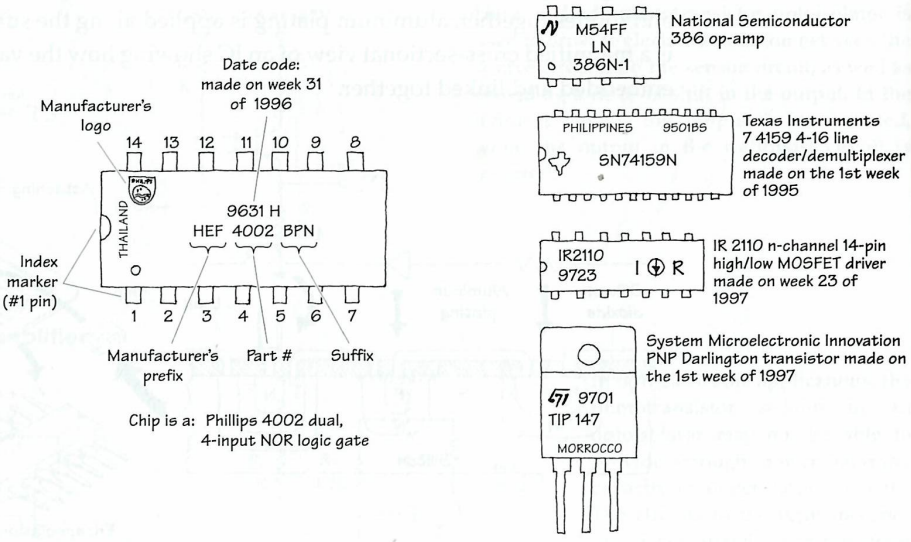


FIGURE 6.2

Notably, some IC labeling systems use an "xx44c55p-1" format. "xx" represents the manufacturer's prefix, "44" represents the chip family code, "c" represents the fabrication process (e.g., c = CMOS, f = fast, hc = high speed CMOS, hct = high speed CMOS TTL compatible, ls = low power schottky, etc.), "pp" (the suffix) represents the package code (specific to an individual manufacturer), and "1" represents the speed of the device.

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Table 6.1 presents a partial list of company prefixes. It is important to note that the prefixes may not always be helpful in determining the actual manufacturer. As it turns out, a number of different manufacturers use similar prefixes. For example, the prefix "P" is used by the following companies: ASD, Harris, Hewlett-Packard, Intel, Mitsubishi, Motorola, NEC, Phillips, SGS, and Temic. If you are not sure which company the prefix belongs to, check out the manufacturer's logo.

TABLE 6.1 Company Prefixes

MANUFACTURER	PREFIX	MANUFACTURER	PREFIX
Allegro	A, μPA, UCX	Siliconix	L, LD
Analog Devices	AD	Linear Technology	LT
Advanced Micro Devices	Am, A, AO	Mitsubishi	M
Panasonic	An	Fugitsu	MB,FTU
General Instrument	AY, GIC, GP, GI, FE, GF, W, GI	MOS Technology	MCS
Sony	Bx, Cx, GI	Microsystems International	MIL
Intel	B, C, I, M, IR, A, AP AT	Mostek	MK
RCA (now Harris)	CA, CD, CDP	Plessey	MN, SL, SP
TRW	CA, TDC, MPY, CMP, DAC, MAT, OP	Signetics	N, NE, S, SE, SP
Precision Monolithics	PM, REF, SSS	Next	Nx
National Semiconductor	DM, LF, LFT, LH, LM, NH, NA, ND*x*	NTE	NTE
Sanyo	DSK	Precision Monolithics	PM
Fairchild (now National Semiconductor)	F μA, μL, U*nx*	Quality Semiconductor	QS
Ferranti	FSS, ZLD, Zn	Raytheon	R, RAY, RC, RM
GE	GEL	Silicon General	SG
Harris	HA	Shanghai Belling Micro	SGS
Hitachi	HA, HD, HG, HI, HZ	Siemens	B, BB, BF
Motorola	HEP, M, MC, MCC, MCM, MFC, MM, MWM, HEF, HEED, T, CH, J	Texas Instruments	SN, TL, TMS, TEX
		Toshiba	T, TC, HZ, M, TA, TH, JT
Intersil	ICH, ICL, ICM, IM	Sprague	ULN, ULS
IR	IR, IRB, IR*xx*	NEC	μP, μTD, NRA, NRB, NRx
Sharp	IR	Westinghouse	WC, WM
ITT	ITT, MIC	Exar	XR
Philips	HEF, HCF, M, AD, AJ, J, B, BB, BA, ON, OT	Yamaha	YAC, YM, YMF, YSS
		Hewlett-Packard	5082-*nnnn*, AT
Samsung	KA, IR, K K*xx*		

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Another problem when deciphering IC labels is figuring out what the suffixes mean. Often a manufacturer will place a suffix at the end of a part number to indicate the type of package (e.g., ceramic dual-in-line, plastic dual-in-line package, etc.) or to indicate temperature range. The frustrating thing with suffixes is that there is no standard convention used. Each manufacturer's suffix may have its own unique meaning.

A more complete and up-to-date listing of company prefixes can be found in the Chip Directory's Web site (*www.chipdir.net*). If this link does not work, run a search using "Chip Directory" as your keyword. The Chip Directory also provides listings of company logos, company abbreviations, suffix meanings, chips by number, chips by name, chips by family, chip manufacturers, and links to manufacturers' Web sites.

6.2 Some Basic ICs to Get You Started

TL783 Three-Terminal Adjustable Voltage Regulator

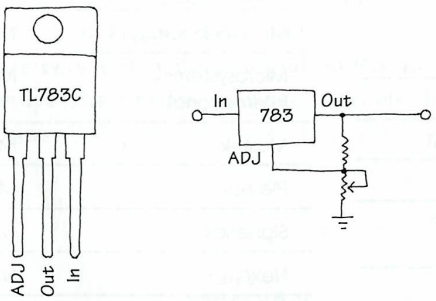


FIGURE 6.3

This device is used as an adjustable voltage regulator for high-voltage applications. Output can be adjusted from 1.25 to 125 V, with a maximum output current of 700 mA. Two external resistors are required to program the output voltage. Voltage regulators will be covered in greater detail in Chap. 10.

741CD Op Amp

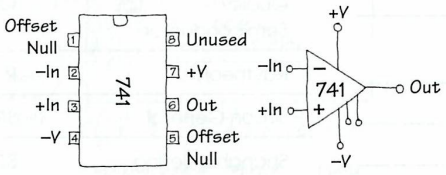


FIGURE 6.4

A 741 op amp is a very popular high-performance linear amplifier IC. When a feedback resistor is connected from its output to its inverting input, the device can be made to do some amazing things. For example, you can use op amps to build inverting and noninverting amplifiers, oscillators, integrators, differentiators, adders, and subtractors. Without feedback, the device acts as a comparator. The 741 op amp is made by a number of different manufacturers. To learn more about op amps, see Chap. 7.

555 Timer

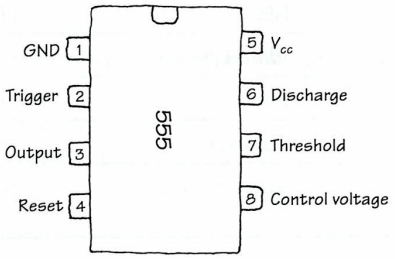


FIGURE 6.5

This is a very versatile IC that acts as a kind of smart on/off switch that can be made to turn on and off at a rate you set by wiring resistors and capacitors between its leads and to and from supply voltages. These devices are used in timer circuits, oscillator circuits, logic clock generators, and tone generators. The 555 timer is described in detail in Chap. 8.

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LM7411 Three-Input AND Gate

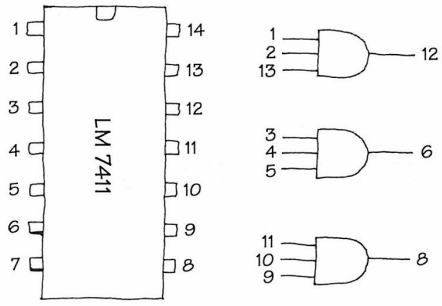


FIGURE 6.6

The 7411 contains three functionally independent three-input AND gates. All three gates are powered through a common supply pin. NAND gates, OR gates, NOR gates, memories, microprocessors, microcontrollers, and other logic ICs are discussed in Chap. 12.

MM5480 LED Display Driver

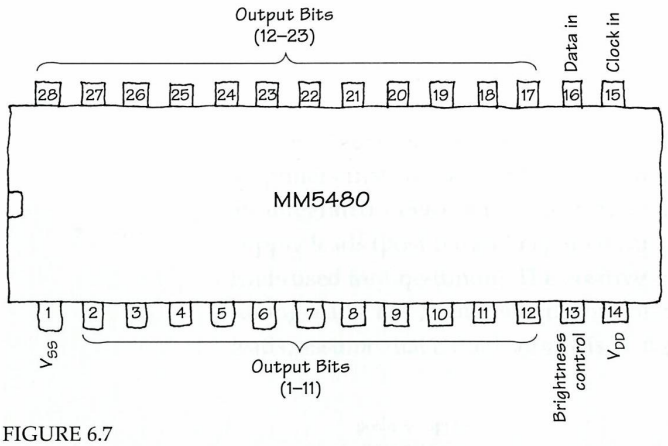


FIGURE 6.7

This IC is designed to drive common-anode, separate-cathode LED displays. A single pin connected to a supply voltage through a variable resistor controls the LED display's brightness. Some features include continuous brightness control, serial data input, no load signal requirement, TTL compatibility, 3½-digit displays, and wide dc power supply operation. The MM5480 can be used in industrial control indicators, digital clocks, thermometers, counters, and voltmeters. LED displays and display drivers are discussed in Chap. 12.

LM628 Precision Motion Controller

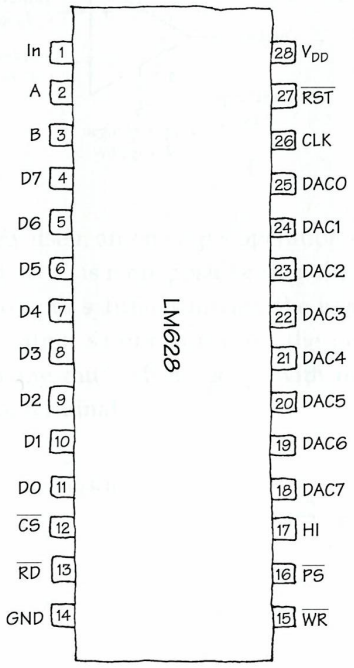


FIGURE 6.8

The LM628 is a motion-control processor that uses a quadrature incremental position feedback signal from dc motors, brushless dc servo motors, and other servo mechanisms. The device has an 8-bit output that can drive an 8-bit or 12-bit DAC, which in turn makes it possible to construct a servo system that includes using a dc motor, an actuator, an incremental encoder, a DAC, and a power amplifier. Features include 32-bit position, velocity and acceleration registers, position and velocity modes of operation, real-time programmable host interrupts, an 8-bit parallel asynchronous host interface, and a quadrature incremental encoder.

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APPENDIX A

Power Distribution and Home Wiring

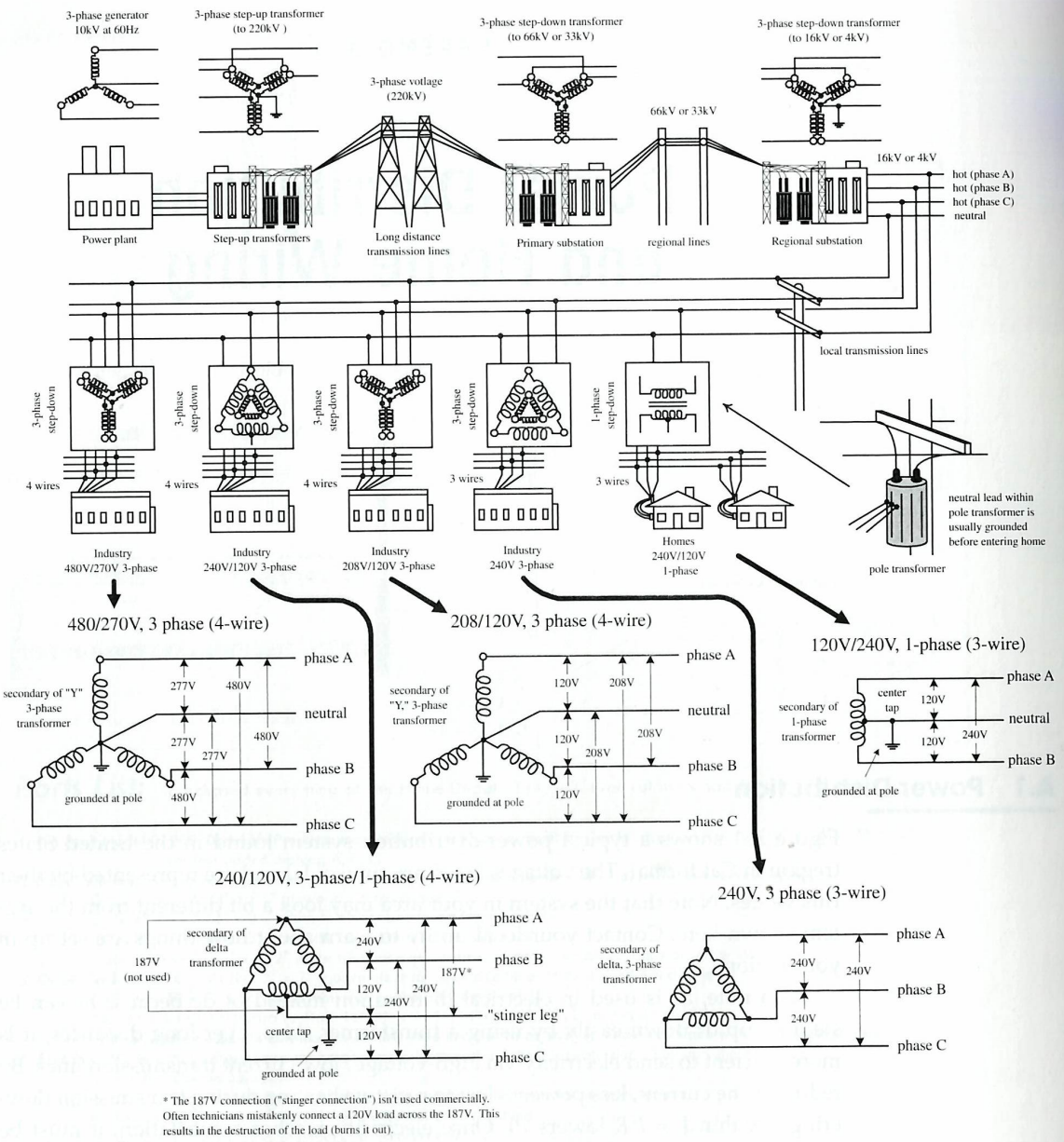
A.1 Power Distribution

Figure A.1 shows a typical power-distribution system found in the United States (region in California). The voltages listed are sinusoidal and are represented by their rms values. Note that the system in your area may look a bit different from the system shown here. Contact your local utility to learn about how things are set up in your region.

As a note, ac is used in electrical distribution instead of dc because ac can be stepped up or down easily by using a transformer. Also, over long distances, it is more efficient to send electricity via high-voltage/low-current transmission lines. By reducing the current, less power is lost to resistive heating during transmission (lowering I within $P = I^2R$ lowers P). Once electricity reaches a substation, it must be stepped down to a safe level before entering homes and businesses.

Notice that industry typically uses three-phase electricity. The natural sequencing of the three phases is particularly useful for devices that perform rhythmic tasks. For example, three-phase electric motors (found in grinders, lathes, welders, air conditioners, and other high-power devices) often turn in near synchrony with the rising and falling voltages of the phases. Also, with three-phase electric power, there is never a time when all three phases are at the same voltage. With single-phase power, whenever the two phases have the same voltage, there is temporarily no electric power available. This is why single-phase electric devices must store energy to carry them over these dry spells. In three-phase power, a device can always obtain power from at least one pair of phases.

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* The 187V connection ("stinger connection") isn't used commercially. Often technicians mistakenly connect a 120V load across the 187V. This results in the destruction of the load (burns it out).

FIGURE A.1

A.2 A Closer Look at Three-Phase Electricity

The simple generator shown in Fig. A.2 can be used to generate single-phase voltage. As the magnet is rotated by a mechanical force, a voltage is induced within the two coils (spaced 180° apart) that yields a single sinusoidal voltage. The output voltage is usually expressed as an rms voltage ($V_{rms} = 1/\sqrt{2}\, V_0$).

In the three-phase generator, three separate voltages are generated by using three different coils spaced 120° apart. As the magnet rotates, a voltage is induced across each of the generator's coils. All the coil voltages are equal in magnitude but are 120°

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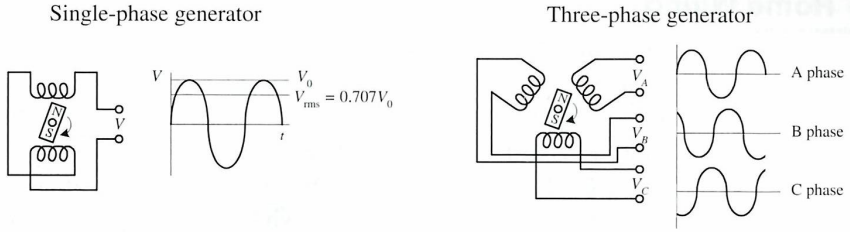


FIGURE A.2

out of phase with each other. With this generator, you could power three separate loads of equal resistance, or you could drive a three-phase motor with a similar coil configuration; however, this requires using six separate wires. To reduce the number of wires, there are two tricks that can be used. The first trick involves rearranging the three-phase coil connections into what is called a *delta connection*—which yields three wires. The second trick involves rearranging the coil connection into what is called a *Y connection*—which yields four wires. Here are the details.

Y Connection

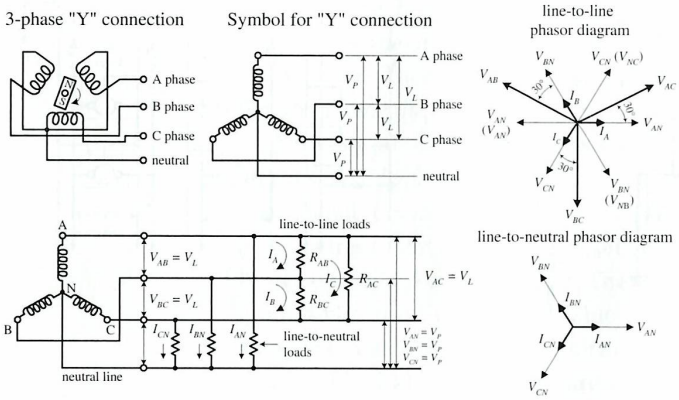


FIGURE A.3

A Y configuration is made by connecting one end of each of the generator's coils together to form what is called the *neutral* lead. The remaining three coil ends are brought out separately and are considered the "hot" leads. The voltage between the neutral and any one of the hot lines is called the *phase voltage* V_p. The total voltage, or *line voltage* V_L, is the voltage across any two hot leads. The line voltage is the vector sum of the individual phase voltages. In a Y-loaded circuit, each load has two phases in series. This means that the current and voltage through and across a load must be determined by superimposing the phase currents and phase voltages. One way to do this is to make a phasor diagram, as shown in the figure. For practical purposes, what is important to note is the line voltage is about $\sqrt{3}$ times the phase voltage. Also, the line currents are 30° out of phase with the line voltages. When a neutral is used, the line currents and line voltages are equal to the individual phases from the generator. No current flows in the neutral when the loads are equal across each phase (balanced load).

Delta Connection

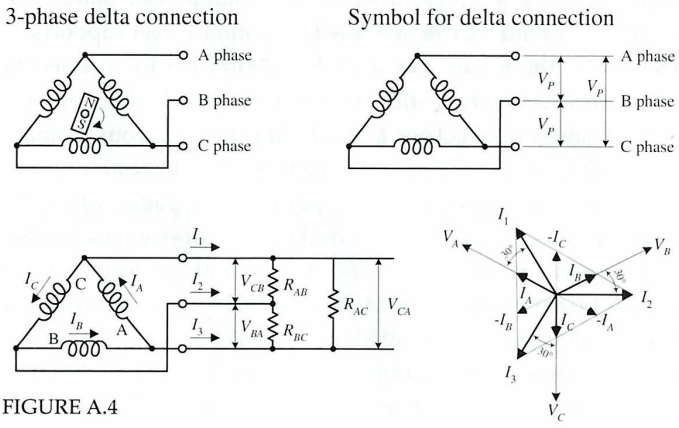


FIGURE A.4

A delta connection is made by placing the three-phase generator's coils end to end, as shown in the figure. Because the delta configuration has no neutral lead, the phase voltages are equal to the line voltages. Again, like the Y configuration, all line voltages are 120° out of phase with each other. However, unlike the Y configuration, the line currents (I_1, I_2, I_3) are equal to the vector sum of the phase currents (I_A, I_B, I_C). When each of the phases are equally loaded, the line currents are all equal but 120° apart. The line currents are 30° out of phase with the line voltages, and they are $\sqrt{3}$ times the phase currents.

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A.3 Home Wiring

In the United States, three wires run from the pole transformer (or "green box" transformer) to the main service panel at one's home. One wire is the A-phase wire (black in color), another is the B-phase wire (black in color), and the third is the neutral wire (white in color). (Figure A.5 shows where these three wires originate within the pole/green box transformer.) The voltage between the A-phase and B-phase wires, or the "hot to hot" voltage, is 240 V, while the voltage between the neutral wire and either A-phase or B-phase wire, or the "neutral to hot" voltage, is 120 V. (These voltages are nominal and may vary from region to region.)

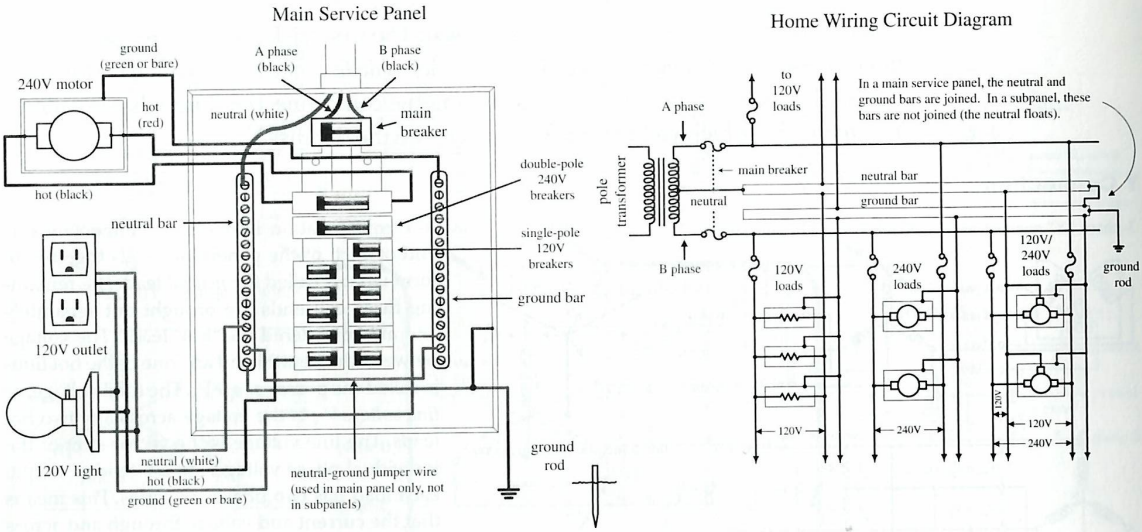


FIGURE A.5

At the home, the three wires from the pole/green box transformer are connected through a wattmeter and then enter a main service panel that is grounded to a long copper rod driven into the ground or to the steel in a home's foundation. The A-phase and B-phase wires that enter the main panel are connected through a main disconnect breaker, while the neutral wire is connected to a terminal referred to as the *neutral bar* or *neutral bus*. A *ground bar* also may be present within the main service panel. The ground bar is connected to the grounding rod or to the foundation's steel supports.

Within main service panels, the neutral bar and the ground bar are connected together (they act as one). However, within subpanels (service panels that get their power from the main service panel but which are located some distance from the main service panel), the neutral and ground bars are not joined together. Instead, the subpanel's ground bar receives a ground wire from the main service panel. Often the metal conduit that is used to transport the wires from the main service panel to the subpanel is used as the "ground wire." However, for certain critical applications (e.g., computer and life-support systems), the ground wire probably will be included within the conduit. Also, if a subpanel is not located in the same building as the main panel, a new ground rod typically is used to ground the subpanel. Note that different regions within the United States may use different wiring protocols. Therefore, do

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not assume that what I am telling you is standard practice where you live. Contact your local electrical inspector.

Within the main service panel, there are typically two bus bars into which circuit breaker modules are inserted. One of these bus bars is connected to the A-phase wire; the other bus bar is connected to the B-phase wire. To power a group of 120-V loads (e.g., upstairs lights and 120-V outlets), you throw the main breaker to the off position and then insert a single-pole breaker into one of the bus bars. (You can choose either the A-phase bus bar or the B-phase bus bar. The choice of which bus bar you use only becomes important when it comes to balancing the overall load—more on that in a second.) Next, you take a 120-V three-wire cable and connect the cable's black (hot) wire to the breaker, connect the cable's white (neutral) wire to the neutral bar, and connect the cable's ground wire (green or bare) to the ground bar. You then run the cable to where the 120-V loads are located, connect the hot and neutral wires across the load, and fasten the ground wire to the case of the load (typically a ground screw is supplied on an outlet mounting or light figure for this purpose). To power other 120-V loads that use their own breakers, you basically do the same thing you did in the last setup. However, to maximize the capacity of the main panel (or subpanel) to supply as much current as possible without overloading the main circuit breaker in the process, it is important to balance the number of loads connected to the A-phase breakers with the number of loads connected to the B-phase breakers. This is referred to as *balancing the load*.

Now, if you want to supply power to 240-V appliances (e.g., ovens, washers, etc.), you insert a double-pole breaker between the A-phase and B-phase bus bars in the main panel (or subpanel). Next, you take a 240-V three-wire cable and attach one of its hot wires to the A-phase terminal of the breaker and attach its other hot wire to the B-phase terminal of the breaker. The ground wire (green or bare) is connected to the ground bar. You then run the cable to where the 240-V loads are located and attach the wires to the corresponding terminals of the load (typically within a 240-V outlet). Also, 120-V/240-V appliances are wired in a similar manner, except you use a four-wire cable that contains an additional neutral (white) wire that is joined at the neutral bar within the main panel (or subpanel). (As a practical note, you could use a four-wire 120-V/240-V cable instead of a 240-V three-wire cable for 240-V applications—you would just leave the neutral wire alone in this case.)

As a note of caution, do not attempt home wiring unless you are sure of your abilities. If you feel that you are capable, just make sure to flip the main breaker off before you start work within the main service panel. When working on light fixtures, switches, and outlets that are connected to an individual breaker, tag that breaker with tape so that you do not mistakenly flip the wrong breaker when you go back to test your connections.

A.4 Electricity in Other Countries

In the United States, homes receive a 60-Hz, 120-V single-phase voltage, whereas industry typically receives a 60-Hz, 208-V/120-V three-phase voltage. Most other countries, on the other hand, work with a 50-Hz, 230-V single-phase voltage and a 415-V three-phase voltage. Now, if you were to take a U.S.-built 120-V, 60-Hz device over to Norway—where 230 V is used—and plug that device directly into the outlet

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(you would need an adapter to do this—their outlets look different), you run a risk of damaging the device. Some devices may not "care" about the voltage and frequency differences, but others will. You could use a converter (transformer plug-in device) to step down the voltage from the outlet, but you would still be stuck with 50 Hz. The 10-Hz difference will not affect most devices, but other devices, such as TVs and VCRs, may not function properly.

Here's a listing of single-phase voltages found in some countries. Note the plug types.

Country	Voltage V	Frequency Hz	Plug Type
Australia	240	50	I
Belgium	230	50	C, E
Brazil	110/220	60	A, B, C, D, G
Canada	120	60	A, B
Chile	220	50	C, L
China	220	50	I
Congo	230	50	C, E
Costa Rica	120	60	A, B
Egypt	220	60	C
France	230	50	C, E, F
Germany	230	50	F
Hong Kong	230	50	D, G
India	230	50	C, D
Iraq	220	50	C, D, G
Italy	127/220	50	F, L
Japan	100	50/60	A, B
Korea	110/220	60	A, B, D, G, I, K
Mexico	127	60	A
Netherlands	230	50	C, E
Norway	230	50	C, F
Philippines	110/220	60	A, B, C, E, F, I
Russia & former Soviet Republics)	220	50	C, F
Spain	127/220	50	C, E
Switzerland	220	50	C, E, J
Taiwan	110	60	A, B, I
US	120	60	A, B
United Kingdom	230	50	G

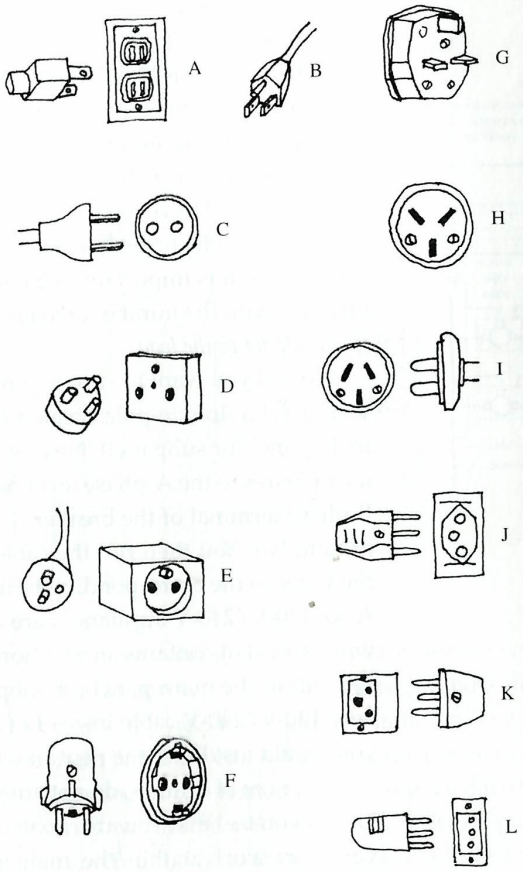


FIGURE A.6

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