Chapter 3
Examining Transmission Systems

The choice of transmission system depends upon the type of coding used and the particular application of the control system. Conversely, it is possible that the type of coding will be second choice and the transmission system will govern its selection.

There are 6 general means of getting information from one point to another:

- radio or electromagnetic waves
- sound waves
- light beams
- heat waves (infrared)
- wires
- magnetics

RADIO TRANSMISSION

This is the most common type of transmission used by the radio-control enthusiast. Since it has such an important role it will be discussed in detail.

SOUND-WAVE TRANSMISSION

This might, at first, be thought a method with limited application. However, it can be the solution to a control problem. Radio-control systems operating on other than the radio-control spot frequencies or Citizens Band require a license; a sound system does not. A sound system might be merely a public-address setup which propagates a pressure wave in the direction of the controlled body. The receiver could be an audio amplifier with a microphone input. Coding could be by different tones or a single pulsed tone.

To answer immediately the question of the disturbing effect of transmitting pulses over a sound system: if the input to the sound system were from an audio oscillator tuned to 15,000 cycles, few people could even hear the transmitted tone. By use of a selective filter in the receiving audio amplifier, the model would respond only to this particular tone and thus give satisfactory operation. Practically all the aspects of radio control would be present except that the transmitting range would be limited.

LIGHT-BEAM TRANSMISSION

A LASER light beam might be used. But be careful! This light beam can be modulated or unmodulated. In the latter case, the beam would be interrupted to send pulses. Of course, the receiver—a solid-state receptor— (which is light sensitive) must be oriented so that it can always see the light source. This can be done by rotating the light-sensitive unit, using slip rings to convey its output to an amplifier. The cell does not respond to ordinary light if it is hooded and the sensitivity control properly adjusted. Another thought would be to arrange three light-sensitive cells in a fixed triangle so that no matter what the position of the model, one or more of the cells would always be able to receive the light signal from the controller. The model then could be controlled with an ordinary flashlight.

INFRARED WAVE TRANSMISSION

Infrared waves, like light beams, can transmit intelligence. They also require that the infrared receiving source be able to "see" the transmitter. These waves are generated by high-temperature arcs or special solid-state infrared devices. The receiver consists of a bolometer connected into a special temperature-sensitive resistance circuit or filtered solid-state cells. This type of transmission system is seldom used.

WIRED TRANSMISSION

This is perhaps the most common method used between fixed transmitting and receiving points. It is possible to attach a pair of flexible wires to a model car or boat and investigate the control technique easily and simply. One or a multiple pair of wires can be used. This is an electric, not an electronic, technique.

MAGNETIC TRANSMISSION

Recently, scientists have explored the area of extended magnetic field radiation, which is in effect, like very low radio frequency radiation. Consequently, using the magnetic portion of this type wave for control is a possibility in the very near future.

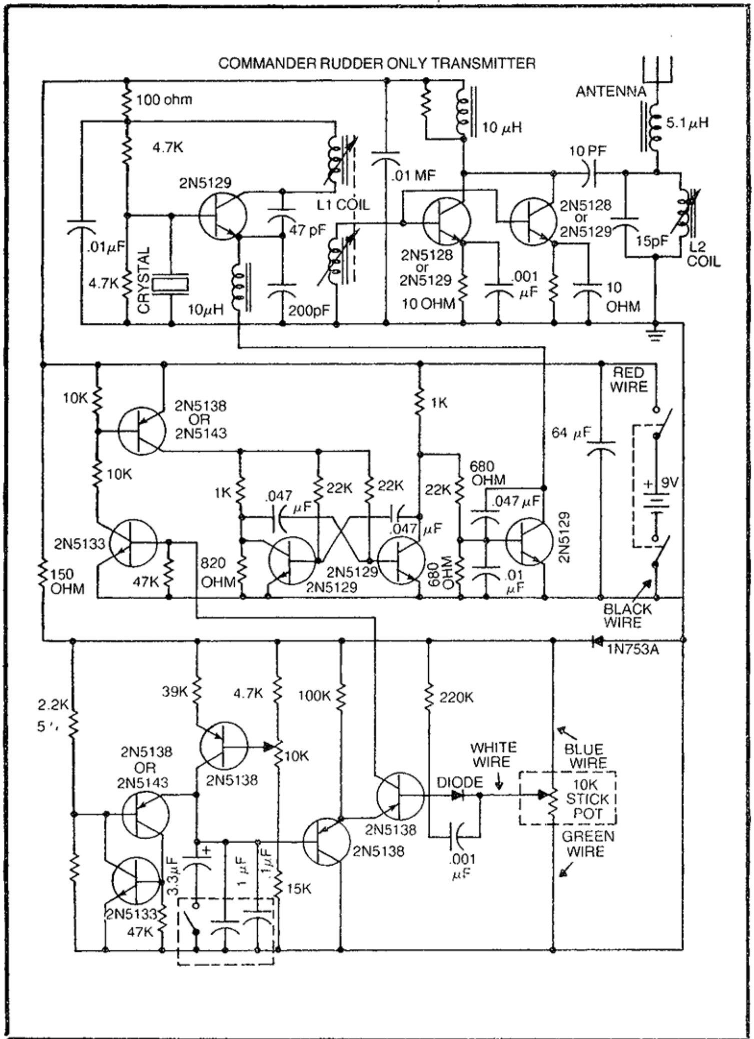

Fig. 3-1. A typical transmitter circuit for radio control using a crystal oscillator and power amplifier. A multivibrator-type modulator turns the crystal circuit on and off with variable timing controlled by the stick pot. This varies the width of the carrier pulses. These are slow pulses and can activate a pulse width actuator directly when fed from a receiver.

RADIO TRANSMISSION

The power and size of radio transmitters are generally determined by the range to be covered and by the coding used. A modulated transmitter might be larger than a nonmodulated unit. The size of the transmitting antenna is also a factor. For example, a transmitter using an antenna which beams energy toward the model might be smaller for a given application since it is required to generate less power than one using an antenna which just fills the atmosphere with energy. In the latter case, the model actually receives but a small portion of the total transmitted output. The physical size of the antenna is also determined by the operating frequency. Generally, the higher the frequency, the smaller the components and the shorter the connections required for any efficiency of operation. As the frequency increases, it is more difficult to obtain high efficiencies, but directivity can be gained.

The power output is governed by FCC requirements and is less than 100 milliwatts for part 15 of the FCC regulations—a Citizens Band spot frequency which does not require a license. The maximum power output is 25 watts at 27.255 MHz, 4 watts from 26.995 to 27.195 MHz, and 0.75 watt from 72 to 76 MHz. These are for Class C stations. In Class D applications, the carrier power is limited to 4 watts and in single sideband the peak envelope power is limited to 12 watts.

It is a common to use rechargeable ni-cad batteries for both the transmitter and all receivers in radio control. A single cell has a nominal voltage of 1.2 volts, and four of these are used in receiving applications for a total 4.8 volts. They can deliver a lot of current for a long time but then, when they do reach exhaustion, they *suddenly* drop their current output, the voltage falls quickly and they must be recharged. In transmitters it is common to use two banks of four cells in series to give 9.6 volts. This gives the required output from a transistorized transmitter circuit such as shown in Fig. 3-1. The receiver shown in Fig. 3-2 uses 2.4 volts—2 ni-cad cells.

The 53-MHz Amateur Band

On those spot frequencies in the 53 MHz band a wider latitude of power is available because these are amateur frequencies. At least a Technician class license is required. Also, it is only on two of the spot frequencies in this range that a superregenerative receiver can still be used. With some restrictions governing possible interference, the amateur transmitter power maximum is set at 1 kilowatt. We have personally used the 53 MHz spots for radio control with transmitters of 5 to 10 watts input and found that with a dipole antenna, we could hardly get a model airplane too far away to be controlled. In fact, we lost sight of the plane before we ran out of radio range.

Perfomance Indicators

Almost all of the multichannel transmitters available now have a built-in performance indicator. It is an rf meter with a red and green band on it to at least let you know whether your transmitter is putting out ok. If your needle reads "in the red" or near it, then usually the batteries need charging, or you have not lengthened your antenna to its maximum position. The equipment is so reliable that you do not have a step position switch to monitor currents inside your transmitter. But if you have constructed an amateur-type transmitter to radio control some models, then it would be advantageous to be able to monitor voltages and currents at various points inside the transmitter, just as with any amateur radio transmitter or transceiver.

If you do not have an rf meter handy, and you do have a tank coil in the transmitter output tuning circuit to which you have access—and which does not have too much voltage on it—you might use a simple loop connected to a low-amperage six-volt pilot light as shown in Fig. 3-3. This will light up when the carrier is on and will flicker if

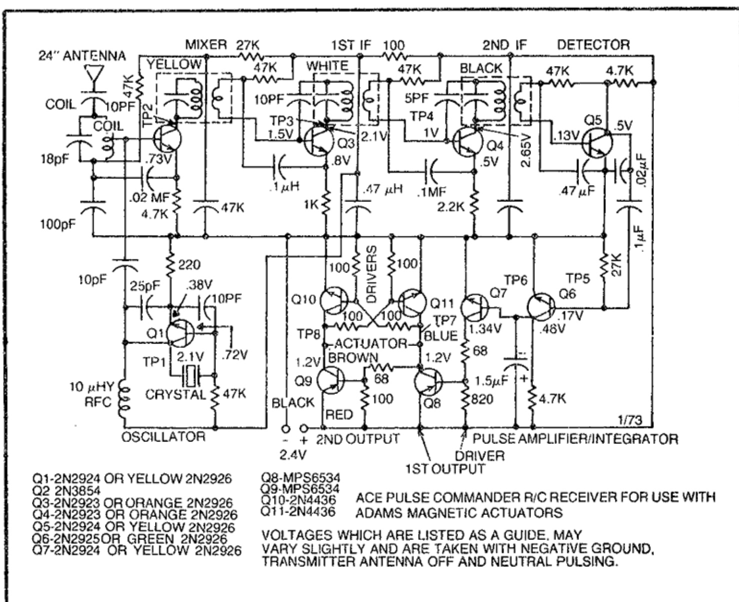

Fig. 3-2. A superheterodyne receiver for single-channel R/C operation.

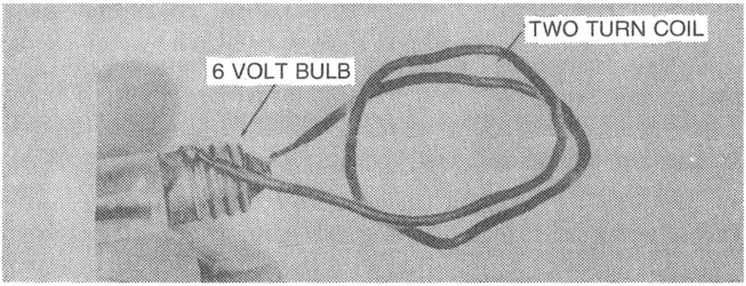

Fig. 3-3. A simple transmitter performance indicator using a brown bead bulb.

you use amplitude modulation or pulsed carrier—if the pulsing is slow. So it does give some idea of operational condition. Of course, it absorbs power and so should not always be left in as part of the circuit.

Keying The Transmitter

Since the transmitter voltage supply is usually low, 9.6 to 11.2 volts for ni-cads or 9 volts for dry cells, you can key this supply voltage directly to pulse a carrier. With a multistage transmitter, you should key the oscillator so that there cannot be any feed-through of signal to the output and possibly on to the model. The oscillator must be adjusted carefully so that it will not stop oscillating when keyed.

If you have a tone section modulating the transmitting section, this is normally itself keyed, and the carrier is on continuously during operation of the model. The basic requirement is that the keying must be done at such a point and in such a manner that tones or carrier pulses will be clean and clear and not ragged or intermittent in any way. The RS 555 timer (Radio Shack 276-1723) is one of the most versatile of the integrated circuit chips. It can be used as a tone generating unit and can be connected to give pulse width modulation or pulse position modulation, as well as act a tone generator. Also another such integrated circuit whose output can be varied by current, voltage, resistor, or capacitor to give different tones is the RS 566 unit (Radio Shack 276-1724). Of course any amplifier with enough positive feedback will immediately oscillate and might be used as a tone generator. A free-running multivibrator, with proper components so that it vibrates slowly can be used: the output is then filtered through a small transformer to get a sinewave output, and this can be a tone producer.

In many radio control systems the multivibrator output is used to turn the crystal stage of the transmitter off and on. This gives carrier modulation directly. When the multivibrator produces a fre-

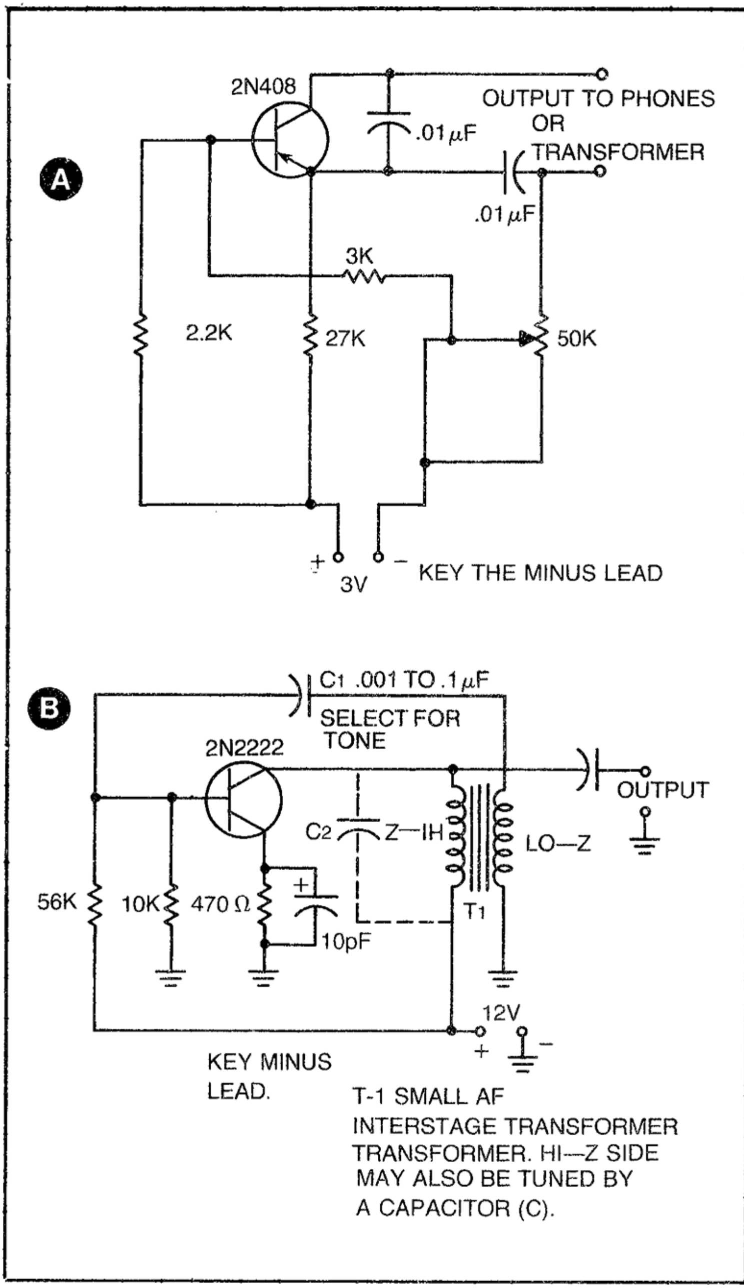

Fig. 3-4. Two simple tone-generating circuits. Suggested circuit values for earphone inductances are listed in (A); in (B), C1 and C2 need adjustment to affect the tone output.

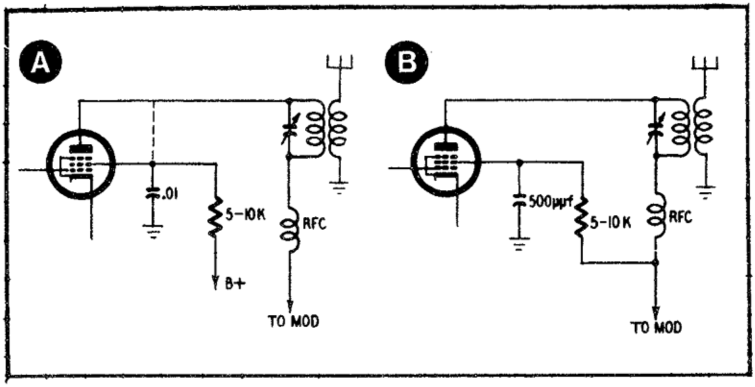

Fig. 3-5. Methods of using plate and screen modulation. At (A), if plate modulation only is used, connect as shown by the dashed lines. At (B), when plate and screen modulation are required, use a small-value screen bypass capacitor.

quency output in the audio range, you have tone modulation. Turning the carrier off and on will give 100 percent modulation. However, this does not add anything to the carrier as, say, plate modulation does. For more about that see TAB book No. 1135, *Radio Control Manual–Systems, Circuits, Construction–3rd Edition.*

Two simple tone generating circuits are shown in Fig. 3-4. In (B) the capacitors C1 and C2 will have to be adjusted as they tune the transformer primary and affect the tone output. Some suggested circuit values for use with earphone inductances (2000-ohm magnetic types) are listed in Fig. 3-4 (A).

METHODS OF MODULATION

A radio control transmitter is usually amplitude modulated. In fact, we very seldom find any kind of remote control transmitter except in the commercial or carrier-current categories which use anything but amplitude modulation.

There is a direct analogy between the tube-type modulation concepts and the transistor concepts. With tubes we had plate modulation, screen modulation and grid modulation. In each case we varied the voltage being applied to these elements. Plate modulation requires that the output of the modulator be coupled into the B-plus lead of the final stage of the transmitter. The final stage is the output. If this stage uses a screen grid-type tube, both the plate and screen leads may be connected to the modulation transformer or just the plate lead alone. If both screen and plate are modulated, there should be no large rf bypass capacitors to shunt the audio signal. Values of 0.005μf are adequate for rf and will not cause a loss of the audio signal. Fig. 3-5 (A) illustrates the modulator connections to such a

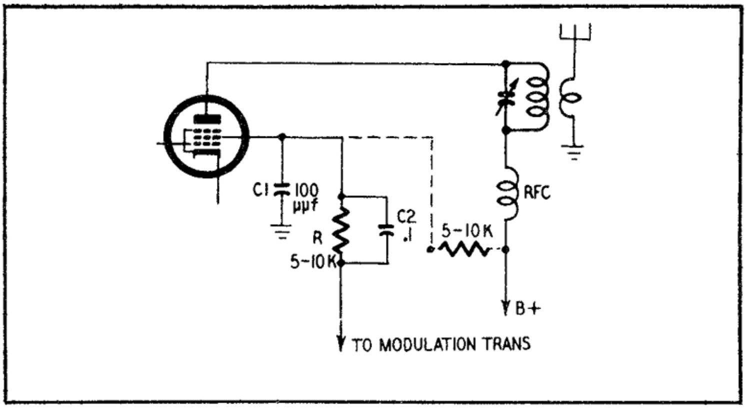

Fig. 3-6. Normally, the screen is connected as shown by the dotted line. To screen modulate, connect R and C2 to the modulation transformer or the plate of the modulator tube.

stage. Fig. 3-5 (B) shows connections for plate and screen modulation.

Modulation of the screen grid alone, as shown in Fig. 3-6, is sometimes used since this requires less audio modulation voltage. No modulation transformer is required, although one can be used.

Grid modulation can be used only when the transmitter is a two-stage type. In this case, the audio signal is applied to the grid of the final stage. Much less audio power is required than for the other methods. However, this method does not allow the final output efficiency obtainable with plate or screen modulation. In the previously described methods, the audio signal adds power to the transmitted signal; grid modulation does not. The method of connecting a modulator into the grid circuit is shown in Fig. 3-7.

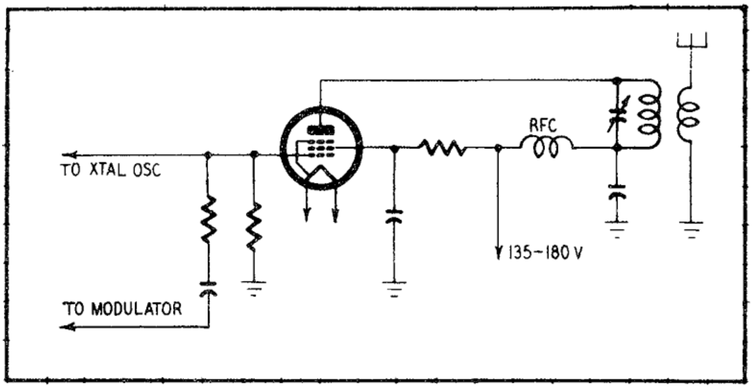

Fig. 3-7. Typical grid-modulated circuit.

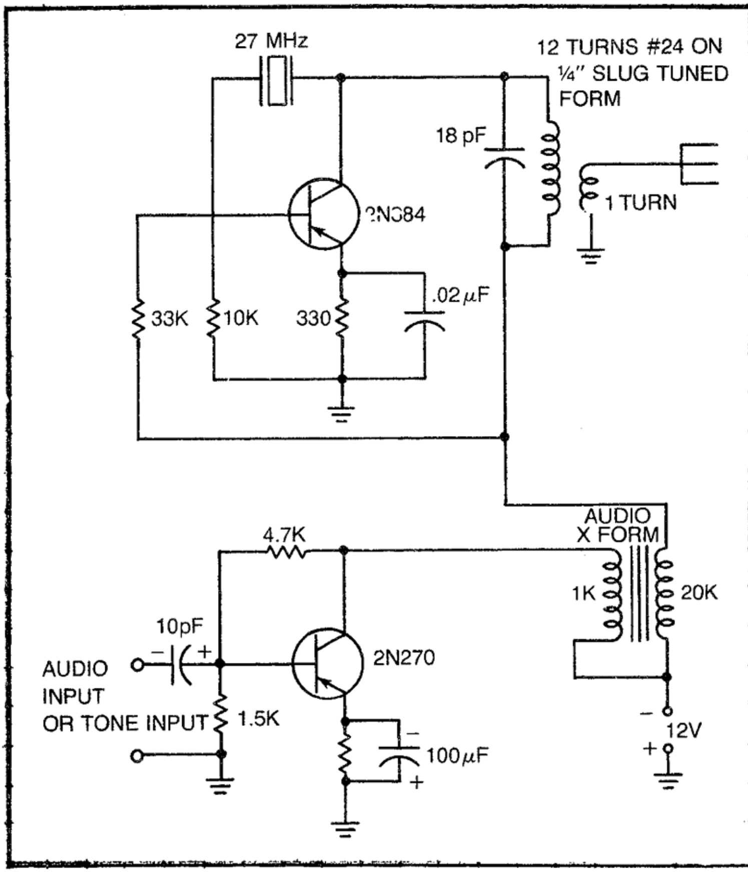

Fig. 3-8. A collector-base-modulated oscillator.

When modulating transistors, it is necessary to vary the current applied, as the transistor is a current-operated device. As we have indicated, the extreme of this can be a turning off and on of the voltage (and thus current) applied to a transistor stage in order to get a pulse modulated output. It is possible to tone modulate or speech modulate a transistor rf stage by simply using a transformer output from an audio amplifier to feed the collector, base, or emitter circuit through a low-impedance secondary as shown in Fig. 3-8.

Many diagrams and methods of modulating transistorized transmitters are shown and discussed in TAB book No. 1135, *Radio Control Manual*. One of these methods is shown in Fig. 3-8.

This circuit is interesting because we can feed a tone generating section into the modulator (2N270). If we use two or more tones which we can select individually, and we have a decoder in the receiver which can separate the tones so that two independent relays are operated, then we can make a fascinating toy robot device as we will show in a later chapter. Since the power here can be kept below 100 milliwatts, no license is required to operate this kind of transmitter. The modulation transformer is not critical and a 1K to 10K type might be used. Experiment with it.

One such toy-controlling transmitter—a small hand-held unit—is shown in Fig. 3-9. A transmitter such as this might have added to it a modulator section as we have described to send out tones. This little unit has very low power and falls within the FCC Part 15 regulations.

You might be thinking that the small walkie-talkies that can generate a tone by means of a small button might be used for radio control applications such as we are discussing. That is true! You might even use the receiver of one and activate it from the transmitter of the second unit. Just add a relay stage to the receiver output.

A MORE COMPLEX TRANSMITTER

The inside view of a longer range, multichannel, digital transmitter is shown in Fig. 3-10. This is a two-stick unit. Each stick will

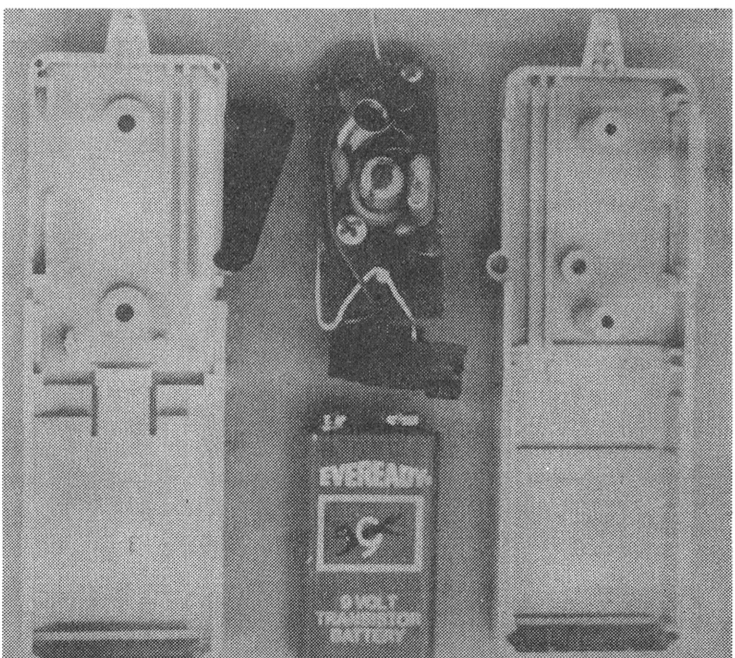

Fig. 3-9. A small hand-held transmitter. This is not a tone-modulated type.

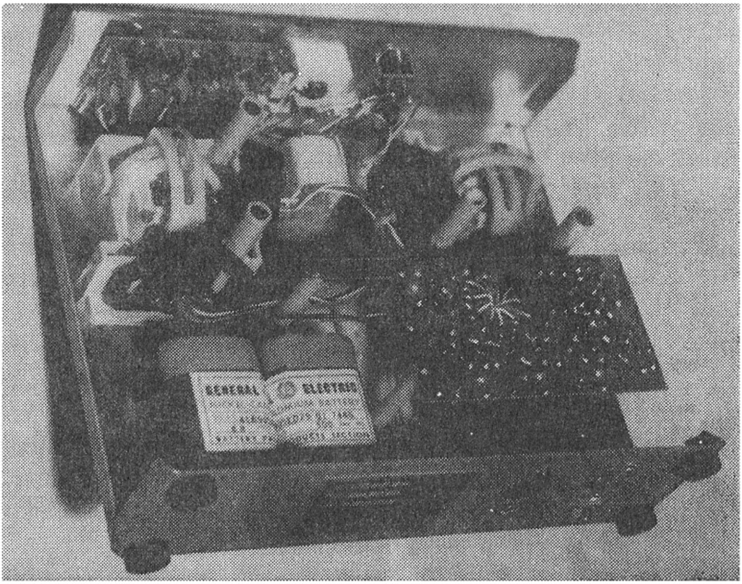

Fig. 3-10. A long-range digital transmitter for control of airplanes.

operate one of the gimbal systems seen at top right and left, the slotted white ring arrangements. When moved in the ring slots, the stick can cause the wiper arm of two potentiometers to move on the fixed resistance of the pot. This, in turn, causes a variation in the pulse width or spacing sent out by the digital transmitter, which causes a servo arm in the receiver system to move in exact proportion to the gimbal ring displacement.

At the bottom of the photo you see the two batteries, G.E. type, which consist of four ni-cads of 1.4 volts each. These power the transmitter. The rf section is at the top left inside the upper case lid. It is very small and compact, and the printed circuit at the lower left is the pulse generating circuitry. Notice the nice clean assembly and relative absence of wires.

TESTING TRANSMITTERS AND RECEIVERS

When testing pulse-operated radio control transmitters, you need a high-quality oscilloscope to follow the waveforms throughout the circuits. In the commercial units, the location of the test points are specifically shown on the maintenance manual diagrams, and the kind of waveforms you should find there are illustrated. When you get other than the required waveform, a troubleshooting chart will tell you which item or integrated circuit probably is the cause and should be replaced. Then you have to use printed circuit soldering techniques—suction of loose solder, low-heat applications, etc.—to replace the suspect part. If you have properly determined the trouble, then simple replacement fixes the unit. If not, then it's a "hunt and try" kind of operation until you do get the defective unit replaced.

Sending your malfunctioning transmitter, receiver, or servo back to the factory or to one of its replacement and servicing centers is wise. They have the experience, ability, parts and equipment to do the repair and replacement job for you, if that is necessary. Normally, you won't have such testing and repair equipment or parts on hand. These places will often have special test equipment similiar to the transistor transceiver tester shown in Fig. 3-11. Of course, for radio control equipment testing, the unit might be different. For example, it might generate pulses for testing of servos. Kraft makes one such unit, and we have seen various types of "home-brew" breadboarded equipment testers made by individual factory personnel to help them test and check and repair radio control units and systems.

Usually, the end result of any repair, adjustment, or replacement is a *range test*. This is done over a certain known distance, proven equal to the maximum flight control distance of a model

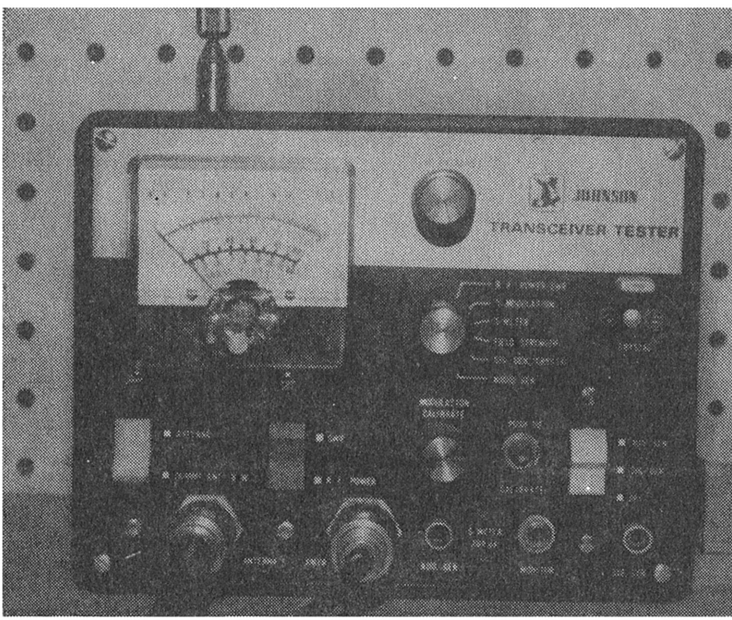

Fig. 3-11. A transistor transceiver tester.

airplane. Also, known responses to control signals must be obtained in repeated operations before a unit is certified as ok for return to the hobbyist.

FINDING SOLUTIONS TO EQUIPMENT "DOGS"

In some cases, as everyone knows who has ever worked with electronic equipment, one will come across a "dog." This is the circuit which works sometimes—usually when you are testing it—and doesn't work when it's in the model. Oh, what problems they present! These are the intermittents. What can you do about them, or what does the factory personnel do about them?

First, a good cleaning and inspection of *everything* is necessary. Every part, every wire, every printed circuit line and connection must be inspected under a high-powered magnifying glass, while some bending, thumping, or other manipulation is being performed. Sometimes, with test probes connected, the problem can be isolated to an *area*.

A "deep freeze" icebox is often used to cool the units to a temperature even below that which might be encountered in the field. This sometimes produces symptons which lead to identification of a failing or malfunctioning part. The opposite is also true: heating the units to a hotter than expected temperature could give the bad part the "fits" and cause it to malfunction while you are testing it.

The result of knowing all this is that your equipment will give better performance if you do not keep it in a hot car or in hot sunshine while it is not being used. Nor do you want to expose it to freezing temperatures in the field while waiting your chance to fly or race. Keep your equipment clean and well maintained. Don't let your transmitter lie around where dust and dirt can get into it (somehow it does, even though some units are said to be sealed), nor leave it so water or water vapor can get inside. Use a plastic wrapping around all R/C model parts which may be exposed to moisture or dirt of any kind, and especially those parts which may be exposed to salt air. Prevention is worth 10,000 cures!

Now take note of the transmitter—exposed—in Fig. 3-12. This transmitter, yet another example of the types found—this one a single-channel Pulse Commander unit from ACE R/C—uses six size D dry cells to get the required 9 volts operating potential. They fit against the springs seen below the circuit plate. Notice how the plate has a hole in its center to accommodate the gimbal ring or stick-operated system in the case below. The antenna is a sliding section type, which is very common with R/C transmitters. It is shown at the top right of the picture. Notice the heat sink around a transistor at the lower left just above the three coils, each of which is slug tuned. The crystal is at the upper right of the circuit plate.

TRANSMITTING ANTENNAS

Because you extend and collapse the antenna of a R/C transmitter at least once a week, and probably more often if you are an active hobbyist, the sections frequently become looser and looser. Ultimately, this can lead to a section collapsing slightly when you are using it to control, say, a model airplane in the field. The weight of

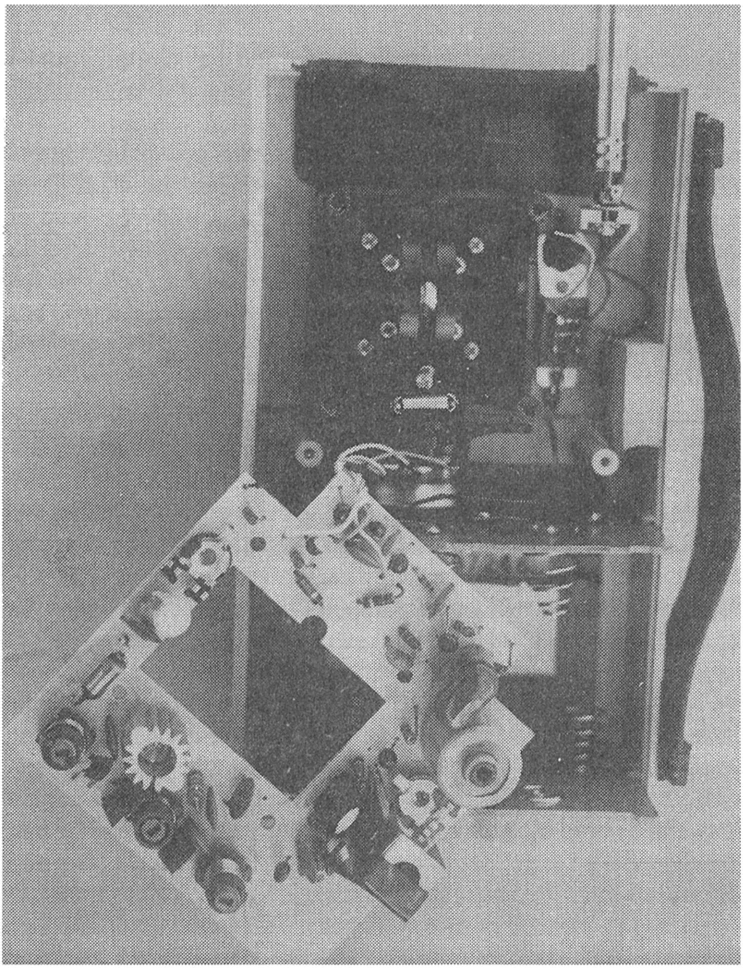

Fig. 3-12. A dry battery-operated, single-channel transmitter.

the antenna will make a light connection while you hold the transmitter still. When you move suddenly, however, as you often do when actually controlling a model, that loose connection may vibrate ever so slightly and cause some static, interference, or loss of signal for just a fraction of a second to the model. But even that small time loss of signal can result in disaster if you are turning fast, controlling a fast model, or sending signals during a critical movement period of the model. Beware of loose or corroded antenna joints. They spell a disaster sooner or later! In Fig. 3-12, such an antenna section is shown fastened inside the transmitter itself.

Also, don't forget that the transmitter is designed to work into a *fixed impedance* load which is represented by the *extended* antenna *and* the transmitter hand-held by a person. The transmitter does not work properly, can draw too much current and may overheat transistors in it, if it does not "see" this proper loading. Ask any amateur radio operator what happens to his final amplifier when it is not loaded properly into an antenna. We believe that a hand-held transmitter, which all current R/C transmitters are, does not work properly unless a naked hand holds the case. Using gloves or other insulating material prevents, technically, the *mirror image* antenna from forming from your body contact. Some like to call this the *counterpoise effect*: loading is not exactly what it should be. Try to use your naked hands to hold the case and hold it tightly with the antenna fully extended for best results at all times.

SOME SPECIFIC ANTENNA SYSTEMS

Considering that in the amateur band of 53 MHz, some more efficient and directional antennas might be used, such as the full dipole, let's examine some antennas which are applicable. The importance of the transmitting antenna system cannot be overemphasized. With manufactured units, the antennas are designed for optimum performance and should not be changed in any way. It is possible to design an output circuit for the transmitter which will allow any wire of reasonable length to be used but, unless this is done, exercise great care in getting the antenna exact. The resulting carefree performance will justify the time and effort.

Three types of antennas are commonly used: the half-wave doublet, ⅝-wave or quarter-wave rod and beam type. The doublet consists of a half-wave antenna divided in the center and connected to the feed line at this point. Either a single wire or folded dipole can be used. The latter is constructed from TV lead-in wire (300-ohm line) cut to the specified length. The ends are soldered together. One conductor is cut at the exact center, the two cut portions being

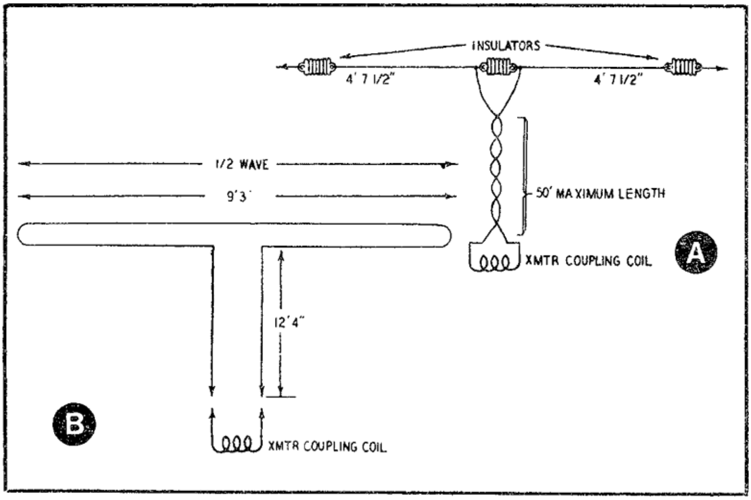

Fig. 3-13. Single (A) and folded (B) dipoles are easy to construct. The dimensions shown are for 50-54 MHz. Double them for 27.255 MHz.

connected to another piece of transmission line. Figure 3-13 shows the two methods. Ordinary twisted lamp cord can be used with the single-wire antenna.

The radiation pattern of a dipole is a doughnut which is curled around the antenna. Minimum radiation is off the ends. For model aircraft flying overhead, this pattern is ideal. Horizontal range is not affected if the antenna is turned so that it is generally broadside to the model. There are no stringent requirements for a ground system, although the height above the earth does affect the radiation pattern. It is best to have the antenna at least a half-wave length above the earth. One-half wave = 468/f(MHz) in feet.

The only requirement in tuning the transmitter to the antenna is to adjust the coupling link for the desired output or loading as indicated on a plate-current meter. Never make this coupling so tight that it takes all the energy out of the tank as this will cause unreliable operation.

The quarter-wave or one-eighth-wave rod is the type most commonly used on 27.255 MHz since it is physically small and allows efficient radiation for practical purposes. The length of a quarter-wave antenna is half that of the doublet, and the one-eighth-wave antenna is half the size of the quarter-wave antenna. This antenna can be so made that it plugs into the transmitter case directly whether the transmitter is a hand-held unit or larger size. Again, the radiation pattern curls around the antenna and so, if the model aircraft is directly overhead, it is in a zone of minimum radiation if the

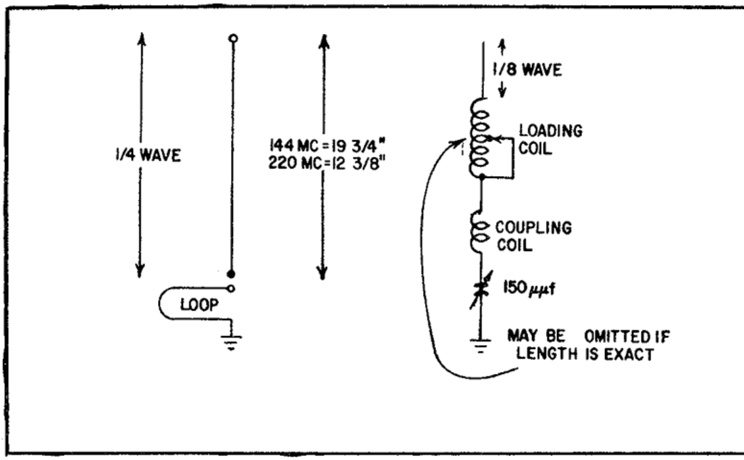

Fig. 3-14. Whip antennas are used in R/C work.

antenna is also vertical. The antenna may be tilted slightly to provide a good signal overhead. Normally the transmitted output and the receiver sensitivity are so great that there is little danger of losing control even if the model is in the minimum radiation zone, unless it is being operated at extreme distances.

These types of antennas work best when operating against some type of ground system—a stake driven into the earth: Connecting the transmitter case to an automobile body through a wire, or the body of the controller himself may serve. A ground system is needed since the antenna has a mirror image in the ground. It is then like a dipole with only one half radiating into space. Looking at it this way indicates the coupling method needed. See Fig. 3-14. The coupling loop or coil is adjusted for the required output. If it is wound close about the tank, the coupling is tight; if spaced about the tank, the coupling is loose. One side connects to the transmitter ground and the opposite end to the antenna. A relatively long transmission line can be used, but it should be a special type known as coaxial cable.

Only a few beam antennas will be considered here although there are others. When the transmitter operates on a high frequency, the size of the antenna becomes small and generally the power output is reduced somewhat due to lowered transmitter efficiency. This makes a beam antenna desirable.

A rod, metal tube or wire of specified length placed a certain distance in front of a dipole and parallel to it tends to draw the radiated output from the dipole toward it. This is called a *director*. A rod, metal tube or wire of specified length placed a certain distance behind the antenna will tend to reflect radiation back to the dipole. This is called a *reflector*. By using directors and reflectors, the radiated energy can be beamed, the sharpness of the beam being determined by the number of elements making up the director and reflector, and the spacing between them.

A beam-type antenna should be pointed in the general direction of the model. Exactness is not necessary as the beam is broad. The method of coupling this antenna to the transmitter is the same as for the dipole since the directors and reflectors have no physical connection to the transmitter.

FIELD-STRENGTH INDICATORS

A field-strength meter is useful as a final check in determining the transmitter's operation. Once the transmitter has been adjusted,

Fig. 3-15. A modern digital transmitter with sliding antenna.

this device will indicate whether the transmitter is radiating properly. A field-strength meter is essentially a tuned circuit connected to a small antenna and through a diode rectifier to a sensitive meter. The

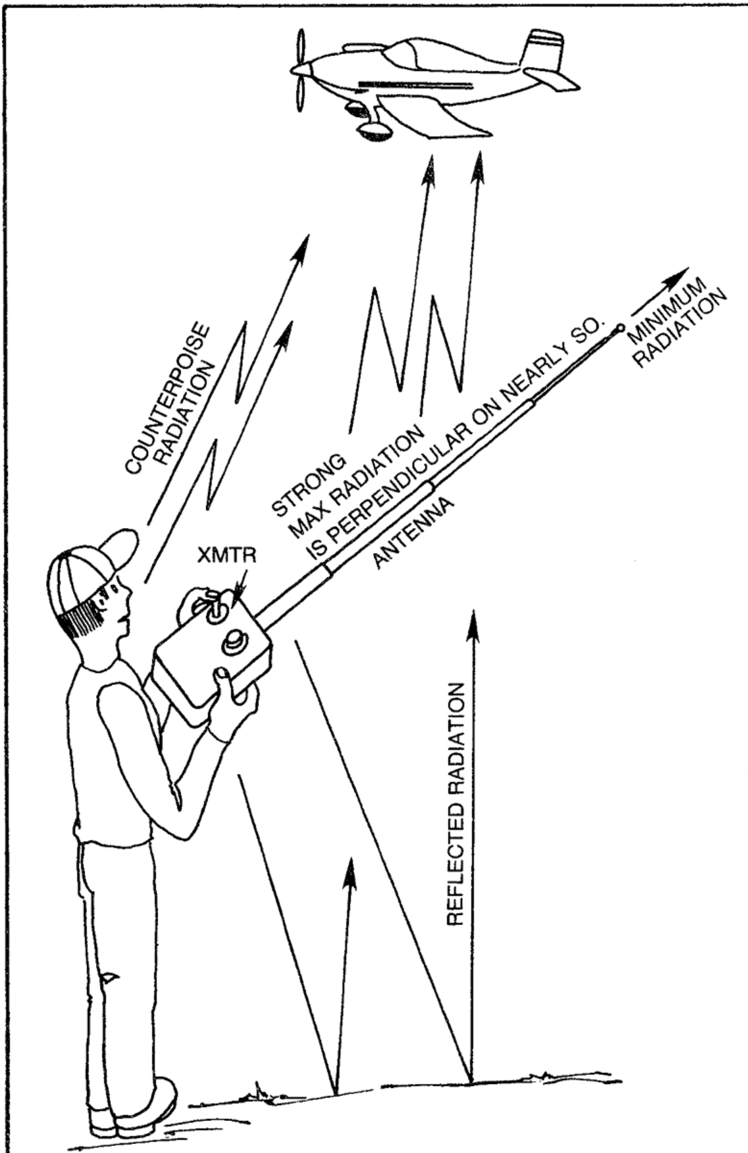

Fig. 3-16. The radiation pattern of a one-eighth to one-quarter wavelength antenna.

unit is placed some distance away from the transmitter, tuned to the transmitted frequency and the reading noted. From then on, if it is placed the same distance each time and the transmitter keyed, the reading should be approximately the same, indicating correct transmitter operation.

RADIATION PATTERNS

In Fig. 3-15 we show a modern digital transmitter with its two sticks for control of the model. The right stick usually controls rudder and elevator. Since this stick can be moved in any direction, you can control either one separately or both together. A trim control is next to the stick. This control permits adjusting the model for straight flight in the air when you release the spring-loaded stick. It positions itself, as shown, at neutral.

The second stick on the left may control motor speed and ailerons. These are general practices and may in some models be changed so that the *right* stick controls ailerons and elevator and the *left* one the rudder and motor. But that choice is up to you. Notice the sliding antenna section at the top of the case, and the performance indicating meter in the top left.

The radiation pattern from the antenna will vary according to ground composition, location, humidity, etc. Generally, you will find a null off the end of the transmitter antenna and maximum signal when the antenna is inclined about 75 degrees away from the model, as shown in Fig. 3-16.

Notice that you never—absolutely never—point the antenna toward the model. We said *never*! Hold the transmitter chest high with the antenna inclined as shown in the figure. Or if the model is far away, hold it high with the antenna vertical. Always, though, hold the transmitter so that the signal goes to the model broadside from the antenna, never from off the end.

Some manufacturers claim that it is permissible to adjust the antenna to less than its full length for very short test periods while the model is on the ground or nearby. All right, but do this carefully and don't prolong the test. Remember that your transmitter transistors are "hurting" during this kind of operation.