or so depending on the specific brand of servo. Unlike the supply voltage, the supply current drawn by a servo varies greatly, depending on servo's power output.

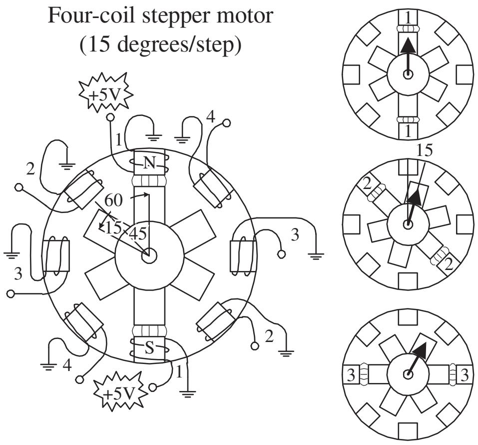
A simple 555 timer circuit like the one shown in Fig. 15.6 can be used to generate the servo control signal. In this circuit, R_2 acts as the pulse-width control. Servos also can be controlled by a microprocessor or microcontroller. See Chap. 13 for two microcontroller-based servo control circuits.

Now, when controlling servos within model airplanes, an initial control signal (generated by varying position-control potentiometers) is first sent to a radiowave modulator circuit that encodes the control signal within a carrier wave. This carrier wave is then radiated off as a radiowave by an antenna. The radiowave, in turn, is then transmitted to the model's receiver circuit. The receiver circuit recovers the initial control signal by demodulating the carrier. After that, the control signal is sent to the designated servo within the model. If there is more than one servo per model, more channels are required. For example, most RC airplanes require a four-channel radio set; one channel is used to control the ailerons, another channel controls the elevator, another controls the rudder, and another controls the throttle. More complex models may use five or six channels to control additional features such as flaps and retractable landing gear. The FCC sets aside 50 frequencies in the 72-MHz band (channels 11–60) dedicated to aircraft use only. No license is needed to operate these radios. However, with an amateur (ham) radio operator's license, it is possible to use a radio within the 50-MHz band. Also, there are frequencies set aside within the 27-MHz band that are legal for any kind of model use (surface or air). If you are interested in radio-controlled RC servos, a good starting point is to check out an RC model hobby shop. These shops carry a number of transmitter and receiver sets, along with the servos.

As a final note, with a bit of rewiring, a servo can be converted into a drive motor with unconstrained rotation. A simple way to modify the servo is to break the feedback loop. This involves removing the three-lead potentiometer (and unlinking the gear system so that it can rotate 360°) and replacing it with a pair of voltage-divider resistors (the output of the voltage divider replaces the variable terminal of the potentiometer). The voltage divider is used to convince the servo control circuit that the servo is in neutral position. The exact values of the resistors needed to set the servo in neutral position can be determined by using the old potentiometer and an ohmmeter. Now, to turn the motor clockwise, a pulse wider than 1.5 ms is applied to the control input. As long as the control signal is in place, the motor will keep turning and not stop—you have removed the feedback system. To turn the motor counterclockwise, a pulse narrower than 1.5 ms is applied to the control input.

15.5 Stepper Motors

Stepper motors, or *steppers*, are digitally controlled brushless motors that rotate a specific number of degrees (a step) every time a clock pulse is applied to a special translator circuit that is used to control the stepper. The number of degrees per step (resolution) for a given stepper motor can be as small as 0.72° per step or as large as 90° per step. Common general-purpose stepper resolutions are 15 and 30° per step. Unlike RC servos, steppers can rotate a full 360° and can be made to rotate in a continuous manner like a dc motor (but with a lower maximum speed) with the help of proper digital control circuitry. Unlike dc motors, steppers provide a large amount of torque at low speeds, making them suitable in applications where low-speed and high-precision position control is needed. For example, they are used in printers to control paper feed and are used to help a telescope track stars. Steppers are also found in plotter- and sensor-positioning applications. The list goes on. To give you a basic idea of how a stepper works, take a look at Fig. 15.7.



Here is a simple model depicting a 15° per step variable-reluctance stepper. The stationary section of the motor, called the *stator*, has eight poles that are spaced 45° apart. The moving section of the motor, called the *rotor*, is made from a ferromagnetic material (a material that is attracted to magnetic fields) that has six teeth spaced 60° apart. To make the rotor turn one step, current is applied, at the same time, through two opposing pole pairs, or coil pairs. The applied current causes the opposing pair of poles to become magnetized. This in turn causes the rotor's teeth to align with the poles, as shown in the figure. To make the rotor rotate 15° clockwise from this position, the current through coil pair 1 is removed and sent through coil pair 2. To make the rotor rotate another 15° clockwise from this position, the current is removed from coil pair 2 and sent through coil pair 3. The process continues in this way. To make the rotor spin counterclockwise, the coil-pair firing sequence is reversed.

FIGURE 15.7

15.6 Kinds of Stepper Motors

The model used in the last example was based on a variable-reluctance stepper. As it turns out, this model is incomplete—it does not show how a real variable-reluctance stepper is wired internally. Also, the model does not apply to a class of steppers referred to as *permanent-magnet steppers*. To make things more realistic, let's take a look at some real-life steppers.

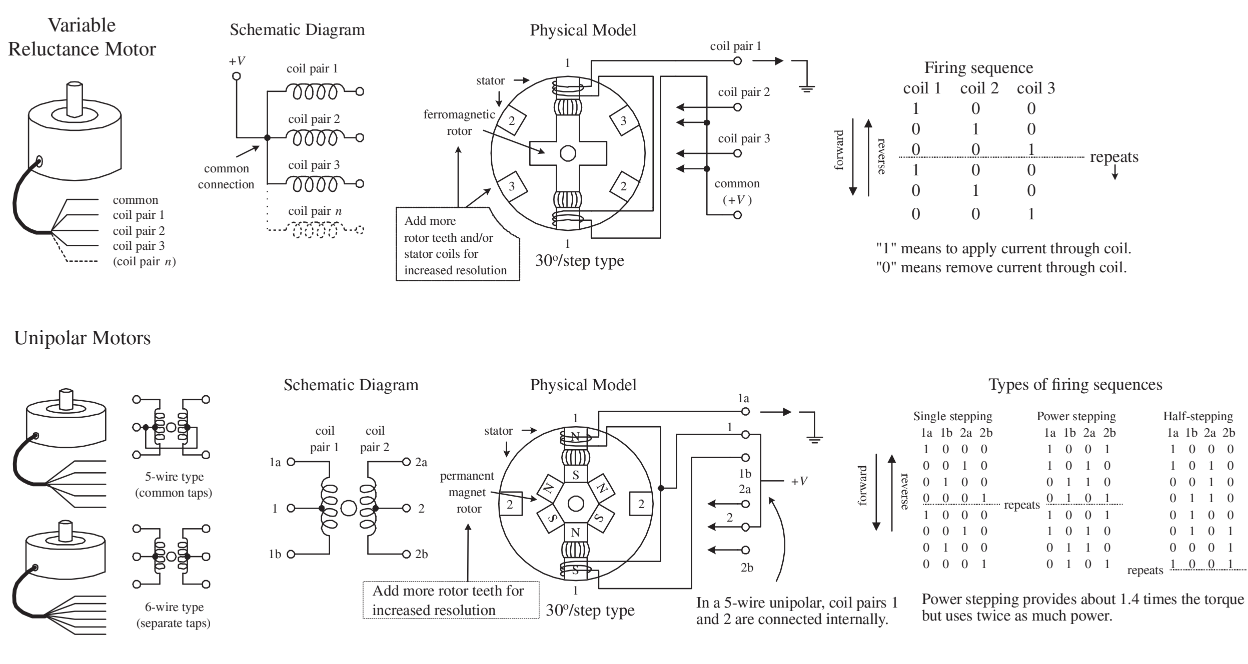


FIGURE 15.8

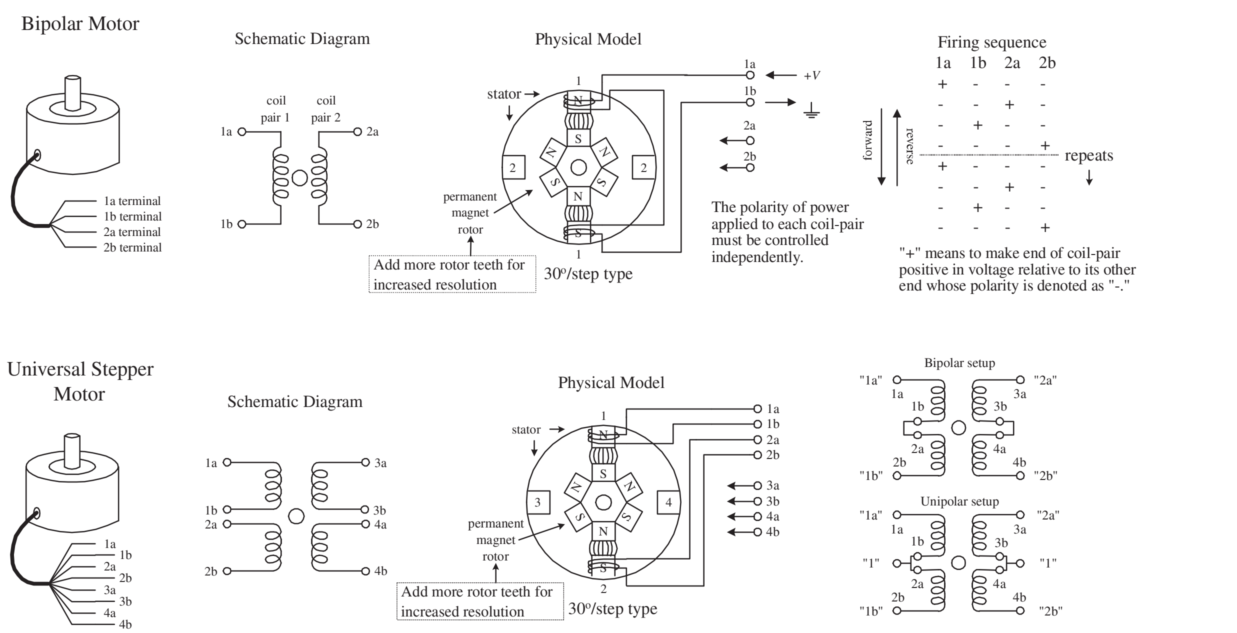


FIGURE 15.8 (*Continued*)

Variable-Reluctance Steppers

Figure 15.8 shows a physical model and schematic diagram of a 30° per step variable-reluctance stepper. This stepper consists of a six-pole (or three-coil pair) stator and a four-toothed ferromagnetic rotor. Variable-reluctance steppers with higher angular resolutions are constructed with more coil pairs and/or more rotor teeth. Notice that in both the physical model and the schematic, the ends of all the coil pairs are joined together at a common point. (This joining of the coil ends occurs internally within the motor's case.) The common and the coil pair free ends are brought out as wires from the motor's case. These wires are referred to as the *phase wires*. The common wire is connected to the supply voltage, whereas the phase wires are grounded in sequence according to the table shown in Fig. 15.8.

Permanent-Magnet Steppers (Unipolar, Bipolar, Universal)

UNIPOLAR STEPPERS

These steppers have a similar stator arrangement as the variable-reluctance steppers, but they use a permanent-magnet rotor and different internal wiring arrangements. Figure 15.8 shows a 30° per step unipolar stepper. It consists of a four-pole (or two-coil pair) stator with center taps between coil pairs and a six-toothed permanent-magnetic rotor. The center taps may be wired internally and brought out as one wire or may be brought out separately as two wires. The center taps typically are wired to the positive supply voltage, whereas the two free ends of a coil pair are alternately grounded to reverse the direction of the field provided by that winding. As shown in the figure, when current flows from the center tap of winding 1 out terminal 1a, the top stator pole "goes north," while the bottom stator pole "goes south." This causes the rotor to snap into position. If the current through winding 1 is removed, sent through winding 2, and out terminal 2a, the horizontal poles will become energized, causing the rotor to turn 30°, or one step. In Fig. 15.8, three firing sequences are shown. The first sequence provides full stepping action (what we just discussed). The second sequence, referred to as the *power stepping sequence*, provides full stepping action with 1.4 times the torque but twice the power consumption. The third sequence provides half stepping (e.g., 15° instead of the rated 30°). Half stepping is made possible by energizing adjacent poles at the same time. This pulls the rotor in-between the poles, thus resulting in one-half the stepping angle. As a final note, unipolar steppers with higher angular resolutions are constructed with more rotor teeth. Also, unipolars come in either five- or six-wire types. The five-wire type has the center taps joined internally, while the six-wire type does not.

BIPOLAR STEPPERS

These steppers resemble unipolar steppers, but their coil pairs do not have center taps. This means that instead of simply supplying a fixed supply voltage to a lead, as was the case in unipolar steppers (supply voltage was fixed to center taps), the supply voltage must be alternately applied to different coil ends. At the same time, the opposite end of a coil pair must be set to the opposite polarity (ground). For example, in Fig. 15.8, a 30° per step bipolar stepper is made to rotate by applying the polarities shown in the firing sequence table to the leads of the stepper. Notice that the firing sequence uses the same basic drive pattern as the unipolar stepper, but the "0" and "1" signals are replaced with "+" and "–" symbols to show that the polarity matters. As you will see in the next section, the circuitry used to drive a bipolar stepper requires an H-bridge network for every coil pair. Bipolar steppers are more difficult to control than both unipolar steppers and variable-reluctance steppers, but their unique polarity-shifting feature gives them a better size-to-torque ratio. As a final note, bipolar steppers with higher angular resolutions are constructed with more rotor teeth.

UNIVERSAL STEPPERS

These steppers represent a type of unipolar-bipolar hybrid. A universal stepper comes with four independent windings and eight leads. By connecting the coil windings in parallel, as shown in Fig. 15.8, the universal stepper can be converted into a unipolar stepper. If the coil windings are connected in series, the stepper can be converted into a bipolar stepper.

15.7 Driving Stepper Motors

Every stepper motor needs a driver circuit that can control the current flow sent through the coils within the stepper's stator. The driver, in turn, must be controlled by a logic circuit referred to as a *translator*. We will discuss translator circuits after we have covered the driver circuits.

Figure 15.9 shows driver networks for a variable-reluctance stepper and for a unipolar stepper. Both drivers use transistors to control current flow through the motor's individual windings. In both driver networks, input buffer stages are added to protect the translator circuit from the motor's supply voltage in the event of transistor collector-to-base breakdown. Diodes are added to both drivers to protect the transistors and power supply from inductive kickback generated by the motor's coils. (Notice that the unipolar driver uses extra diodes because inductive kickback can leak out on either side of the center tap. As you will see in a moment, a pair of diodes within this driver can be replaced with a single diode, keeping the diode count to four.) The single driver section shown in Fig. 15.9 provides a general idea of what kinds of components can be used within the driver networks. This circuit uses a high-power Darlington transistor, a TTL buffer, and a reasonably fast protection diode (the extra diode should be included in the unipolar circuit). If you do not want to bother with discrete components, transistor-array ICs, such as the ULN200x series by Allegro Microsystems or the DS200x series by National Semiconductor, can be used to construct the driver section. The ULN2003, shown in Fig. 15.9, is a TTL-compatible chip that contains seven Darlington transistors with protection diodes included. The 7407 buffer IC can be used with the ULN2003 to construct a full-stepper driver. Other ICs, such as Motorola's MC1414 Darlington array IC, can drive multiple motor winding directly from logic inputs.

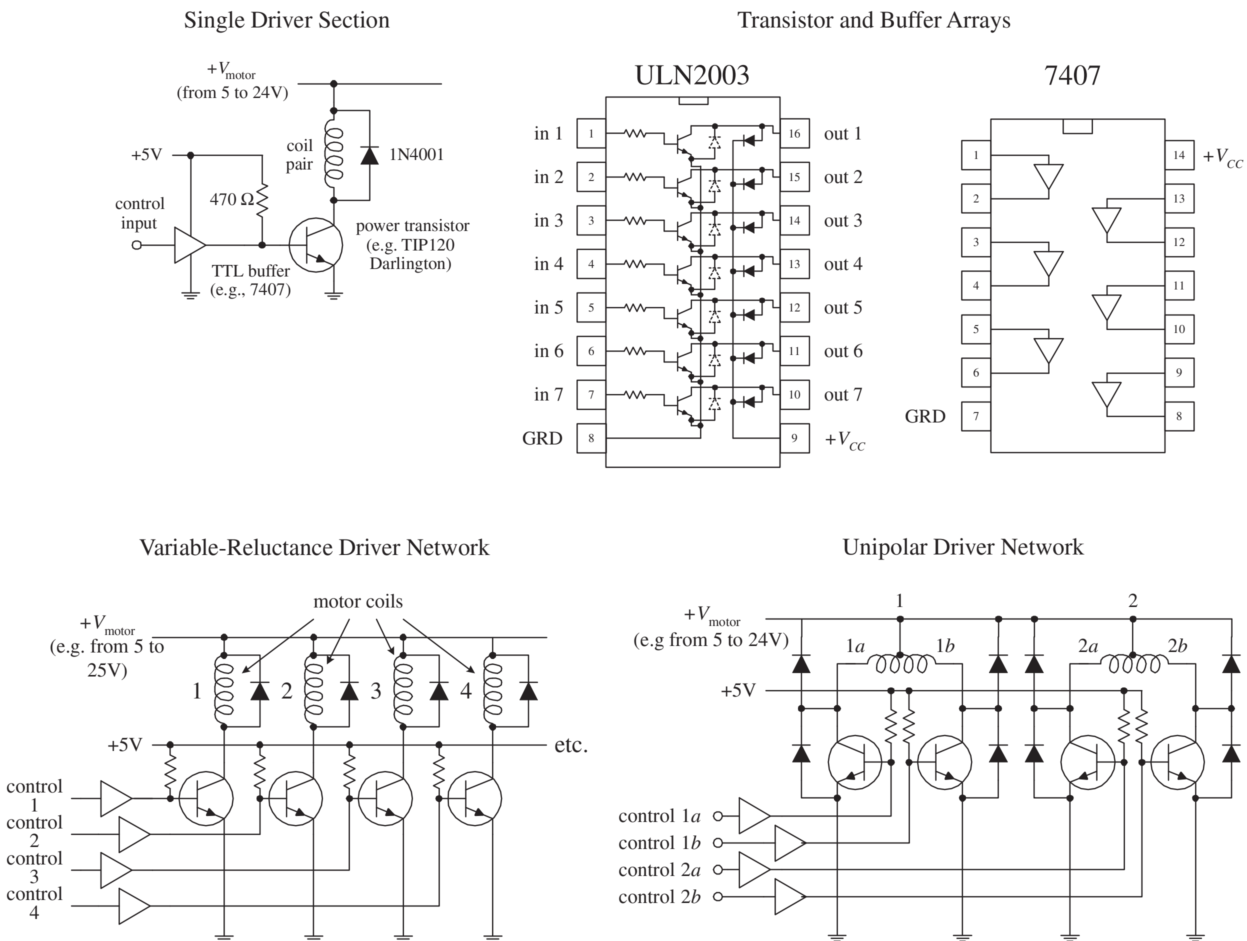
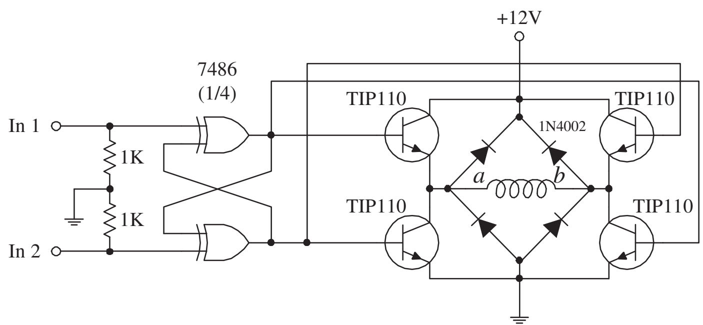


FIGURE 15.9

The circuitry used to drive a bipolar stepper requires the use of an H-bridge circuit. The H-bridge circuit acts to reverse the polarity applied across a given coil pair within the stepper. (Refer back to the section on dc direction control for details on how H-bridges work.) For each coil pair within a stepper, a separate H-bridge is needed. The H-bridge circuit shown in Fig. 15.10 uses four power Darlington transistors that are protected from the coil's inductive kickback by diodes. An XOR logic circuit is added to the input to prevent two high (1's) signals from being applied to the inputs at the same time. [If two high signals are placed at both inputs (assuming that there is no logic circuit present), the supply will short to ground. This is not good for the supply.] The table in Fig. 15.10 provides the proper firing sequence needed to create the desired polarities.

H-bridge used with Bipolar Stepper



Digital input		Polarity	
In 1	In 2	*a* end	*b* end
0	0	0	0
0	1	-	+
1	0	+	-
1	1	0	0

FIGURE 15.10

As mentioned in the dc motor section of this chapter, H-bridges can be purchased in IC form. SGS Thompson's L293 dual H-bridge IC is a popular choice for driving small bipolar steppers drawing up to 1 A per motor winding at up to 36 V. The L298 dual H-bridge is similar to the L293 but can handle up to 2 A per winding. National Semiconductor's LMD18200 H-bridge IC can handle up to 3 A, and unlike the L293 and L298, it has protection diodes built in. More H-bridge ICs are available, so check the catalogs.

15.8 Controlling the Driver with a Translator

A translator is a circuit that enacts the sequencing pulses used to drive a driver. In some instances, the translator may simply be a computer or programmable interface controller, with software directly generating the outputs needed to control the driver leads. In most cases, the translator is a special IC that is designed to provide the proper firing sequences from its output leads when a clock signal is applied to one of its input leads; another input signal may control the direction of the firing sequence (the direction of the motor). There are a number of stepper translator ICs available that are easy to use and fairly inexpensive. Let's take a look at one of these devices in a second. First, let's take a look at some simple translator circuits that can be built from simple digital components.

A simple way to generate a four-phase drive pattern is to use a CMOS 4017 decade counter/divider IC (or a 74194 TTL version). This device sequentially makes 1 of 10 possible outputs high (others stay low) in response to clock pulses. Tying the fifth output (Q_4) to ground makes the decade counter into a quad counter. To enact the drive sequence, a clock signal is applied to the clock input (see Fig. 15.11). Another four-phase translator circuit that provides power stepping control as well as direction control can be constructed with a CMOS 4027 dual JK flip-flop IC (or a 7476 TTL version). The CMOS 4070 XOR logic (or 7486 TTL XOR logic) is used to set up directional control.

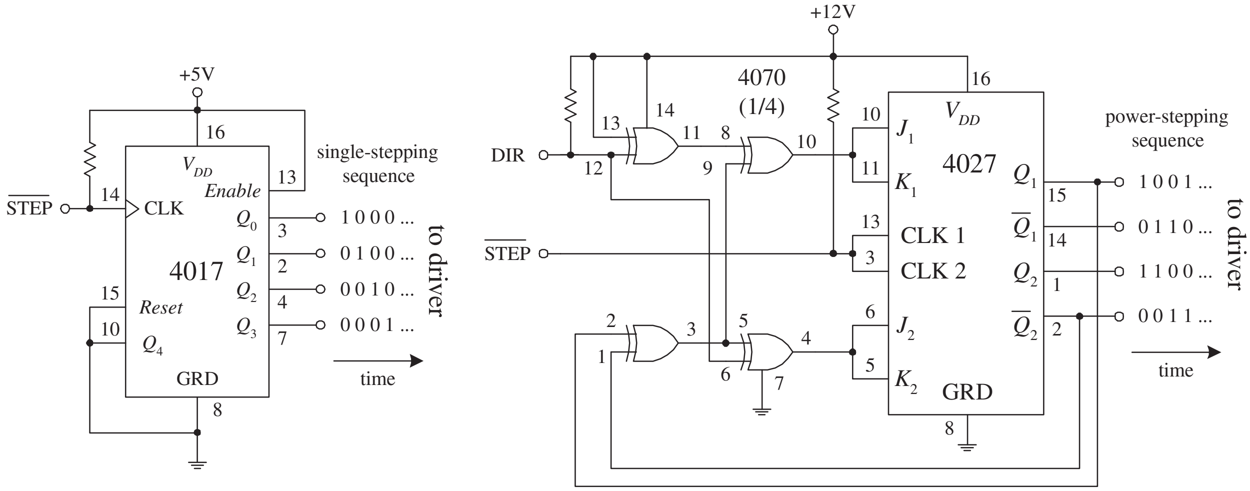


FIGURE 15.11

Figure 15.12 shows a circuit that contains the translator, driver, and stepper all in one. The motor, in this case, is a unipolar stepper, while the translator is a TTL 74194 shift counter. The 555 timer provides clock signals to the 74194, while the DPDT switch acts to control the direction of the motor. The speed of the motor is dependent on the frequency of the clock, which in turn is dependent on R_1's resistance. The translator in this circuit also can be used to control a variable reluctance stepper. Simply use the variable-reluctance driver from Fig. 15.9 and the firing sequence shown in Fig. 15.8 as your guides.

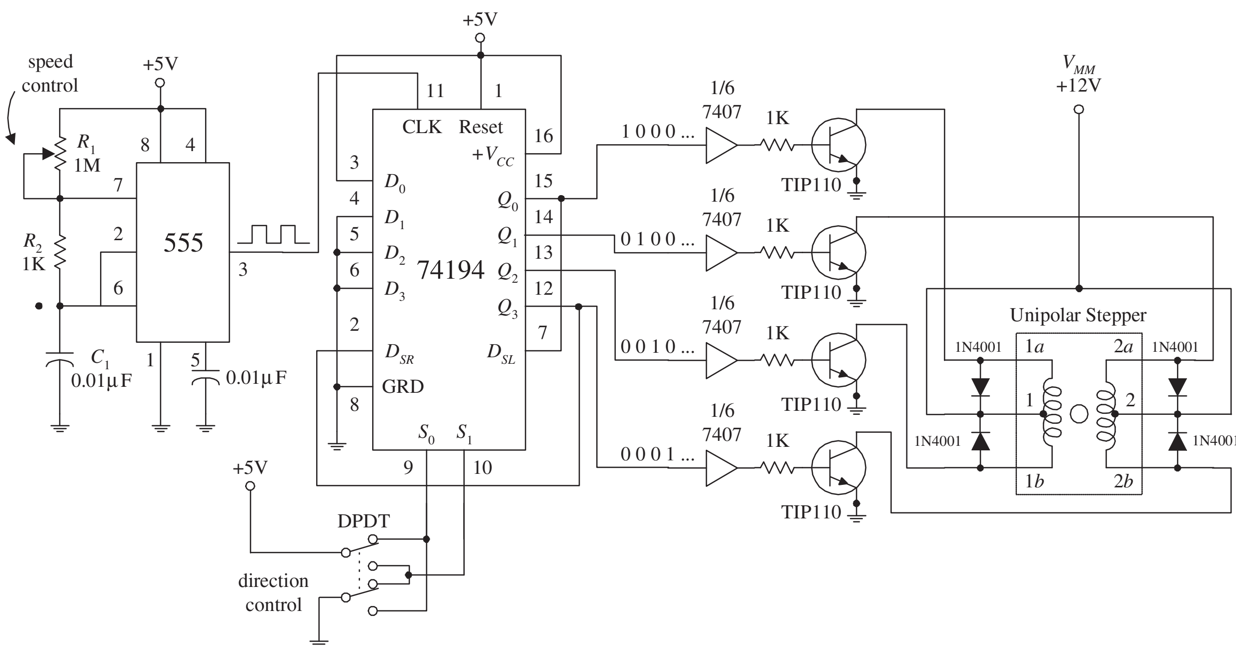
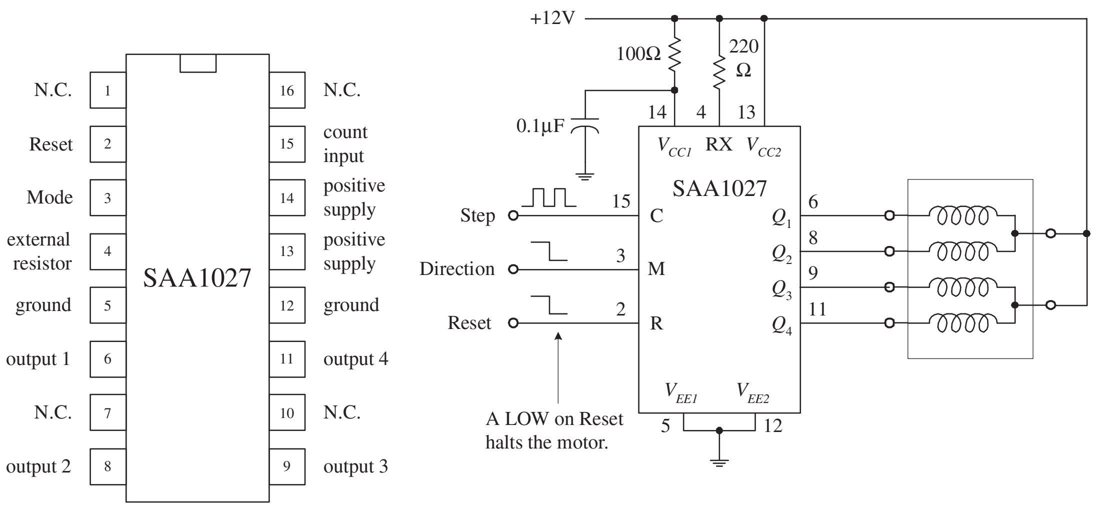


FIGURE 15.12

Perhaps the best translator circuits you can hope for come in integrated packages. A number of manufacturers produce stepper motor controller ICs that house both the translator and driver sections. These chips are fairly simple to use and inexpensive. A classic stepper controller chip is the Philips SAA1027. The SAA1027 is a bipolar IC that is designed to drive four-phase steppers. It consists of a bidirectional four-state counter and a code converter that are used to drive four outputs in sequence. This chip has high-noise-immunity inputs, clockwise and counterclockwise capability, a reset control input, high output current, and output voltage protection. Its supply voltage runs from 9.5 to 18 V, and it accepts input voltages of 7.5 V minimum for high (1) and 4.5 V maximum for low (0). It has a maximum output current of 500 mA. Figure 15.13 will paint the rest of the picture.

As mentioned, the SAA1027 is a classic chip (old chip). Newer, better stepper control ICs are available from a number of manufacturers. If you are interested in learning more about these chips, try searching the Internet. You will find some useful websites that discuss stepper controller ICs in detail. Also, these websites often will provide links to manufacturers and distributors of stepper motors and controller ICs.



M = 0				M = 1			
Q_1	Q_2	Q_3	Q_4	Q_1	Q_2	Q_3	Q_4
0	1	0	1	0	1	0	1
1	0	0	1	0	1	1	0
1	0	1	0	1	0	1	0
0	1	1	0	1	0	0	1
0	1	0	1	0	1	0	1

FIGURE 15.13

***Count input C (pin 15)*—A low-to-high transition at this pin causes the outputs to change states.**

***Mode input M (pin 3)*—Controls the direction of the motor. See table to the left.**

***Reset input R (pin 2)*—A low (0) at the *R* input resets the counter to zero. The outputs take on the levels shown in the upper and lower line of the table to the left.**

***External resistor RX (pin 4)*—An external resistor connected to the RX terminal sets the base current of the transistor drivers. Its value is based on the required output current.**

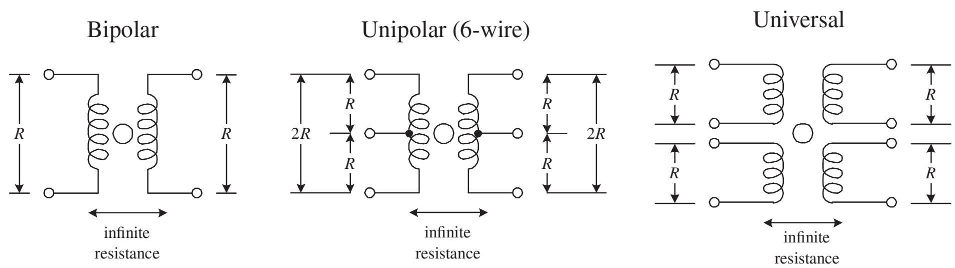
***Outputs Q_1 through Q_4 (pins 6, 8, 9, 11)*—Output terminals that are connected to the stepper motor.**

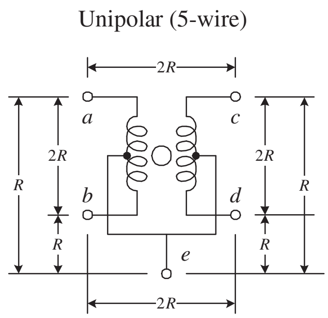
An alternative to using a hardware translator is to use a microcontroller that generates the signals for the coil drivers. Microcontrollers and microcontroller boards such as the Arduino will have libraries of code that provide all the sequencing necessary to drive a stepper motor.

15.9 A Final Word on Identifying Stepper Motors

When it comes to identifying the characteristics of an unknown stepper, the following suggestions should help. The vast majority of the steppers on the market today are unipolar, bipolar, or universal types. Based on this, you can guess that if your stepper has four leads, it is most likely a bipolar stepper. If the stepper has five leads, then the motor is most likely a unipolar with common center taps. If the stepper has six leads, it is probably a unipolar with separate center taps. A motor with eight leads would most likely be a universal stepper. (If you think your motor might be a variable-reluctance stepper, try spinning the shaft. If the shaft spins freely, the motor is most likely a variable-reluctance stepper. A coglike resistance indicates that the stepper is a permanent-magnet type.)

Once you have determined what kind of stepper you have, the next step is to determine which leads are which. A simple way to figure this out is to test the resistance between various leads with an ohmmeter.





a	*b*	*c*	*d*	*e*	Resistance
•	•				2*R*
•		•			2*R*
•			•		2*R*
•				•	***R***
	•	•			2*R*
	•		•		2*R*
	•			•	***R***
		•	•		2*R*
		•		•	***R***
			•	•	***R***

FIGURE 15.14

Decoding the leads of a bipolar stepper is easy. Simply use an ohmmeter to determine which wire pair yields a low resistance value. A low resistance indicates that the two wires are ends of the same winding. If the two wires are not part of the same winding, the resistance will be infinite. A universal stepper can be decoded using a similar approach. Decoding a six-wire unipolar stepper requires isolating two three-wire pairs. From there, you figure out which wire is the common center tap by noticing which measured pair among the isolated three wires gives a unit *R* worth of resistance and which pair gives a unit of 2*R* worth of resistance (see Fig. 15.14). Now, decoding a five-wire unipolar (with common center tap) is a bit more tricky than the others because of the common, but hidden, center tap. To help decode this stepper, you can use the diagram and table shown in Fig. 15.14. (The dots within the table represent where the ohmmeter's two probes are placed within the diagram.) With the table you isolate *e* (common tap wire) by noting when the ohmmeter gives a resistance of *R* units. Next, you determine which of the two wires in your hand is actually *e* by testing one of the two with the rest of the wires. If you always get *R*, then you are holding *e*, but if you get 2*R*, you are not holding *e*. Once the *e* wire is determined, any more ohmmeter deducing does not work—at least in theory—because you will always get 2*R*. The best bet now is to connect the motor to the driver circuitry and see if the stepper steps. If it does not step, fiddle around with the wires until it does.