Chapter 2
Coding and Coders

We have used a simple code to command operation of the motorized decoder described in the previous chapter. In this chapter we will expand on this code idea and learn more about how we can send signals to a remote object to command it to do various operations. A code is essentially a "machine language." That is, it is a set of signals which will vary in some predetermined and unique manner to convey particular commands.

As you can readily imagine, a code must *not* be ambiguous. The machine must not mistake one command for any other command. When we send a signal for left turn, that is what we want accomplished. We do not want the drive motor to slow down and brakes be applied, or flaps lowered, or bombs dropped or anything else. We just want a simple left turn accomplished by the remotely controlled body. That means the command for left turn must be different from any other command which might be sent. It must be such that it can be sent over and over again without any change in its meaning or its result.

ANALYSIS OF THE SIMPLE COMMAND CODE

In the simple code we used with the motor decoder—and which indicentally is used with escapements—one command is "signal on and hold," and a second command is "signal on, then off, then on and hold." We pointed out that some rhythm is required to permit the motor to turn the output cam to the required switch position for the commanded maneuver. There will always be some rhythm (time of operation) to any code transmission reception and decoding. The type of decoder will generally govern the speed at which the rhythm is sent.

For example, if we use the motor decoder and a lot of gears so the output shaft turns very slowly, our rhythm must be very slow to allow the output cam to turn to its proper switch position. As we reduce the number of gears and consequently, the output torque, our rhythm becomes faster and faster. Finally, we can reach an optimum for hand operation where we are moving our thumb or finger as fast as is comfortable, and we are getting the required torque output to move the steering element. If we cause the motor to run faster or have the gearing still less, then we just can't move our control finger fast enough on the signal transmitting button to stop the motor when we should. What we need then is an automatic code transmitting device.

This is one comparison between an escapement, rubber band-operated, and the kind of motorized decoder we have shown. Both use the same code. The escapement snaps around extremely fast, but is delaying in moving from one position to another by its very precise mechanical construction. It will work almost as fast as we can send signals to it. But it also uses no gearing and requires power to hold it in the turn positions. It therefore has small torque and consumes battery power when responding to any command other than neutral.

This may affect you when you are trying to land a small model plane. You may find that winds cause you to constantly steer left and right as you approach the landing strip. If the control system is too slow, you just can't maneuver the plane properly. So you must be able to send signals and have them cause the proper steering fast enough to quickly compensate for wind effects or any other physical disturbances as during flight, take offs, or landings. Trial and adjustment of motor gearing, or use of escapements, will make this possible with these kinds of systems. By the way, rudder steering in a model plane does not need much torque, so escapements work well there. For elevator, flaps or anything else except motor control, however, a motorized unit with more torque is generally necessary. You do need the motorized system for boats and cars, as some power is necessary to move the steering elements of these models.

AUTOMATIC TRANSMISSION OF CODES

When we can't send codes fast enough ourselves, we devise other methods that use electronics or a combination of electronics and mechanics—units that will send out the proper codes when we

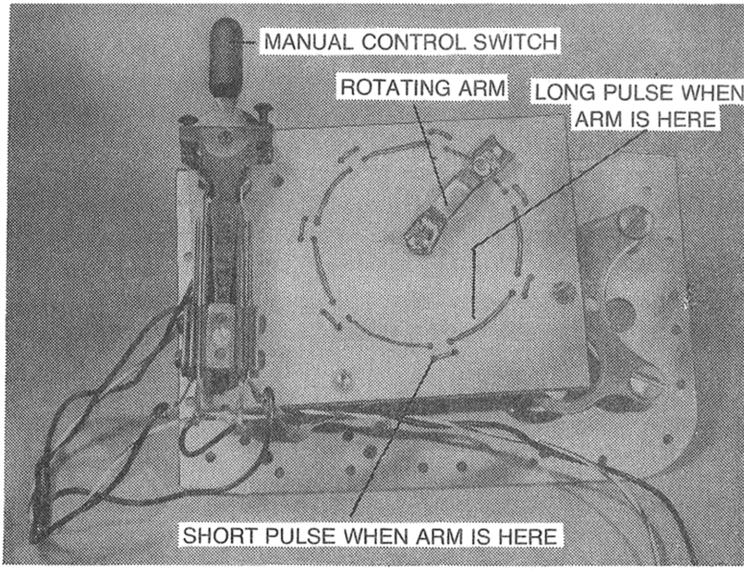

Fig. 2-1. A mechanical coder.

move levers, or turn dials, or close switches. We don't have to worry about forming the various discrete signals with our fingers or thumbs or hands. Amateur radio operator's use electronic and semi-automatic keys to send International Morse code, and "How nice it is!" Similarly, we can think of ways to open and close switches with insulated cams. Or we design electronic circuits such as automatic pulsers (multivibrators). These are controlled by a lever on a potentiometer, or a switch arrangement which then, in turn, sends out the proper coded signal to cause the model to do what we want it to. We can then devote our attention to racing, flying, or sailing and not have to worry about remembering just which kind of coded group calls for left or right or up or down or whatever.

In the following pages, we show some codes that we use and have used in control application. You will see some mechanical devices which R/Cers have used to send out specific codes, such as short pulses or long pulses, or no pulses (neutral). One, in fact, is shown in Fig. 2-1. There are other ways to send a particular code that you might want to use in controlling a remote model with which you want to experiment. Remember that the speed of rotation of the arm, and transmission of pulses have to be compatible with the decoder at the other end of the system. In the next chapter we will see how some relays with delay capacitors can be used to decode this kind of coded signal.

In this general discussion, we want to point out that you can send these coded signals by many means. Remote control is not limited to the transmission of radio signals. The reason radio signals are discussed so much is because of the range obtained and the reliablility of such systems. However, you might also use sound, light beams, heat waves (infrared), wires, LASER beams, magnetic fields, or anything which will change in some predetermined manner for coding. We do not rule out electronic elements as the beneficiaries of decoded commands, as a signal might activate a remote television camera-action by electronic means, rather than by moving some kind of arm or gear or cam. The command signal must cause something to happen on the receiving end, no matter what phenomena it uses, or for what purpose the receiving element output device has.

There may be other codes than those we consider here, and there may be combinations and variations of what we discuss. But we hope we will provide enough basic information to stimulate your imagination and inventiveness as you consider all kinds of codes for remote control of models.

OFF-ON CARRIER OR TONE CODE

As explained in the first chapter, we can use an off-on system of transmission to make some coded commands for the model. When the transmitter (or modulator) is on briefly—sending out a signal—we call this a *pulse*. It can be a pulse of radio frequency energy (when the transmitter itself is on) or it can be a tone pulse if the transmitter *carrier* is on continuously during operation but a *tone section* in it is pulsed to send out tone pulses. In this latter case the transmitter is usually modulated in much the same way as a CB or amateur radio transmitter is modulated to send voice. You can hear tone pulses if you have a speaker on the output of a tone-type radio control receiver. Indeed, in some cases, this is the way they are tuned: adjust the tuning for the maximum signal strength.

Because radio frequency pulses have no particular identity, we must cause them to change in some way to make various distinguishable commands. With tone pulses we can use one tone and *shape* it in some manner or we can use different tones for different commands. Note, however, that because the audio hand (audible range) is limited, our commands would also be limited if we use discrete tones for the different commands. There are some ways to expand this, though. For example, we might consider using first the range of separate and distinct tones, then use, perhaps, the first tone with all others, and then the first two tones with all others. The decoding equipment becomes rather complex, perhaps more so than we want

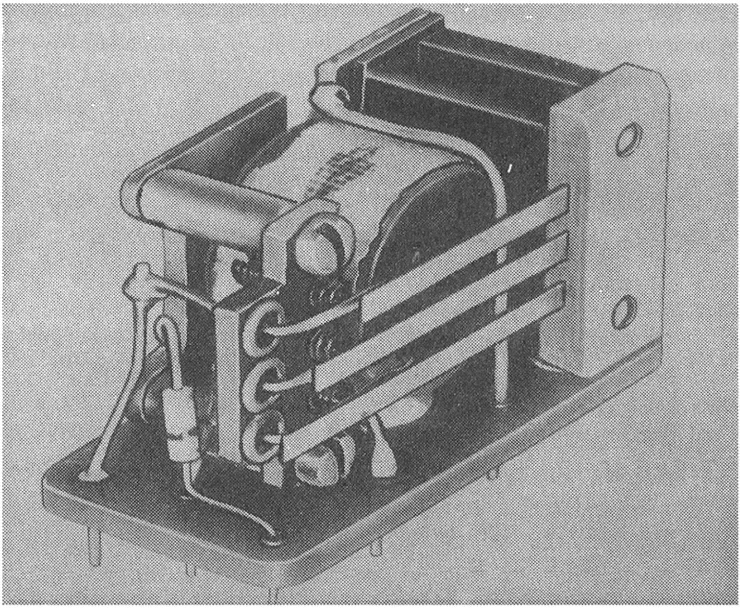

Fig. 2-2. Each reed vibrates to a different tone, usually spaced 50 hertz from the first. Intermittent contact at the points is a disadvantage.

to consider, but it could be done and would give an expansion over the number of commands that would be possible using strictly separate tones in the audio range. Remember that there must be guard bands and filters may be somewhat broad. Using very tight audio filtering is possible with resonant reed decoders, one of which is shown in Fig. 2-2. In fact, tones can be separated by as little as 50 Hz. Using band-pass band-rejection filters, the separation is from 300 to 3,000 Hz because the band of vibrations from zero to infinity is logarithmic. With some types of active filters using twin T feedback around operational amplifiers, it may be possible to tighten the spectrum even more. Physical-electronic filters such as ceramic elements may also give a very small bandpass so that more tones might be used.

HARMONIC CONSIDERATIONS

Whenever you use tones or low rf frequencies for control purposes, you must be careful that you do not use *harmonically related* tones or frequencies. Filtering is made much more difficult under this condition, and harmonics can excite circuits which are supposed to pass only fundamental frequences. Even third harmonics have been known to cause wrong controls to operate because they permitted a signal to develop in a circuit which was not supposed to be excited, or to pass the signal. So be careful to watch out for harmonics and make sure that your filters eliminate them if they happen to exist on your control signal spectrum and coincide with some control signal *fundamental* frequency.

PULSE CODES

Pulse codes can exist in six distinct groups:

- numerical sequences.
- width variation.
- spacing variation—width constant.
- sequences of pulse-presence—pulse—omission.
- rate variation.
- amplitude variation.

This, however does not mean that a code will consists of just one of these six methods. The code may be a combination of two or more, depending upon the application.

When choosing a code system to use in control, you must always consider how you are going to transmit this code, and how it will be decoded. It's easy to dream up dandy codes; encoding or decoding them is a different story. In the end, we have a system so complex that we cannot ensure its reliability, easy maintenance, or small size.

Numerical Pulse Sequence

A numerical pulse sequence method of coding is one in which the *number* of pulses transmitted conveys a command. For example, this arrangement might be used in connection with a simple electric motor.

Motor on	1 pulse
Motor off	2 pulses
Motor full speed	3 pulses
Motor half speed	4 pulses

If a great number of commands are to be given, the number of pulses in the last sequence will require a comparatively large amount of time. We must consider the relative spacing between the pulses in each numerical sequence and the spacing between sequences. The interval between all pulses in a command or sequence should be the same; the spacing between each sequence should be much longer or at least long enough so that the decoder in the receiver knows that a command has been given and thus is able to distinguish it from the

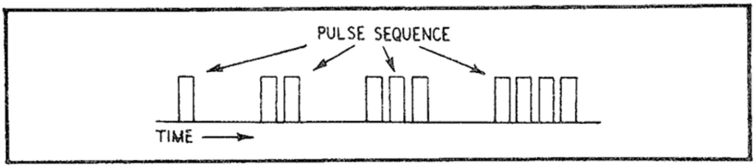

Fig. 2-3. Each group of pulses represents a separate command. The entire sequence might be used to key four separate functions.

others following. If four commands were sent, one after another, they would appear as shown in Fig. 2-3.

One of the best examples of a coder which puts commands into a numerical sequence form is the telephone dial. In this case the dial performs the dual function of coder and control device. This unit has a cam on the underside which closes a set of contacts a given number of times when a number is dialed. It is spring-powered and has a friction governor so that when the dial is pulled back and released, the pulses come at a uniform rate and with uniform spacing and duration. The time it takes to dial a second number is so much longer than the interval between pulses that each command is well separated even though one might dial as fast as the unit will allow. A sequence of up to 11 pulses is possible.

Pulse Width Variation—Spacing Constant

The second form of pulse coding is that in which the *pulse width* varies but the spacing between the pulses remains constant. An

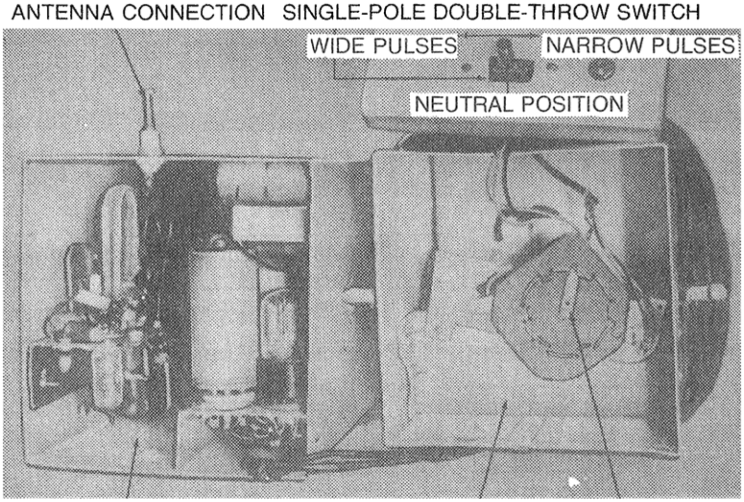

Fig. 2-4. A motor-driven coder which produces wide or narrow pulses. In this unit, the spacing between pulses is constant.

excellent example of this is the code used in radio telegraphy. As far as model application is concerned, a series of short pulses might represent one command and a series of long pulses a second.

Fig. 2-4 shows a small transmitter designed for radio control on 144 MHz. Note the single-pole double-throw manual-lever switch immediately above the coder. This is the control switch. When, for example, the control switch is pushed toward the left, the coder opens and closes either the transmitter B-plus bus or the tone modulator circuit, resulting in a succession of wide pulses. Narrow pulses are produced when the control switch is pushed toward the right. When the control switch is in the center or neutral position, the transmitter is open-circuited and does not send out carrier or tone pulses.

Pulse Spacing Variation—Width Constant

In this coding system the pulse width is constant but the spacing varies. To illustrate the use of such a sequence we should first visualize a unit of time, say one second. All commands will use this length of time. If only four pulses are needed to convey the commands, then the spacing between them in this one-second period would determine which command is transmitted. See Fig. 2-5.

With this system, since the spacing between the pulses varies, it might be advisable to use some means other than a long time interval between commands to allow the decoder to distinguish one command from another. Each command might be started with a double pulse of some fixed duration. This would signal the fact that a command is coming, and each time it is received it would inform the decoder that a new command was on the way or that the previous command was going to be repeated. These identifying pulses serve to separate the commands, however used. A sequence of this type for two commands is represented in Fig. 2-6.

A second means to denote commands by using pulses of constant width, variable spacing, is to cause *each* of the pulses following the identifying marker to shift independently back and forth, regarding time, about a rest position. This is a method of handling a large number of commands in a short period of time. The rate at which the

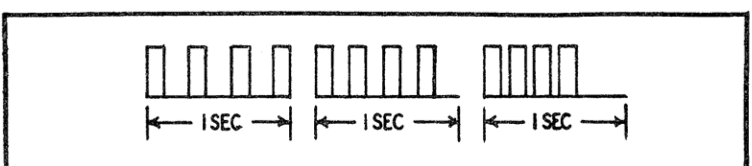

Fig. 2-5. A series of pulses of equal duration. Notice the variation in spacing.

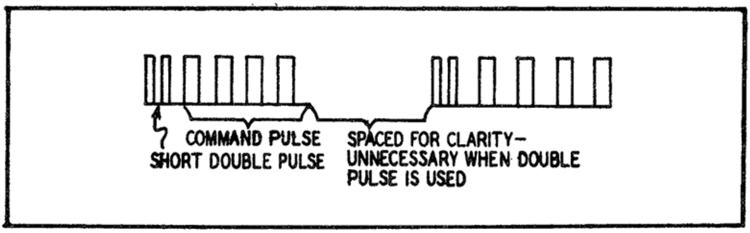

Fig. 2-6. The short double pulse preceding the command pulses separates the commands from each other.

intelligence pulses are shifted about the rest position can be made to represent various audio tones. For example, a shift rate of 1000 times per second would be a tone of 1,000 cycles when decoded. In decoding equipment using this method, the decoder knows the rest time of each pulse following the marker. Through a circuit like a discriminator, it produces the positive and negative alternations of a sine wave as each pulse is received early or late with respect to its rest interval. This idea is illustrated in Fig. 2-7.

Pulse Width—Spacing Variation—Individual Pulses

In current radio control systems called *digital systems,* we find a variation of this concept. Figure 2-8 shows modern equipment that uses a digital code. In this code a series of up to eight pulses of a nominal width are transmitted. Then each pulse may have its width or spacing increased or decreased by command, or movement of a control lever, stick or wheel. When the width increases, the spacing might or might not change. Or when the width is constant, the spacing changes somewhat. Instead of a two-pulse chain identification, a *sync pause* is initiated which serves the same purpose. With

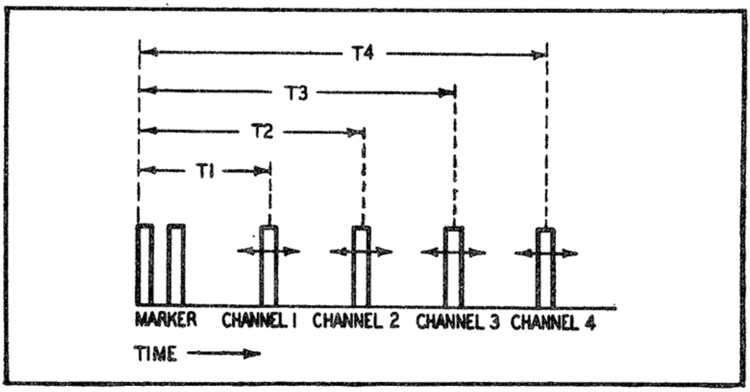

Fig. 2-7. Time modulation of the pulses is often used when a great many commands are to be sent in a short period.

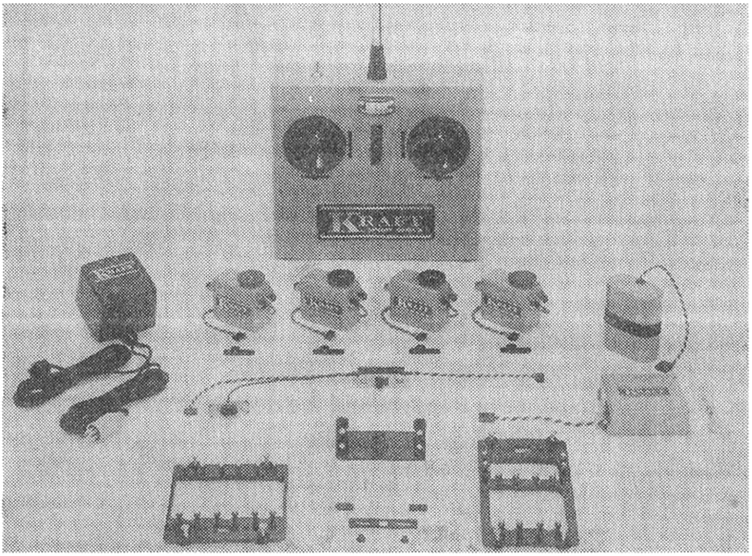

Fig. 2-8. A modern digital transmitter and system.

each pulse or space between two pulses representing a *channel,* we have up to eight commands (for nine pulses) which can be put into operation by the model. Each pulse may have its width or spacing varied gradually, so this means *proportional control* with a proper servo (see a later chapter about servos) over function. You can turn the model gradually instead of just going hard left or right. Also, you can adjust the motor speeds gradually, instead of just having a high and low, or on and off type of motor control. One such code would appear as shown in Fig. 2-9.

This control system is employed by Heath in their equipment. It holds the spacing (carrier off) at a constant interval and varies the width (carrier on) time. Notice the time that the carrier is *on.* The fact that it is off only during the interval between commands means the receiver has very little time to receive any interference. The *sync pause* is a long *carrier on* signal. This next code might be called a "computer code" for it is like the bits, bytes, and words used in control of computers. Actually it is a binary system and here we have called a zero an "omission," and a "1" a "presence."

Pulse Sequences (Pulse-Presence-Pulse-Omission)

Codes dependent on pulse sequences, other than numerical, are generally of the pulse-presence-pulse-omission type. Consider a sequence of five pulses within each command block. The pulses all have the same width and spacing. The commands result from the fact that they may be transmitted or omitted:

Command 1:	Pulse	Pulse	Pulse	Pulse	Pulse
Command 2:			Pulse	Pulse	Pulse
Command 3:				Pulse	Pulse
Command 4:					Pulse
Command 5:	Pulse			Pulse	Pulse

Each pulse has a definite time to be transmitted, and the particular command results from whether it is transmitted or not. With this group of five pulses, it is possible to get 32 combinations, no two of which are identical. If more operations are desired, the block may be raised to six or higher, and the possible combinations are astonishing.

The coder for this particular arrangement might again, in a mechanical sense, be a motor-driven arm which sweeps over a set of contacts. The line from each contact to the transmitter energizing circuit might then run through a switch and, depending upon how many switches were thrown, the functions would be performed.

In one system using this sequence, the motor-driven arm passed over a number of contacts every revolution. Four of these

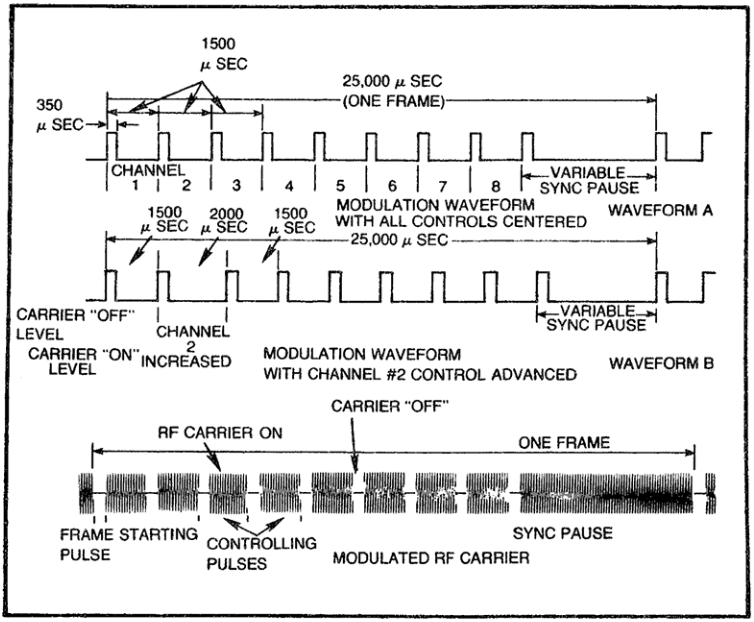

Fig. 2-9. A modern digital control code, in this case Heath's. The pulse width, or carrier on time varies.

contacts were the command contacts, a fifth caused the receiving motor to slow down, and a sixth notified the receiving motor to speed up. (The receiving motor was in the decoder and caused a similar arm to pass over a set of contacts duplicating the coder. The two arms had to be in synchronization so that a contact in the coder would represent a circuit in the decoder.) A seventh contact of the coder was used to energize the circuit set up by the command pulses. Computer books show how such pulses are generated electronically.

Pulse-Rate Variation

Pulse-rate variation is another means of coding commands in a pulse system and is still used. To vary the pulse rate means that the number of pulses transmitted per second will be changed according to the command. For example:

Command 1: 20 pulses per second
Command 2: 30 pulses per second
Command 3: 40 pulses per second

A coder that can generate this kind of code could be a simple multivibrator whose RC (resistor—capacitor) timing elements are switched into the circuit by manually controlled switches or levers. It is also possible to use a motor-driven arm which steps over a series of contacts, with the motor speed changed by moving switches or levers. This might not be as exact as we would like for the motor speed depends on supply voltage, loading, and other such factors. But it could be used, with care in construction and allowance for the time to increase armature rotation speed from slow to fast to faster.

Pulse Amplitudes

Coding by variation of pulse amplitudes means increasing or decreasing the amount of power the transmitter puts out with each pulse or pulse train. This method is *not* recommended because of the tendency of the receiver to become confused, the normal signal varying as the controlled body moves. This makes it almost impossible to distinguish between a transmitted command or a fading signal. This coding method is useful in a wired transmission system. For example, at the receiving end a group of relays might be so arranged that some of the relays respond to pulses of low voltage, others to higher voltages, and so on. A change in polarity of the signal (if DC) might also be part of the command method. The coder would simply be a contact selector which would choose the contact having the proper amount of voltage and/or polarity for the command to be transmitted.

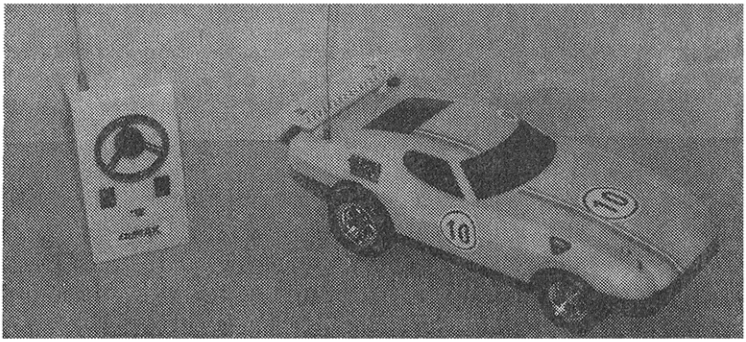

Fig. 2-10. This model radio-controlled race car uses an electric drive motor.

A MODEL RACING CAR

We have mentioned that in current digital systems you may have nine pulses generating eight channels of control. It isn't always necessary to have that many channels. In Fig. 2-10, you see an example of a two-channel system used to control a model race car. Notice the steering wheel which causes proportional turning of the road wheels when it is turned a proportional amount. A switch provides forward or backward drive, and an off-on switch.

With many of these cars, which use small servos to steer them and to control the drive-motor current, the linkage is such that when you call for forward motion you can then gradually vary the speed forward. When you put the control in stop position, not only is the current to the drive motor cut off, but also a brake is applied to the wheels to stop the car. The car is quick and easy to handle. With the kind of transmitter used, the car will operate over as long a range as the car can be seen.

So you see that you might use a system with two or three channels, or you might even want a system with as many as eight channels. Digital systems can give you as few or as many channels as you might want or need, but if you obtain a system with over eight channels (the standard today), it probably would have to be a special order.

HOW MANY CHANNELS?

We conducted a survey not too long ago and asked that very question—how many channels are needed?—of thousands of recipients. They replied, on the average, that you should get at least *four* channels if you plan eventually to fly radio-controlled model airplanes. You might not use all channels at first. In fact, you might use only two—rudder steering and motor control are considered to be mandatory—but later you might expand to what is called the "full house" of rudder, elevator, motor and aileron control.

Many model ship builders and hobbyists tell us that three channels are adequate. You use one for rudder, one for motor and one for sails. That would be the minimum for, say, model yacht control. You see, in each channel you can consider forward and reverse motion of a wheel or arm, and you can consider proportional control in either direction. Thus, one channel for motor control gives you forward-reverse and an off position, and the forward and reverse would be at proportional or gradual speeds. That is with electric motors. With glo-plug motors you can get proportional speed or possibly off in one direction only, unless you are able to get an expensive gear-shifting set.

Two channels are enough for model race cars: one for steering and one for speed control of glo-plug or even electric motors. As mentioned earlier, when the speed is reduced to minimum, the lever arm which advances the throttle will be applying some kind of mechanical brake to the wheels. You therefore have a kind of automatic braking arrangement with these cars. Reverse drive of the motors is not usually found, except in electric cars. And then it can be just a simple forward-reverse switch which operates a polarity reversing relay, such as we have described earlier. The proportional steering and speed control will apply in either direction with electric cars and can apply to glo-plug engines with a proper gearing transmission.

So how many channels? If you are experimenting with radio control and want to try various models, try four channels so you will have enough for any model. If you think you will want to do more things than just steer and control speed—things like lighting lights, dropping anchors, winding winches, firing small guns, dropping bombs, using flaps, raising and lowering sails you might get an eight channel system to start with. It could be more economical than buying two systems later.

Finally, notice that you can get one transmitter and then buy two receivers and countless servos for the same system. That way you can have the same transmitter to use for many independent receivers and control systems in many different models.