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MODEL RADIO CONTROL - 3rd Edition

A complete, updated guide to the fascinating world of model radio control!

by Edward L. Safford Jr

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Preface

This book is a second revision of the book first published in 1951. The first revision was published in 1959, and we thank you for your acceptance of those two works. We hope and trust that you will find this work just as valuable. It is practically a *new* book on radio control.

There is much new material in this edition. It still retains all of the valuable and still useable ideas and information of the two previous works. They are updated and now considered in light of the current state of the art of radio control. We hope and trust that all of you whom we have met through the pages of the previous works, or our other books, and those of you whom we meet for the first time in these pages, will find this new edition as worthy as you have reported the original and first revision to have been. As in the previous editions, we start at the beginning and will advance the ideas fully and carefully so that if you are not familiar with radio control, you can learn what it is all about and how it works. If you are familiar with the hobby, you can still find valuable ideas and concepts within these pages.

Radio control enthusiasm has not diminshed during the years since its inception. If anything, its popularity has increased. We are constantly amazed at how many new applications modern technology is able to develop. In some cases the gains are not just in a hobby sense. For example, there are now on the market, some remote (triggered by radio control) alarm systems to warn neighbors if an intruder is present. The alarm will report if an intruder is present or if there is a fire burning out of control. It might even be able to tell someone if you are hurt or seriously ill. In a way this is remote monitoring of your welfare and as such can be extremely valuable.

The fact is that radio control of models—and other things— is an accepted hobby and business throughout the world. Radio control simply means that someone or something (a computer) somewhere is going to cause certain events, operations, or conditions to occur at some other place. This happens only when certain commands are sent by radio, sound, light, heat, or other method suitable for the conveyance of commands.

Citizens band radio came, was accepted, and is here. We think nothing of being able to communicate with that car at our "front door" or "back door". In fact, we get upset if we cannot communicate with everyone we want to. We use radio transmission to convey ideas in this case, and not necesarily commands to do things. So there is really nothing unusual, except for the change in equipment. All we need do is convert a *talking* system into a *commanding* system, which is necessary for radio control.

Everyone would like to be a pilot—well, almost everyone. Some can't for various reasons. But almost everyone can become a *model pilot*, flying a true airplane from the safety and security of a ground position. A dream is thus realized, and believe me, the feeling is almost the same as flying the big machine. So this is one reason for radio control of a model airplane. Then there is that great desire to build something, to fabricate and construct, to design and assemble, to plan and activate. Some can build skyscrapers and bridges and whatnot. Some cannot. But again they can realize the essential elements and satisfaction of this desire in the building of models. And since radio-controlled models must, in reality, function and operate just as their larger counterparts do, they must be made properly. Therefore, a second dream is thus realized.

Escape from boredom is another reason why models are built and sailed or raced or flown, or operated. For the most part, people like to have "brain challenges." The building of the models, the installation and operation and test adjustment of the radio control equipment will provide a challenge that is rewarding and satisfying. And everyone can do it. There is no restriction as to sex, age (except young), color, race or creed. And costs can be selected to be within the means of just about everyone. When hobbyists get together with their models, there is no boredom, and the results of these gatherings, or even the isolated building and operation of models, will give that fertile brain new concepts and directions and challenges, so believe me, the boredom can be gone forever.

Radar control is being tested in automobiles as an automatic safety system to prevent a car from getting too close to the car ahead. Also, automatic information transmission and activation of various auto control devices can take place without appreciably slowing down the car or causing the driver or occupants any discomfort.

Radio control will be used more and more in conjunction with home computers as it becomes necessary to gather physical sensor data and activate various electrical-mechanical devices through this increasingly popular instrument. Wireless as well as wired remote control systems—wherein the signal is transmitted over the air or on wires already carrying electrical currents in your home—will be used extensively in the future.

All this is in addition to the ever popular hobby aspect of radio control. How much fun it is to guide your beautiful—and some not so beautiful—airplanes and sail planes through the sky or drive your model car or sail your model boat! What a feeling of freedom and power as you make the model do whatever your mind can conceive in the way of airplane aerobatics, or picture taking, monitoring, or whatever! And how graceful the modern model ship, sailboat, or racing boat is as it cuts through the waters responding to your slightest whim. One just can't find an end to the R/C things which can be incorporated into a model boat. Just think of launching a small plane from a ship deck, and controlling this at the same time that you are controlling the speed direction, whistles and the lowering of lifeboats of the mother ship. Imagine trimming the sails—just so—to gain the greatest speed and the thrill of winning a sailboat race.

Model car racing with either fuel-powered or electric-powered motors is fast becoming a great area of hobby fun and a test of your coordination and skill. Races are being held all over the globe. This gives the electro-mechanically inclined hobbyist a chance to really get involved as well as to give a good show. Of course, he can have fun trying to negotiate the various turns and straight-ways of model car racing roadways.

All this means that radio control systems have come into their own. They have progressed from the single-channel escapement-operated systems into multichannel, proportional systems. The latter are extremely reliable, easy to apply, install and use. A far cry, indeed, from "those days when...."Those of you "old timers" will gain a bit of nostalgia from our mentioning some of the older systems. And, of course, they still work. They can still be used even though they are limited in what they can do. You might want to develop and modify them "just for the fun of it."

The sages tell us that the days of computers and robots are in the offing. Of course, radio control will have its place in this scheme of things. Remote control of scientific robots is best illustrated by the Mars, Saturn and Venus ventures of NASA, and the techniques they use are but extensions of those used in R/V.

We have written and have required many books on radio control. In each we have given the reader something a little different, and perhaps a little more advanced, depending on which book you choose as your next bookshelf addition. This book is the fundamental one that gives basic information on the mechanics of the systems involved. We hope this will be the one to give you a foundation of knowledge for our more advanced and specific books on R/C.

So let us get at it. Grant us permission to keep intact those concepts and systems which are fundamental for those who aren't familiar with Radio Control. We hope the new material here meets with your approval. Thank you again, as always, for your acceptance of our works. We hope that your own imagination and creativity will be sparked by what you read herein.

As always, we have met many wonderful people over the years at so many flying fields, R/C club meetings, hobby shops, and homes who have added to our basic supply of knowledge that we just cannot list them individually here. We do, however, extend our gratitude to each and every one of you in a most personal way.

So be it! Let us begin.

Edward L. Safford, Jr.

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MODEL RADIO CONTROL-3rd Edition
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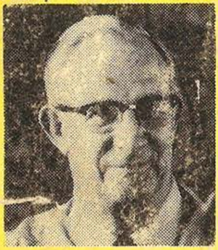
This *all new* and complete revision will thoroughly acquaint you with everything you need to know about model radio control—how it works, how to design a system, how to install it, and how to operate model airplanes, cars, boats, toys or virtually anything by radio control. Starting out with fundamental RC concepts, the author takes you through all the latent and most modern equipment, including coding and coders, relays, superregenerative receivers, decoders, power control circuits, servo motors, tone-operated and proportional control systems and much more!

Here is complete description of every RC system ever devised—including the latest digital proportional control systems. *Nothing* is left out—you can choose the system you prefer and then read all about it. Even if you're a novice in the world of radio control, you can learn from this book, and be in charge of a radio control system in no time at all! If you're a veteran hobbyist, there's still plenty of *all-new* info on the most modern equipment here. This book will bring you up to date and keep abreast of the constantly changing, constantly developing RC technology. So, if you want to keep up with the changes in radio-controlled modeling, or if you want to get in on the ground floor of the hobby, this lucid guide should be part of your library.



Edward L. Safford, Jr. is a technical writer and amateur radio buff of long standing who has published over 60 articles, 20 technical books and 5 novels. He is the author of several TAB electronics books, and lives in Houston, TX.

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Chapter 1

Fundamental Concepts, Devices and Operations

In this chapter we will explore the fundamental ideas associated with radio control. We will examine some modern systems—simple types—and we will learn what devices and units are required for radio control operation. It will be fun, so let's get started!

The most fundamental unit in radio control is, perhaps, the output device. This is the element which converts the radio signals into some kind of mechanical motion, and that, after all, is probably the ultimate end product we desire from our radio control system.

Some mechanical motion is necessary to move the rudders on boats or planes, or the steering wheels of cars, or the arms, legs and head of a robot. To make each of these kinds of models do something physical, be it sail, fly, race or track over a rugged terrain, we first need this mechanical motion.

THE NECESSARY MOTIONS

What kind of mechanical motion do we need? Well, we generally need to have some kind of two-way movement; that is, left-right, up-down, turn and bank, etc. Also, if you think of steering whatever the output element (rudder, steering wheels, etc.) may be, you will also think of a *neutral* position which always makes the model go straight ahead, or the robot relax. (After all, we humans have such relaxed positions, don't we?).

We can also think of three positions for the driving elements of a model. That is, it should have a forward and perhaps reverse, and if not a reverse (a model airplane doesn't have one) then it should have a normal speed forward and a high and low speed at least associated with this "normal speed." Again we are thinking in terms of three positions of some governing element like the throttle of a model engine, or a forward, stop and reverse position of a model drive motor.

Models nowadays employ one type of drive motor, the glo-plug fuel engine that's used in racing cars and boats and almost always on model airplanes. We say "almost" because some airplane types now have electric motors. These motors are small and powerful and can give good performance, even in model airplanes. They are reasonably lightweight, and the battery supply is not too heavy for a small model aircraft to carry. But we need steering motors or an *ACTUATOR* to steer the models, or move things and certainly a drive motor to propel it, except in the case of sailplanes and sail boats.

THE ACTUATOR

Let's think of what an actuator is. It is a kind of motor which will turn one direction or another when electricity is applied to the winding of a coil associated with it. But it does not rotate! It has a magnet which is free to turn on an output shaft, and when the electricity is applied in one direction (plus to minus on the coil windings) the magnet will rotate in one direction and stop. When the battery connections to the magnet are reversed, the magnet will cause the output shaft to rotate to the other extreme in the opposite direction. When the magnet moves, the created force can cause a rudder to move, or other relatively lightweight, low-force (torque) output element to move. But it is not as powerful, nor as versatile as a small electric motor with a good gear system. Usually the small electric motors run so fast that we cannot use the output directly from their motor shaft until we slow it down through gears. Realize that when we gear down a motor, we also get more turning power or torque from it, and we want that also. The only time we want the fastest possible rotation with as few gears as possible is when the electric motor is used as an airplane engine and turns a propeller. Then we want speed as well as torque. Sometimes we want speed in rotation if we use the motor to drive the wheels of a race car, or turn the propeller of a model boat. But for steering or movement of an arm or other device, we want a reasonable speed—not too fast—and quite a bit of power in the output shaft turning ability (torque).

SIMPLEST ELECTRIC MOTOR CONTROL

With this bit of background on why we are interested in electronic control of a motor, let's now examine the fundamentals of electric motor control, using wires first, and then using a radio system as the connecting element between the controller and the model. Figure 1-1 shows the most basic arrangement possible. Remember that you might be able to substitute an actuator for the motor as it looks about the same physically, has two output leads and an output shaft and reverses direction of movement when the battery connections are reversed. However, the actuator does not rotate; it just turns approximately 60 degrees each way from its neutral.

The basic idea behind radio control is to send a command or series of commands from a control point to the model being controlled and to have the model follow the commands exactly as directed. The person sending the commands will be referred to as the controller.

Suppose a controller wants to *start and stop an electric motor located* some distance away. Fig. 1-1 shows that four items are necessary: a switch the controller may turn off and on (A); connecting wires that link switch, motor and battery (B); a battery which causes the motor to run when the switch is closed (C); the motor itself (D). The control operation is simple: when the switch is closed, the motor turns in one direction. When the switch is opened, the motor stops, although it may coast a bit without a brake of some kind.

This is a very limited operation but it could be used to start and stop a boat drive engine, the motion of a car, or an electric airplane engine. Speaking of electric motors, let's look at one which is used in a control system, just to have some idea of the size and type of electric motors that are a fundamental part of almost all modern radio control systems. Notice that we always hedge our statement with that "almost"? We are quite certain that some system probably doesn't use an electric motor.

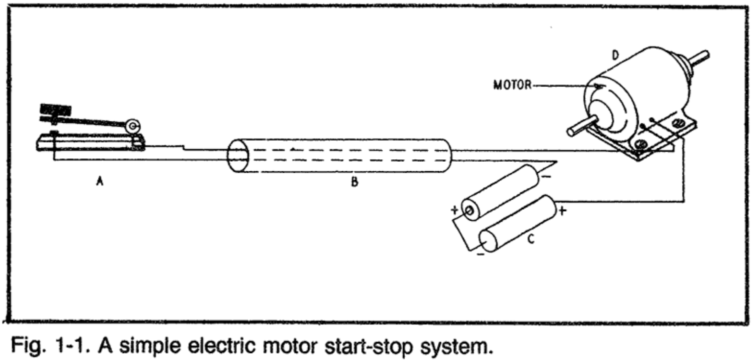


Fig. 1-1. A simple electric motor start-stop system.

Fig. 1-2. Typical electric motor used in modern radio control systems.

Again we must hedge a little. It might be that in some larger radio control systems, and other types of control systems, it is necessary to use much larger electric motors to get that enormous amount of physical power needed. In that case, the motors would be very much larger. The battery or primary supply of electricity must have larger capacity in this case, too.

THE "GLO-PLUG" ENGINE

The glo-plug engine is used in model aircraft, boats and cars as a propelling engine. See Fig. 1-3. To move the throttle arm, which is right next to the input air venturi, in order to close the fuel intake line slightly and also close the exhaust port slightly as the speed is controlled, we need a physical motion. This is accomplished by having a small electric motor geared to an output shaft. The electric motor is made to run forward or backward by radio signals. So even though we use this kind of engine as a propelling system in the model, we need electric motors to make them operate as we desire. We cannot reverse direction of rotation of this kind of engine, and usually they are not geared to the propeller they drive. They do have a kind of gearing or pulley drive to the wheels of model racing cars as we shall see later.

ELECTRIC MOTOR DIRECTION OF ROTATION

What must be done to make the *electric* motor reverse its direction of rotation? The idea also will apply to the reversing of an actuator. In Fig. 1-4, the electric motor is known as a permanent magnet (PM) type. There are other types, but with this kind you simply have to reverse the battery connections to make it run in the opposite direction.

Notice the control switch. In its center position it does not make contact to either of its lever points. The motor, then, does not run, because the circuit is not complete. But when pushed up, the common motor lead is connected to the top contact which applies a plus voltage to this connection. Since the other motor winding is connected permanently to the minus end of battery number 1, the motor runs in one direction. Moving the switch to the down position

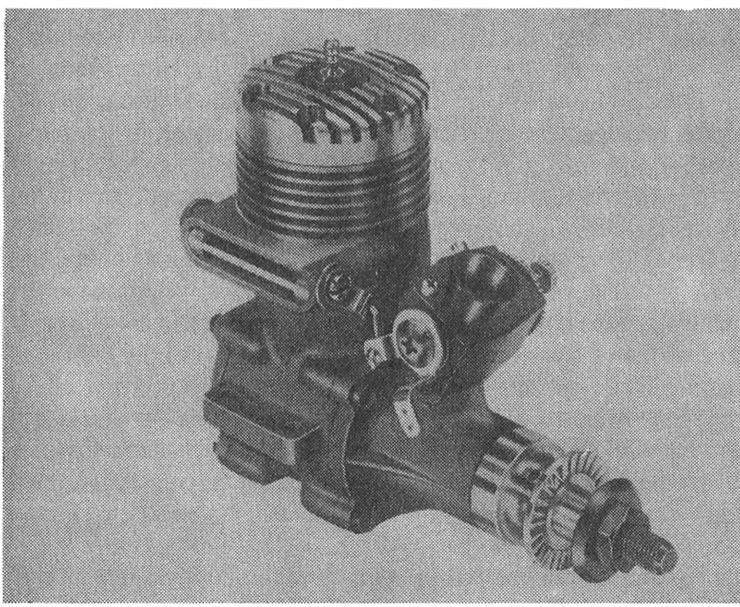


Fig. 1-3. Glo-plug engine with throttle control.

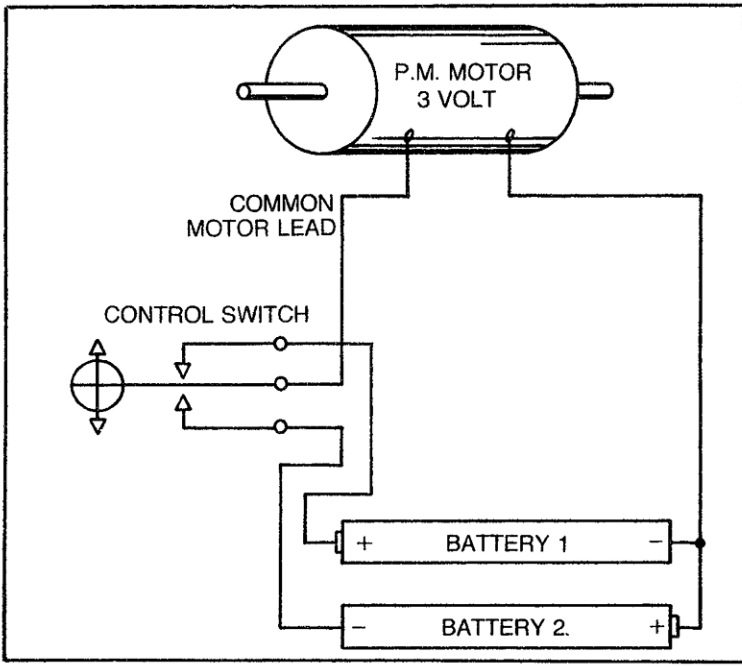


Fig. 1-4. Reversing direction of a pulse-modulated (PM) electric motor.

changes the polarity of the electricity to the motor leads by connecting battery number 2 into the circuit and eliminating battery number 1, so the motor will run in the opposite direction. With this simple switch arrangement we have now accomplished the forward, reverse and neutral (stop) positions which we said are needed for radio (or other) control systems. We did this with a wire connection to the motor, and this is a good way to start out. The wires from the switch to the motor can be pretty long—up to, say, 25 feet— and this permits you to walk around and follow the model as you move the switch to make it go. In Fig. 1-5, a small airplane on a tower has its electric motor connected through a nonreversing switch, such as in Fig. 1-1. The plane takes off and flies around the plylon. It uses a slip ring connection to the rotating arm that supports the model and which is fastened to the top of the pylon tower. As the model rotates it flies outward and thus rises from the floor or carpet. You can test complete control systems with a wire connection between the control box and the model.

You must be sure that the motor runs in the right direction to make the propeller *pull* the airplane. If it does not, reverse the connections to the battery. There is no motor driving the support arm; all the power to pull the airplane and make it fly comes from its own propeller.

A RADIO-CONTROLLED MODEL CAR

Before we examine what can be done with a simple electric motor and a connecting control system, let's look at a modern radio-controlled toy, such as the little car in Fig. 1-6.

This model uses a *short-range radio system*. Notice the antenna from the little hand-held transmitter. The car operates as follows: when you turn the drive motor on by moving a switch on the car body, the car will run forward without any signals being sent to it. When you press the little switch on the radio transmitter, the car will back up. It never reverses in a straight line, however. The arrangement of the front wheel, shown in Figs. 1-7 and 1-8, causes the car to back up in a circle.

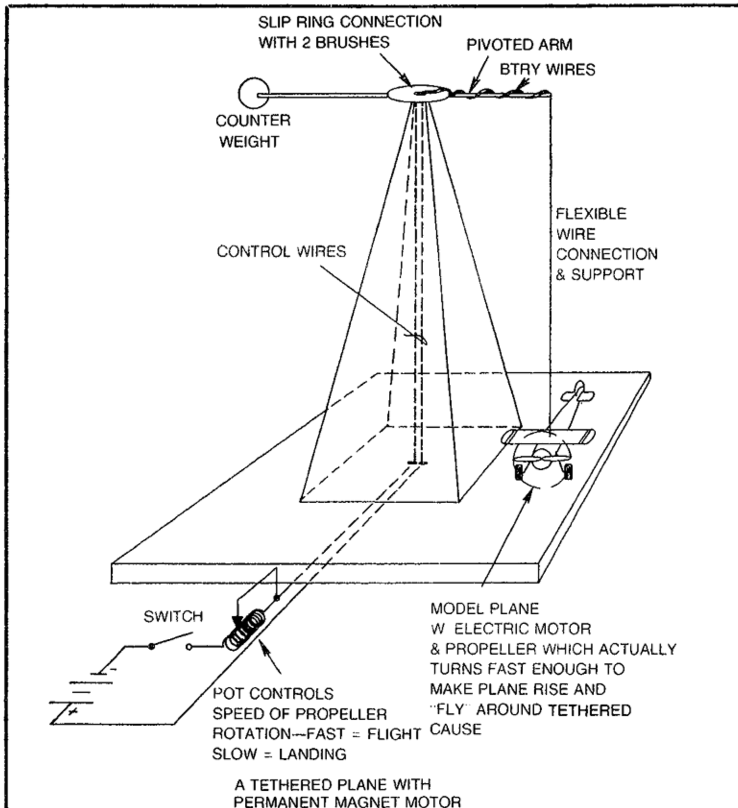


Fig. 1-5. A tethered plane with a permanent magnet motor.

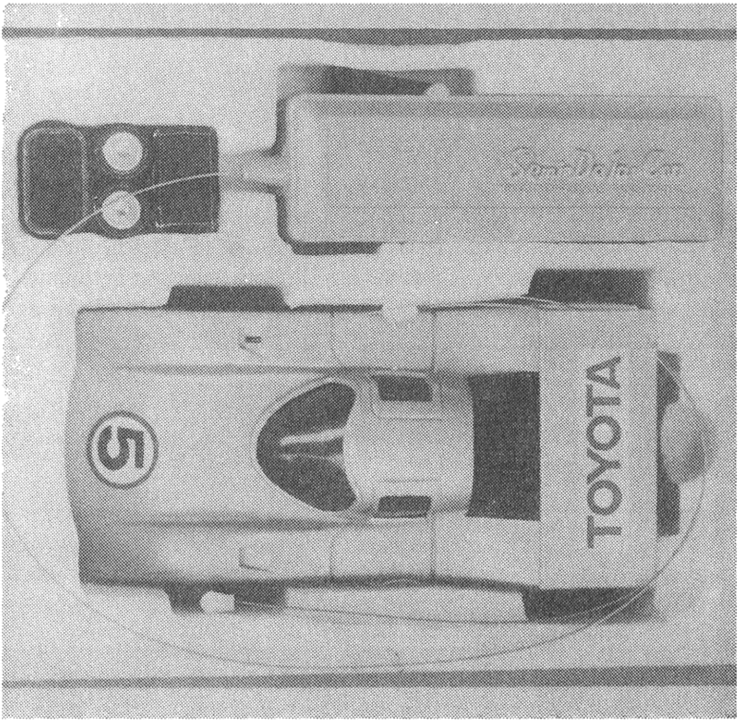


Fig. 1-6. Boxed Toyota radio-controlled car.

The center wheel is the one on the floor. The two others are for appearance only. This means that the car changes its direction if you *release* the radio transmitter button, so you can get a *kind of steering* with this arrangement. When the car goes forward, the steering wheel moves backward in its slot so that the car goes straight. The position of the wheel as shown in Fig. 1-7 is when the car is in reverse. The steering wheel moves freely to this position just by friction drag on the floor.

The Elements Of The Radio Link

In this simple model, whose parts are shown in Fig. 1-8, and relative size in Fig. 1-9, there is just a simple electric motor, batteries, a receiver inside the car body, the transmitter and its switch. The wires of our previous system have been replaced by the radio link, making this model a radio-controlled one.

To understand what happens in the radio part of the system, see Fig. 1-10. You can see that the switch of Fig. 1-4 has been

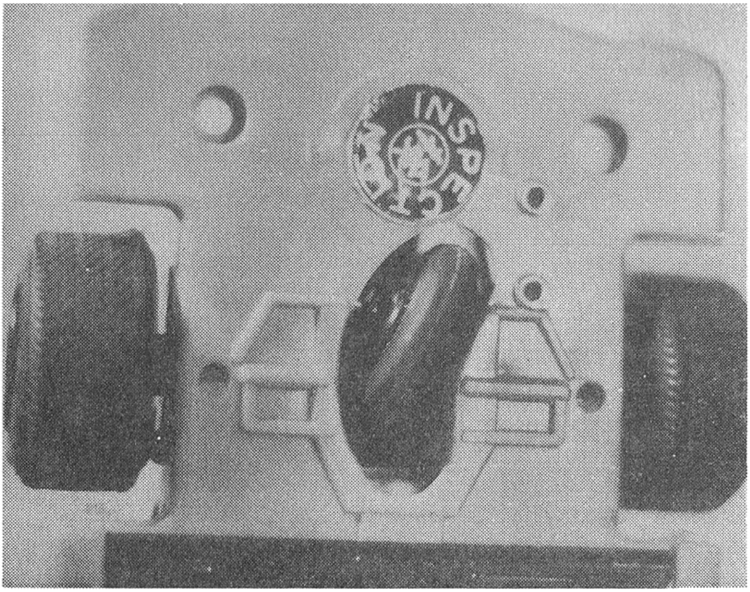


Fig. 1-7. The mechanical steering arrangement of the toy car.

replaced by an identical kind of unit called a *relay*. It also has two contacts: (1) and (2). The armature of this electrically-operated switch moves down with a signal to make contact with (2), and when there is no signal, the armature rests against contact (1). Since we described how the motor would run in Fig. 1-4, we won't repeat that here, but the two are identical in operation. The *only* difference is that we now close the relay-switch remotely by a radio signal from the little transmitter when we push its on button.

The Relay

We can use a lot of relays in radio control systems. Some types most used are shown in Fig. 1-11. Relays are operated by transistors and may have one or two armatures in most common applications. When one armature is used that makes two contacts as we have shown, this is called a single-pole double-throw relay. When two armatures make contact with two contacts each, the relay is called a double-pole-double-throw type. We will use both kinds as we proceed.

One Type Of Transmitter

We have already seen the little transmitter in its case, and if we judge from the space for the battery, we can assume that the

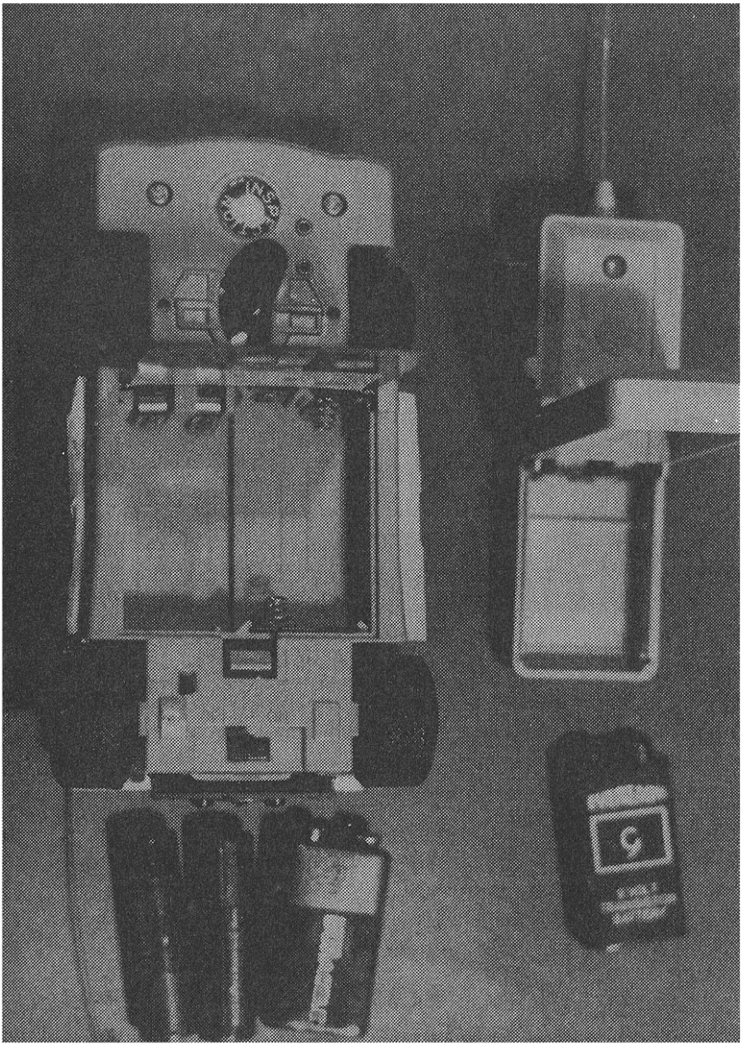


Fig. 1-8. The parts of the radio-controlled car, including car, transmitter and batteries.

electronic circuit inside the rest of the case must be very small and compact indeed. This is true, as shown in Fig. 1-12.

You can judge from the hand in the figure how small this little unit really is. A few transistors, a crystal, a coil, a resistor and capacitor or two and that is all there is to it. Notice the off-on signalling switch on the lower side of the case—the protruding black bar. Perhaps you can see its workings better in Fig. 1-13.

Fig. 1-9. Battery installation is simple for many toy R/C systems.

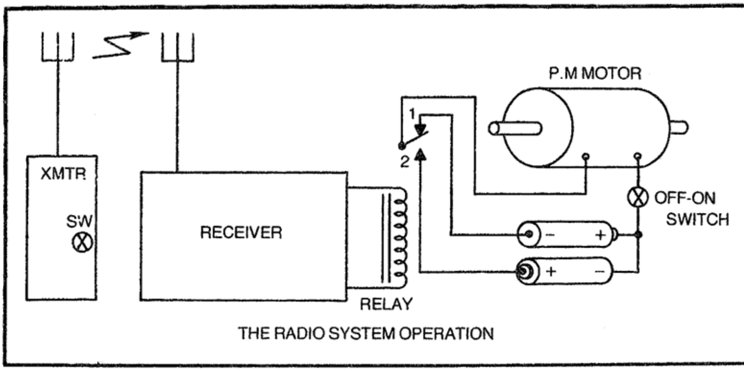


Fig. 1-10. The radio system operation.

Nothing about the transmitter needs adjustment and nothing is critical, except the antenna length. The antenna must never be changed after it is adjusted for proper range and operation. Batteries, of course, must be kept in good condition, but since the only time you have drain from the battery is when you transmit, these last a long time if they start good. Later we will see how rechargeable ni-cad batteries are used in place of the dry batteries shown here.

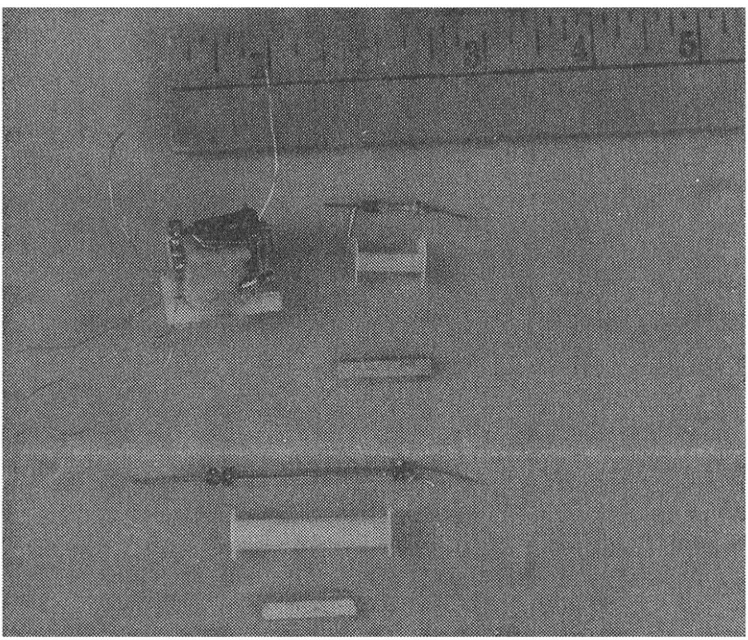


Fig. 1-11. Some types of relays. At the top left is a standard sensitive relay. At the top right is a small reed relay. At the bottom is a larger reed relay. Reed relays can also be closed with a magnet, shown below each.

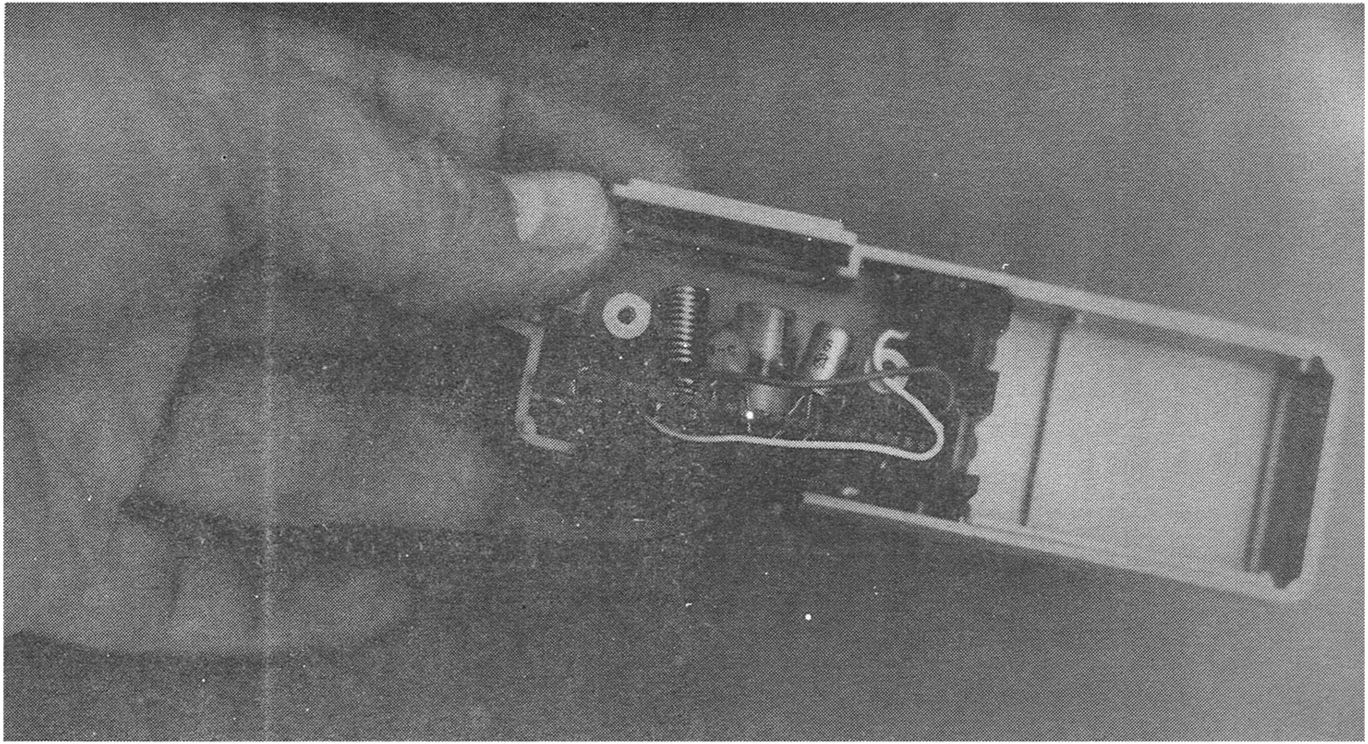


Fig. 1-12. The transmitter of toy R/C car.

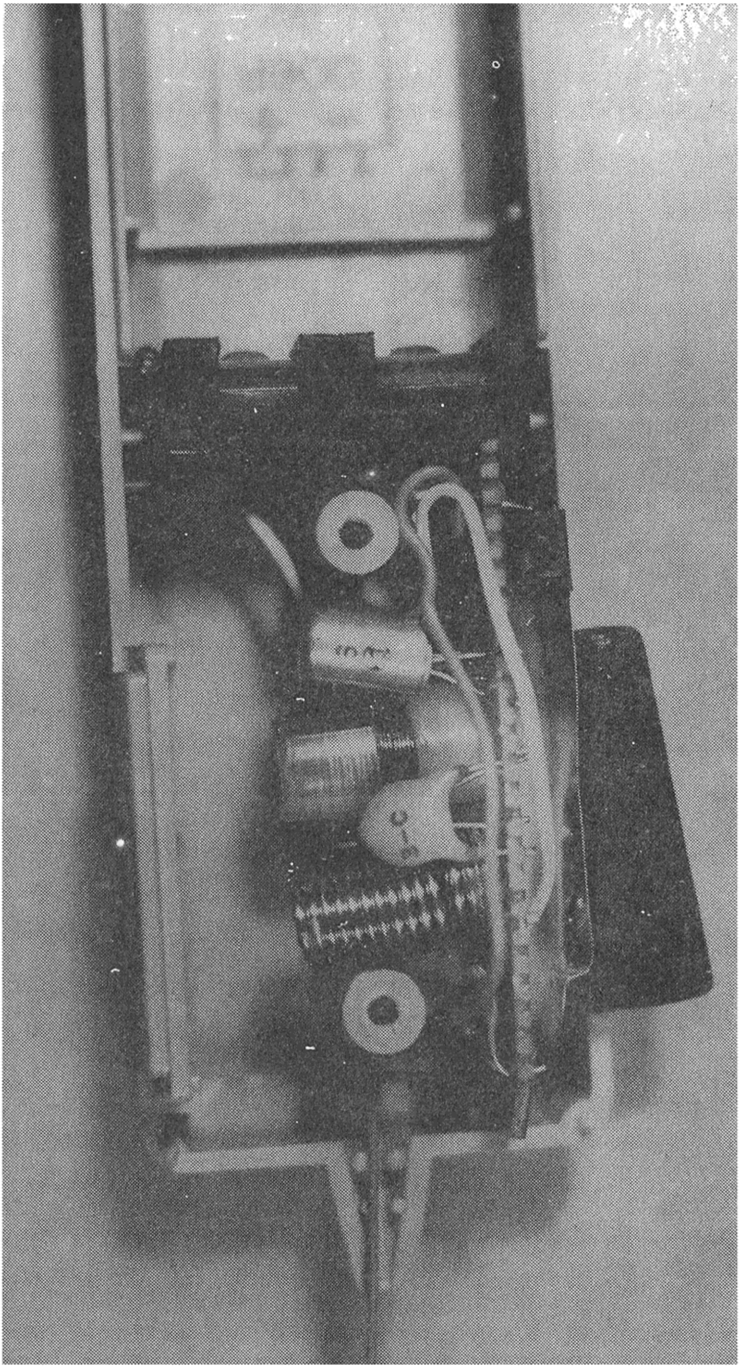


Fig. 1-13. A closeup of the transmitter working.

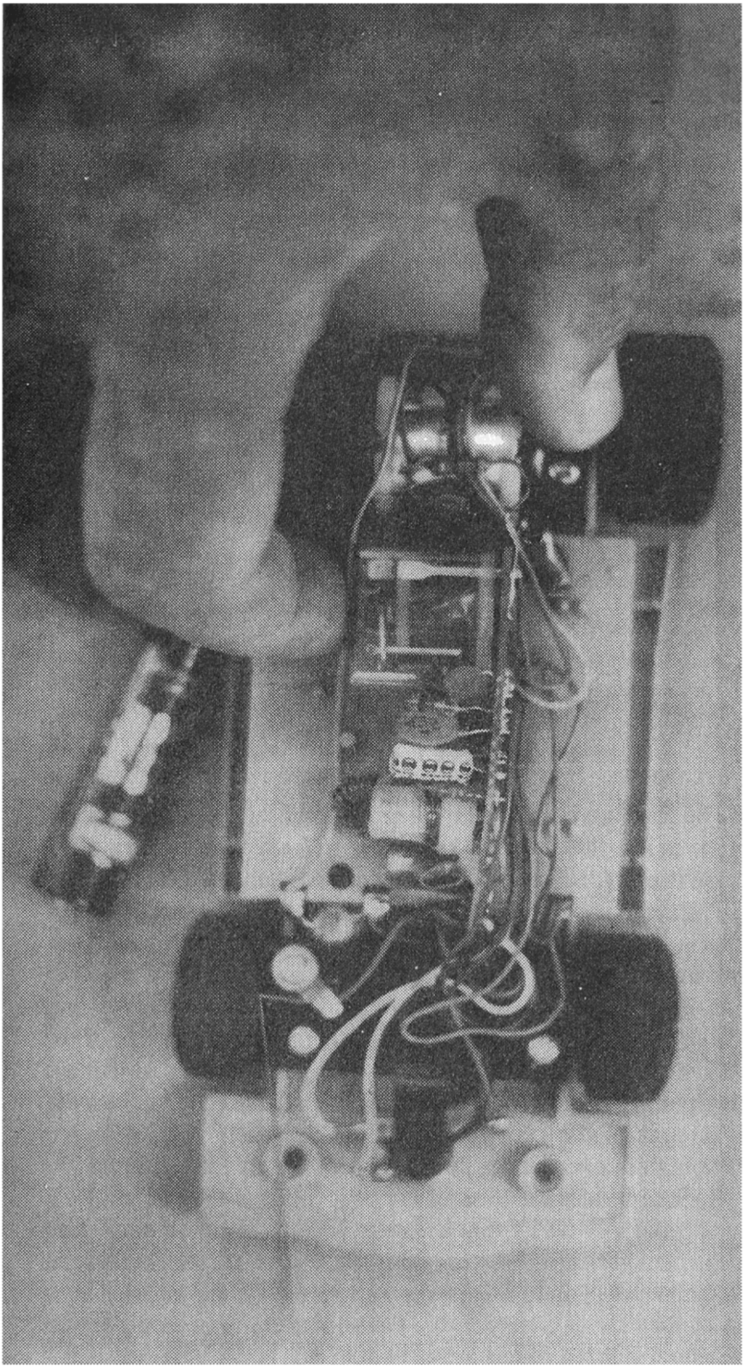


Fig. 1-14. Inside the model radio-controlled car.

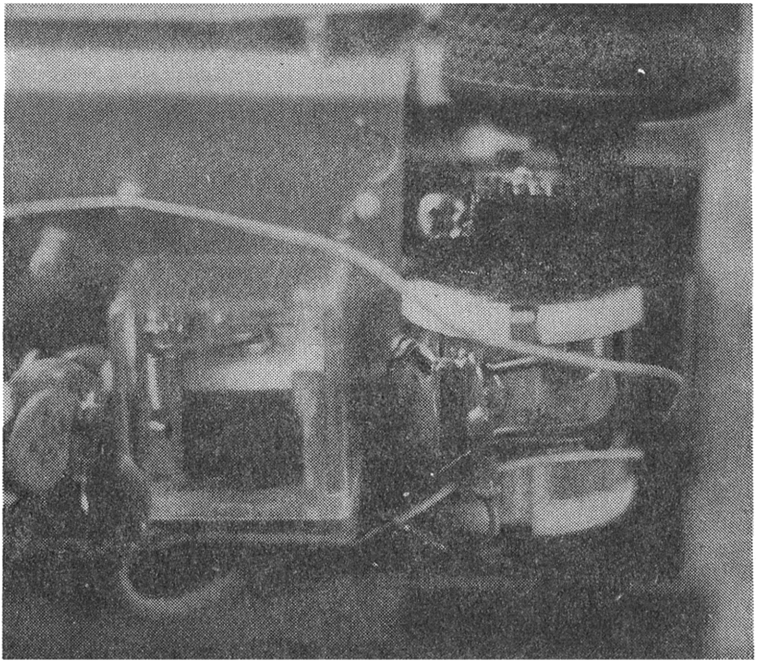


Fig. 1-15. Closeup of the relay and drive motor. Note the capacitor across the motor terminals and the relay armature.

The Receiver

The receiver is always in the model, and this receiver, like the diagram of Fig. 1-10, uses a relay. We make a point of saying this because in many radio-controlled systems nowadays, we don't have to use relays. Instead, we use transistors to do their job. The reason for this is smaller size, simplicity, and no mechanical moving parts to worry about or adjust. But using relays is a good way to start, so examine the inside of the model in Fig. 1-14.

The receiver is that electronics section just to the left of the relay. Isn't it small and compact? The wiring to the off-on switch and battery compartment runs forward underneath the receiver chassis. The antenna of the receiver is also critical and on radio control systems, you never lengthen or shorten this antenna, either.

A close-up of the drive motor and the relay is in Fig. 1-15. Between the PM motor and the rear wheel it turns, a small gear arrangement gets more power and slows down the car. These small motors can turn at up to 6-7000 revolutions per minute and that is far too fast for driving a model car. Some circuits for energizing and reversing the drive motor are shown in Fig. 1-16.

Some Technical Details

Just in case you are knowledgeable in electronics and feel a sudden desire to build a simple radio link to go with some little system you have in mind, we give you the circuit schematic of a short-range transmitter in Fig. 1-17.

This is a so called Part 15 transmitter which simply means that the FCC does not require a license for its operation. It will operate in the 27-MHz band and causes a tone signal to be sent out when you press switch S1. There is a power switch S2 to turn the unit off and on.

To tune the unit, connect a 25 mA meter in series with B1. Remove the crystal and flip S2 to on. You should get a reading of about 2 MA. Turn the core in T1 all the way in. Then insert the

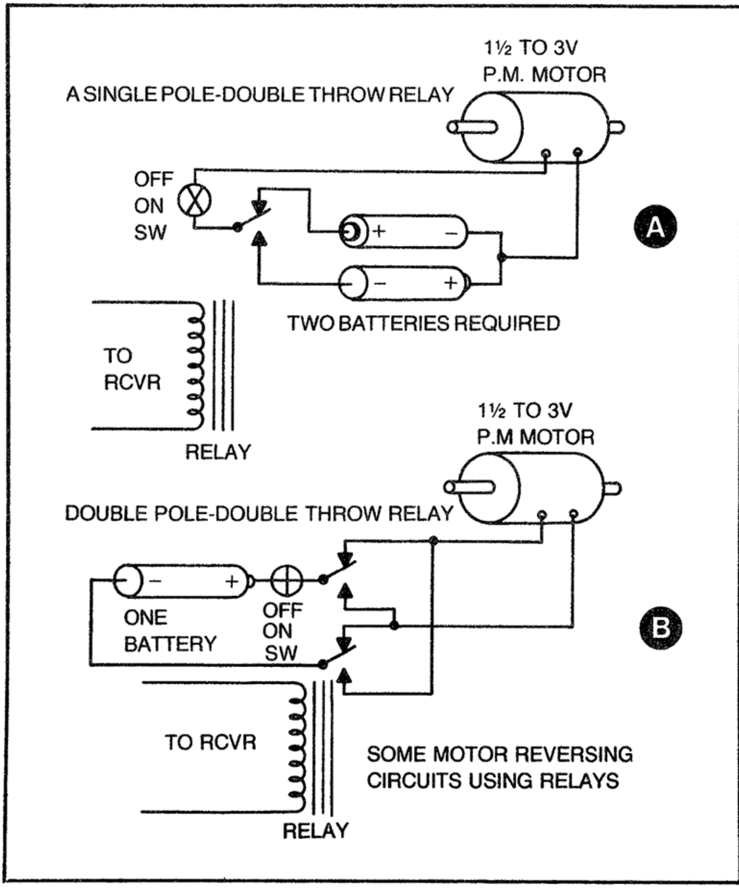


Fig. 1-16. Some motor-reversing circuits using relays.

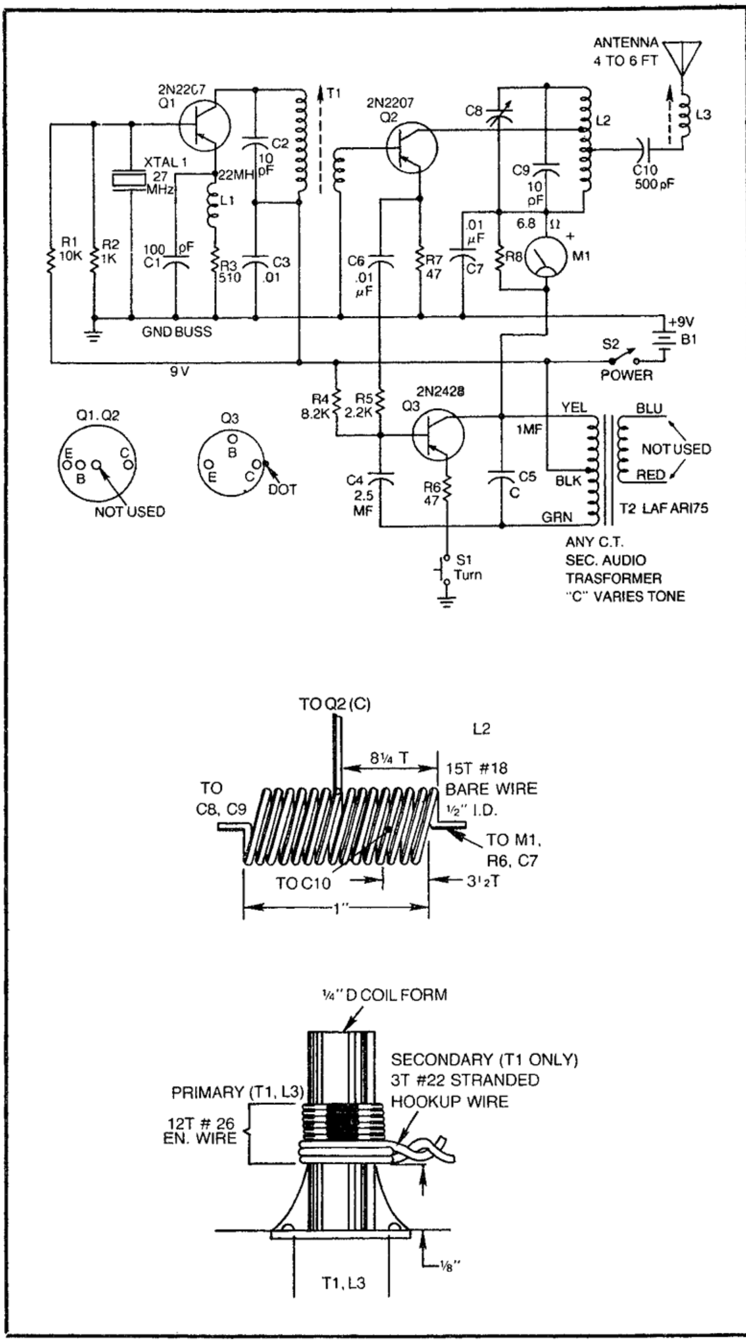


Fig. 1-17. A short-range "Part 15" transmitter.

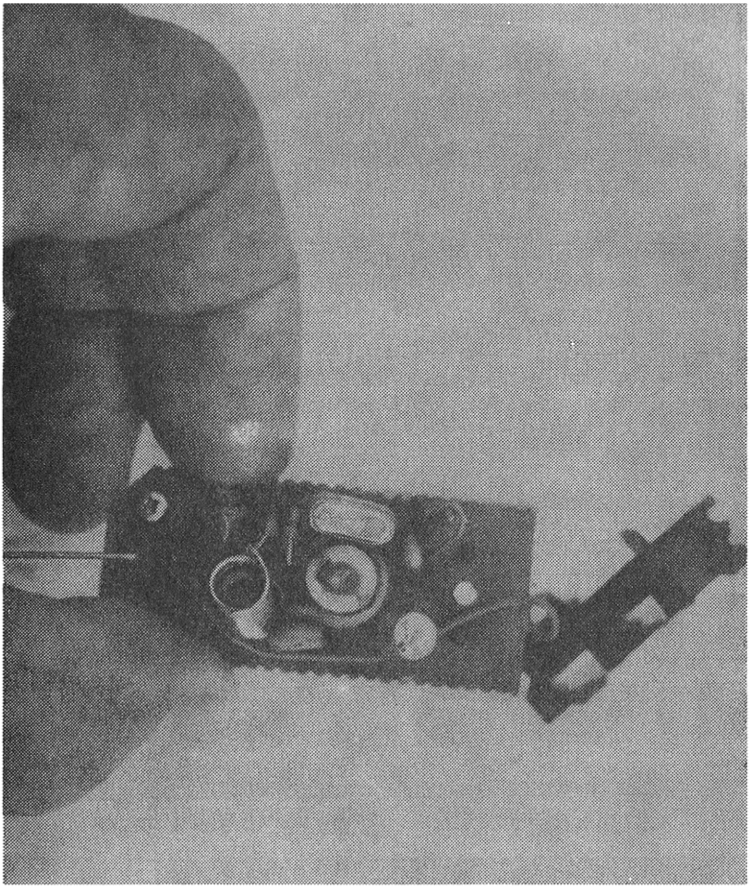


Fig. 1-18. Coil core adjustment slot.

crystal and rotate the core slowly outward. You should see a sudden jump in the meter hand. Move the core one full turn further out.

Extend your antenna fully. Hold the transmitter case and put the core of L3 about 2/3 out of its winding. Turn C8 with an insulated screwdriver and watch the meters. They will *drop*, indicating that you have tuned the transmitter. L3 may need adjustment to keep the total current less than 11 MA. When operating properly, Q1 will draw about 2 to 3 MA, and the total transmitter current with both transistors operating will be about 12 MA. Tune C8 and L3 for a minimum dip at about 8 MA when the antenna is very short. With modulation, the current drain is about 20 MA. In Fig. 1-18 you can see the screw adjustment inside the left coil, a slot which permits the powdered iron core to be moved up and down (out and in) the coil.

Operating The Car By Sound Signals

If you don't want to use the radio link in this kind of a control system, you might want to experiment using a *sound signal* to make it operate. Realize that a continuous tone is necessary at this stage of development to make the car back up, but you might whistle to make it do this and you'd have fun watching it go forward *until* you whistle. What is needed is a sound-operated relay, shown schematically in Fig. 1-19.

You can get a kit with a transmitter to assemble and a receiver already built that works fine for this kind of radio control system, and other, even longer range models. One is available from Ace R/C, Higginsville, Mo. 64037. Ask about their WEE 1 transmitters and receivers. The transmitter is shown in Fig. 1-21. It is about 4 inches by 3 inches by 2 inches and operates with ni-cad rechargeable batteries. Its circuit is shown in Fig. 1-21. The receiver is not shown here but is available as a companion unit. The transmitter and receiver can be used to control a model airplane at quite a long range and may be obtained with capabilities on any of the FCC-allocated radio control frequencies listed in Fig. 1-22. It is important to know that in the 26-27 MHz range, some frequencies, especially 27.255, are shared with other kinds of services, so you might get interference from these machines and transmitters. Also, you might get intereference from stations in the 72-75 MHz region. Model car racing equipment does operate on the other 27-MHz spot frequencies, and due to the splendid selectivity of the equipment does not suffer from the adjacent CB transmissions unless a nearby CBer

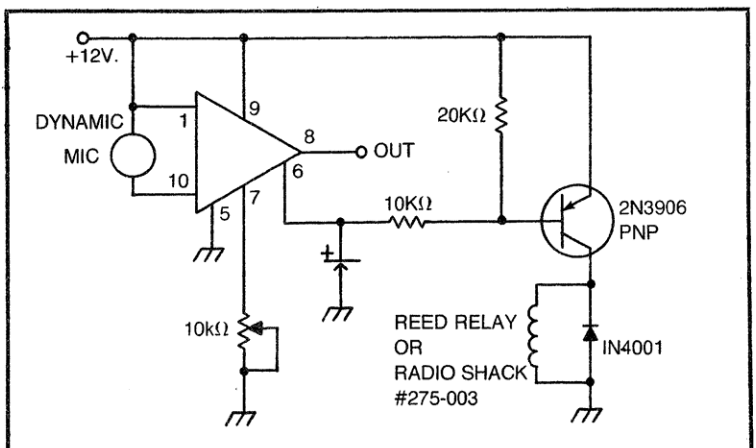


Fig. 1-19. A sound-operated relay (courtesy National Semiconductor Applications Handbook).

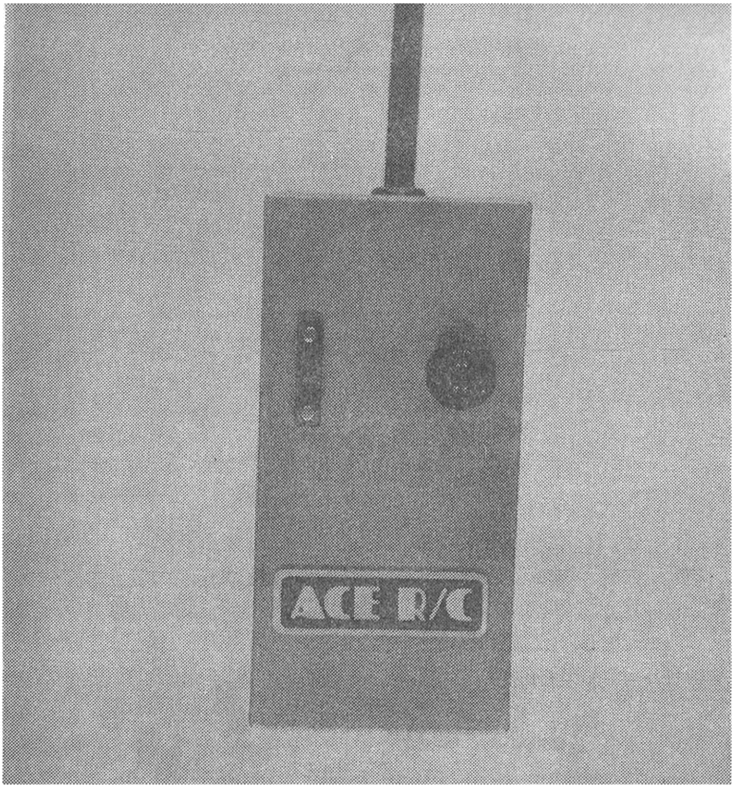


Fig. 1-20. Wee-I transmitter kit assembled.

uses illegally high transmitting power. Check with local model clubs about interference problems and which channels are best to use *before* you buy equipment.

It is also important to know that legal operation in the frequencies in the 50-MHz range requires at least an amateur radio Technician class license. Notice the two spot frequencies which the Academy of Model Aeronautics (AMA) has designated through the FCC for superregenerative receivers. We will see why this is important as we consider the second part of the radio link, the receiving system.

THE SUPERREGENERATIVE RECEIVER

A radio control receiver has but one function: that is to control the electric current to some electro-mechanical devices which, in turn, cause something to move. The receiver can do this in two basic ways. First, it can generate within itself a signal to close a relay after

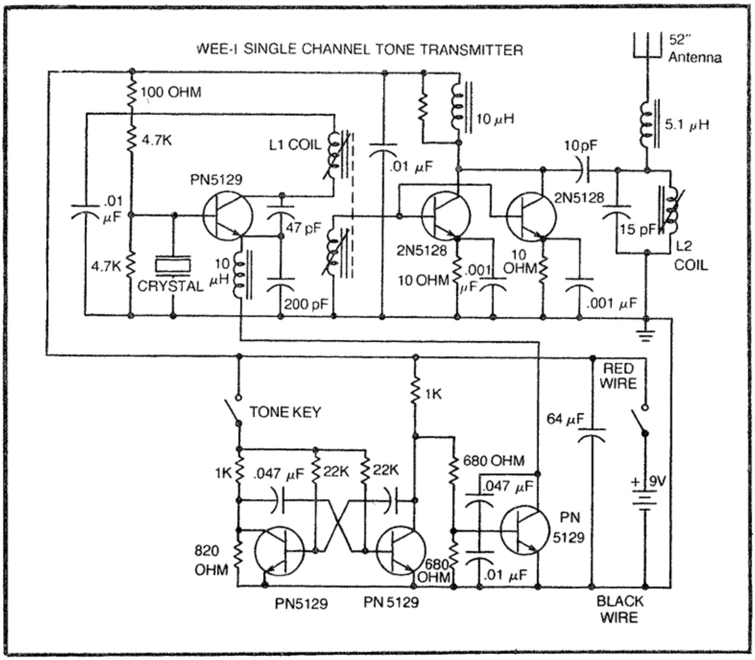


Fig. 1-21. Circuit diagram of the WEE-I transmitter, a single-channel tone-modulated unit.

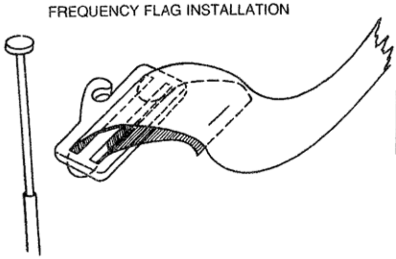
rectification, by causing a transistor to conduct a rather large amount of current. Or it can receive, amplify, rectify and shape a transmitted signal to do the same task. In the first case, the transmitted signal stops the internal transmitted signal and thus causes the relay to *open*. In the second case, the transmitted signal causes the relay to *close*. By the way, use the proper relay contacts for radio control.

The kind of receiver which generates a signal within itself is called a superregenerative receiver. It is normal with this kind of receiver that the detector make a hissing noise which can be amplified and rectified and caused to control the current through a transistor to a relay or a motor. When this kind of receiver receives a carrier-only signal—a carrier to which it is tuned,—it tends to stop hissing and becomes very quiet. Thus, in the simplest operational sense, it will then let the relay or other controlled device move to that position where it would normally be without current applied to it.

The superregenerative receiver can also receive a modulated signal—a tone—in the *carrier silent* condition and use this signal to make a relay operate or a motor run. This type receiver has a wide band of signal acceptance, which is a disadvantage, because it will

NOTE: IT IS YOUR RESPONSIBILITY TO INSURE THAT THE FREQUENCY FLAG COLOR CORRESPONDS TO THE TRANSMITTER FREQUENCY AS SHOWN IN THE TABLE BELOW:

FREQUENCY FLAG INSTALLATION



FREQUENCY	RIBBON COLOR
26.995	BROWN
27.045	RED
27.095	ORANGE
27.145	YELLOW
27.195	GREEN
27.255	BLUE
SUPER-REGENERATIVE RECEIVERS	
51.200	BLACK & LIGHT BLUE
52.040	BLACK & VIOLET
53.100	BLACK & BROWN
53.200	BLACK & RED
53.300	BLACK & ORANGE
53.400	BLACK & YELLOW
53.500	BLACK & GREEN
* 72.080	WHITE & BROWN
72.160	WHITE & BLUE
* 72.240	WHITE & RED
72.320	WHITE & VIOLET
* 72.400	WHITE & ORANGE
72.960	WHITE & YELLOW
* 75.640	WHITE & GREEN

* MODEL AIRCRAFT USE ONLY

Fig. 1-22. Local frequencies for radio control operations.

pick up signals off the frequency to which it is tuned. However, it has an extremely high amplification factor in just one stage, the detector, and thus needs to have only a simple audio amplifier following this detector stage. Also, because of the type circuit employed, this receiver has an automatic gain control ability which keeps the receiver from swamping on loud signals and increases its sensitivity for weak or distant signals.

The superregenerative radiates a signal too, and that is its really bad trait. It is a controlled oscillator—an intermittent oscillator—and so it can create interference with other receivers even if they are not exactly on its frequency. That really bad characteristic is the one which has limited the use of the superregenerative. A number of circuits for the superregenerator appear in our TAB book No. 1135, *Radio Control Manual–Systems, Circuits, Construction–3rd. Edition*. One circuit which shows the general layout is given in Fig. 1-23. You will have to try various high-frequency transistors in the detector stage to find one that is suitable and operates satisfactorily. We list two possible types which you might start with, one for 27-MHz and one for a higher frequency. You must adjust the voltage carefully to get the hiss sound in earphones at the audio output that tells you the detector is working. The hiss should be soft. If it is extremely loud, then the voltage is usually just a little too low. C1 may not be needed as feedback. Experiment to find out. Also, in Fig. 1-24 we show you one type of receiver which does *not* use an integrated circuit amplifier. The use of this kind of device would make the receiver even smaller and more compact.

THE SUPERHETERODYNE RECEIVER

The radio control superheterodyne receiver may also generate a signal inside itself with the presence of a carrier, in order to operate a relay or motor. If the receiver has a beat-frequency oscillator (BFO) built into it, then when a *carrier* is received, a tone will be generated that can be rectified and used to make a transistor draw enough current to operate a relay, motor, or actuator. But the BFO must be extremely stable.

Normally, however, the superheterodyne receiver requires a *modulated* signal as its input, which it then converts into the transmitted tone, or received pulses or whatever is used to make the radio control system operate. We don't think of carrier pulses as a

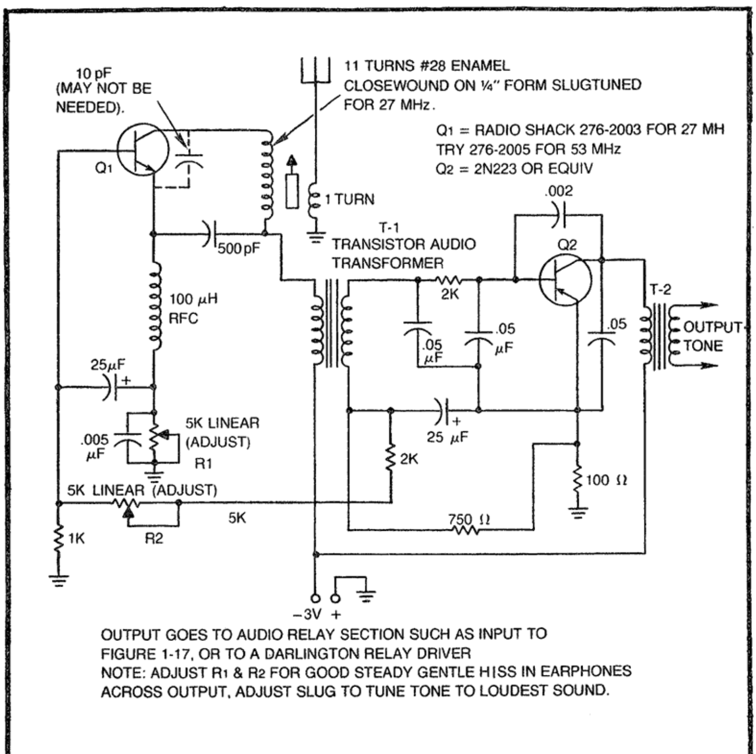


Fig. 1-23. A typical superregenerative circuit.

form of modulation but they are. Modulation is simply the variation of the carrier in some definite and consistent manner, and pulses which turn the transmitter on and off, even if at a very fast rate, do exactly that. One example of a cased superheterodyne receiver is shown in Fig. 1-25. The rf and oscillator portions of the receiver are plug-in units so that frequencies can be easily changed.

The advantages of the superheterodyne receiver are many. It is very selective, using crystals as frequency control devices, so it does not pick up signals from adjacent spot frequencies. It has gain control so it doesn't swamp easily and has great sensitivity at long range. It is small and compact and does not radiate a signal as the superheterodyne receiver does.

The superheterodyne receiver requires a modulated signal to produce an output which is useful for operation of a relay or motor(s). This signal can be pulses, turning the transmitter off and on. It can be an audio tone or a combination of them. But the receiver will not operate on a carrier alone unless you have a beat-frequency oscillator built into it. With a BFO, an internal audio tone is generated

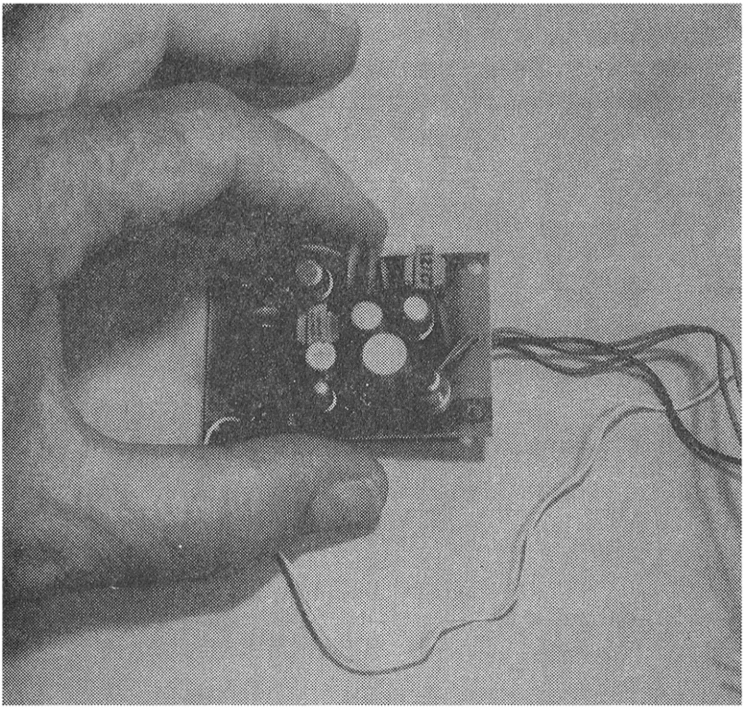


Fig. 1-24. A superregenerative receiver with a slug-tuned coil. It uses a transistor output instead of a relay to drive an actuator or motor.

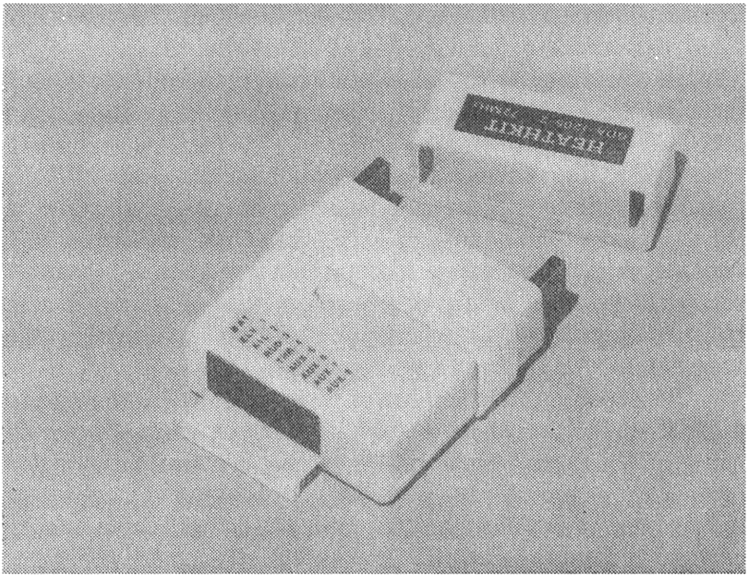


Fig. 1-25. Heath receiver with module unplugged.

when you receive a carrier, and this, in turn, can be rectified and used to cause a relay or motor to operate. We will examine some systems of sending intelligence to make different things operate and get many operations from small motors in a later chapter.

Many manufacturers, including Ace R/C, supply receivers and receiver kits. Ace R/C has a companion superhet receiver for its WEE I transmitter, but it is *not* furnished in kit form. Most other manufacturers do have kits, but the receivers are designed to operate with their companion transmitters and are not interchangeable in most cases with the equipment of other manufacturers. So be careful about purchasing a receiver from other than your transmitter manufacturer.

CHANNELS, CODING AND DECODING

When we speak of *channels* in radio control we simply mean how many functions are controllable. For example, with a model airplane, if you use just one command for, say, left, right and neutral rudder, you will be using one channel. If you also control the elevator, the motor and ailerons, then one channel is required for each, so you will be using four channels of command.

It is possible to make a model do many things with just one channel, but usually when this is done, the operations are in sequence. You normally cannot do two or more things at the same time with only one channel. With a multichannel system, you can be sending commands over many channels at practically the same time, so you can have simultaneous control over many things. For you computer enthusiasts, it's like a series operation for single-channel, and a parallel operation for multichannel.

Coding is the method of sending discrete commands in either system. Some difference in signals must exist which the *decoder* in the receiver can recognize. It can then make different things happen with the different signals. International Morse code is one type of coding used to send information. You, the *decoder*, convert the dits and dahs to letters and numerals. We will examine coding in more detail in the next chapter.

In Fig. 1-26 you can see one example of a multichannel system at the top, and two possible arrangements of a series of single-channel systems at the bottom. Notice, however, that if you use the two units at the bottom together—that is, transmit from one transmitter to one receiver for one channel, and to the second receiver on a different frequency from a second transmitter—the two together make up a two-channel system. Modern systems are generally of the top multichannel type. The boxes marked A are the control levers, or wheels or switches which you move to send commands.

There is a particular significance to the bottom arrangement in Fig. 1-26. If you substitute multichannel systems for each of the two

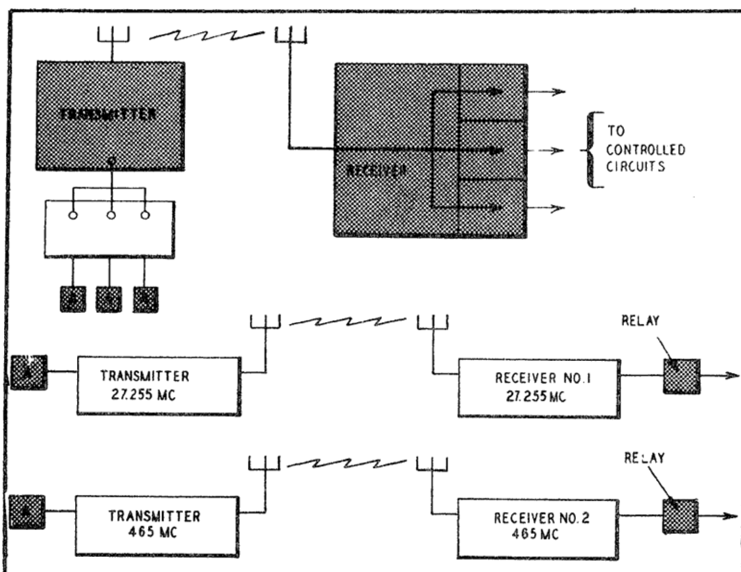


Fig. 1-26. Single-channel and multichannel system concepts.

Fig. 1-27. A two-channel radio-controlled toy "18-wheeler."

shown, and reverse the location by putting the bottom system inside the model so that it *transmits back* some information on model control positions, altitude, speeds, or other kinds of data, then you have a *telemetry system*. This could permit you to fly airplane models or sail boats out of sight. It could also permit you to develop and invent a ground control system that would be a duplicate of the control system inside an airplane where the instruments and such are all operated by the ground receiver and decoding system of the telemetry system. Of course, the channel going to or transmitting to the model would be your control channel. As models develop and systems advance, we may see this kind of arrangement come into being. The military uses it to fly high-speed drones at possibly very high altitudes. See TAB book No. 122, *Advanced Radio Control*.

TWO-CHANNEL TOY CAR

We have looked at a single-channel toy car in some detail. These kinds of radio control systems are very popular and have been expanded upon in the manner shown in Fig. 1-27.

Two buttons are on the transmitter to send out two different signals: one signal for steering left and one for right. The signals are sent out by pushing buttons on the transmitter.

Another way to control a model with two signals is to use the *carrier* to cause the drive motor to operate in a forward direction. Therefore, when you turn on the transmitter, the model starts to move, providing you have turned on its own switch. Then if you send one tone, the model will turn left; push a second button and consequently, a second tone, to cause the model to turn right. No tone at all will be an *automatic* straight ahead, or neutral. You might think about having *three* relays in such a model, all activated by these radio signals.

We can fabricate a simple motorized decoder for more *than one function control* based on a device developed some years ago, which is still very usable in boats, cars, or slow-flying airplanes. It is a

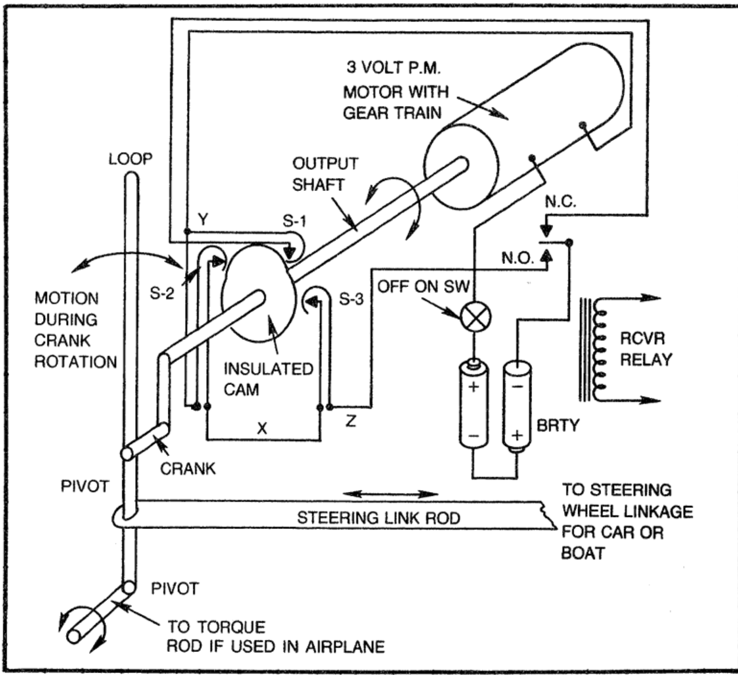


Fig. 1-28. A mechanical decoder for a single-channel system. Switches S-1, S-2, S-3 are normally closed.

sequence device, so it won't give control of two or more operations *simultaneously*. Nevertheless, in the types of models we would use it, we will have only one thing operate at one time such as the motor, or the road wheel or rudder. With this unit, control of the two functions of steering does not occur during control of a drive motor.

You might ask, How do you get *two* functions for steering? The answer is that we are thinking of one signal for left and one signal for right motion of a rudder or steering wheel. The return to straight steering must be automatically accomplished, but we will use just a single channel system to do this. This type of system is one you might get with a toy. We will need just one single-pole double-throw type relay in the receiver output.

A SIMPLE STEERING ARRANGEMENT

We will first describe this unit as used in a model airplane. Be aware, however, that if you use a toy model car radio system, it is designed to operate up to only about 200 feet. So you really cannot use that system for a model airplane. You need a better radio system for that kind of model with a range of at least ¼ mile. More about the airplane system transmitters and receivers later.

Let's first examine the basic principle of the decoder, which is the heart of this kind of system. Study Fig. 1-28. Notice that there is a small permanent magnet motor, say 3-volt type, with a gear train attached or built-in so that the output shaft with the insulated cam will move reasonably slowly. Three switches which are *normally closed* are mounted around the cam so that as it rotates it will open each one in turn. Then examine the linkage output, which is yoke-driven by the crank so that it moves back and forth. For airplane use, the yoke will turn a torque rod which in turn can position a rudder. For model cars or boats, an attachment linkage will move back-and-forth to position road wheels or rudder. An off-on switch is located at the battery site, although in operation this kind of system will position itself to cut off all electricity so it uses current only when in motion. This latter feature is excellent for gliders and sailboats.

When the receiver relay is de-energized as shown, the armature makes contact with the normally closed contact. Follow the circuit and you will find that power is applied to the motor through switch Sl. This means that the motor will rotate the output cam and yoke until the riser on the cam opens the switch S1 and stops the motor. We set the position of the switch so that when this happens the yoke will be straight up, or in a *neutral* position. Adjust the system to give straight motion for a car, boat, or plane.

Imagine that you depress a button which sends out a tone or other kind of signal to cause the receiver relay to close and stay closed as long as you keep sending the signal. Through the normally open (N.O.) contact of the relay, we now find the battery applied to the motor through contacts S2 and S3 in series. This means that the motor will stop if *either* of these switches is opened, as long as the signal is being sent to the receiver.

The first switch to be opened is S2. If this switch is so positioned that the cam will rotate 90 degrees from neutral, you then have a maximum left movement of the yoke. This could be left steering of the car, boat, or plane. If, then, you stop sending the signal, the motor will again rotate as we first described until the cam opens switch S1. You are back to neutral and straight motion.

Now, consider that you depress the signal sending switch of your transmitter and hold it while you count, say, "one two." If this time interval is long enough to make the motor rotate to position of switch S2, it would then *stop* if you didn't then release the button that keeps the cam moving toward switch S3. You then count "one two" again and depress the transmitter signal sending switch. Now, when switch S3 is opened, the relay armature is on the normally open contact, so the motor will stop in this third position. This should be 180 degrees away from the position it stops at when opening S2. This is the right turn position of the road wheels, rudder or whatever. When as much of a turn as you desire has been accomplished by the model, you release the transmitter button and the motor will drive the steering elements to neutral again, ready for another set of signals.

THE STEERING CODE

As with all kinds of control systems, we must have a *control code* to make the system work as it does. In this case it is as follows:

- Neutral—No Signal.
- Left—Signal on and hold.
- Right—Signal on, then off, then on and hold, with a rhythm to match the motor rotation.

It's simple, but very effective. And remember that the advantage of this system is that you can take one of the small systems available in toys, which have a relay in their output, and add this kind of decoder and expand your control over the model. Of course, you might use sound signals to operate the relay using the sound

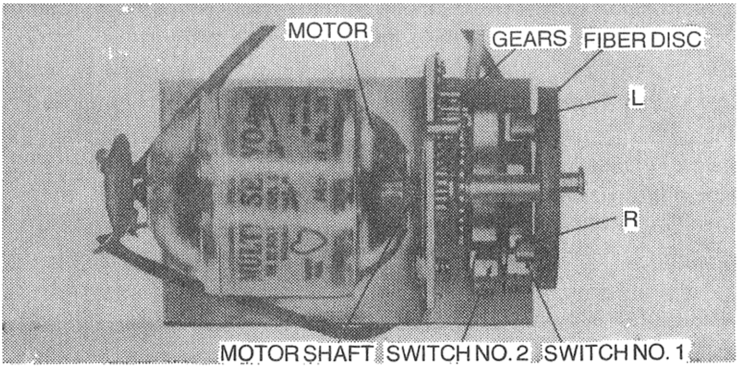


Fig. 1-29. A cam-and-pin arrangement on the motor.

amplifier shown earlier, or you might build your own system transmitter from the diagram we have shown and a receiver using the sound amplifier as the audio section for a receiver, and a superregenerative kind of detector feeding into this amplifier instead of the crystal microphone. Superregenerators, remember, are used *only* on the prescribed spot frequencies in the 53MHz band. Do not use a superregenerator for airplanes on any other frequency.

There are many ways to make the cam-switcher for the motor. Figure 1-29 shows another concept of mechanical construction on a unit which was produced commercially some years back.

THE AIRPLANE SELF-NEUTRALIZING MOTOR

We chose to examine the simple self-neutralizing servo in an airplane concept next because it is self-powered and its motor speed or running time does not need control. With a model such as we are about to examine, the propeller motor running time is limited to only a few minutes by having a small fuel tank. Nevertheless, this is long enough for the plane to get pretty high. Then the airplane motor runs out of fuel and stops. If the airplane is properly adjusted, it will glide for a long time as it comes down. You then will be steering a glider down to a landing. Of course, you steer the model while its engine is running and try to keep it upwind from our position. You also turn it around and maneuver it to keep it close enough to always receive its radio signals and to keep in sight. In case it gets up a little higher than wanted, give it a sharp turn by holding a turn command signal on. This can make the model lose altitude with a large rudder deflection. The arrangement shown in Fig. 1-30 has the various switches positioned on the base mounting plate, instead of around the cam as shown in Fig. 1-29. Before examining the operation, note the fiber disc and the insulated shafts N (neutral), R (right), and L (left). In the neutral position shown, shaft N is depressing contact switch 2, opening its connection to D. This shaft does not open switch 1 since this switch is not as high as switch 2 and N is nearer to the center of the fiber disc than L or R. Notice also how the mechanical output of the motor, the rotation of the fiber disc, is coupled to the control surface through yoke Z. As the disc turns, the yoke loop will be moved left and right from the neutral or center position and this in turn will cause the rudder to move left or right.

Assume that the code signal "on and hold" is transmitted. The armature of the relay is pulled down to make contact with G. This lets power flow from the motor battery through the relay to B switch 1. At this moment, B is in contact with A, so the power goes to one lead of the motor. Since the other motor lead is directly connected to the opposite side of the battery, the motor begins to run, turning the fiber disc in a clockwise direction. It will continue to run until shaft R opens switch 1, breaking the circuit. At this point, loop Z has been moved to the right and, through the linkage, the rudder is moved to the full right position. As long as the signal is held on, the steering element will be thus deflected, but since the circuit to the motor is open, the motor consumes no power from its battery. This is an important consideration in operation over long periods of time.

Now assume that the signal for neutral is sent. According to the code set up, this simply means that no signal at all is transmitted. The relay armature is pulled up by the spring opening the circuit to G, but closing the circuit to E. The battery is now connected to the motor through switch 2 and so the motor runs again. It will continue to turn the fiber disc until shaft N again opens the circuit by opening

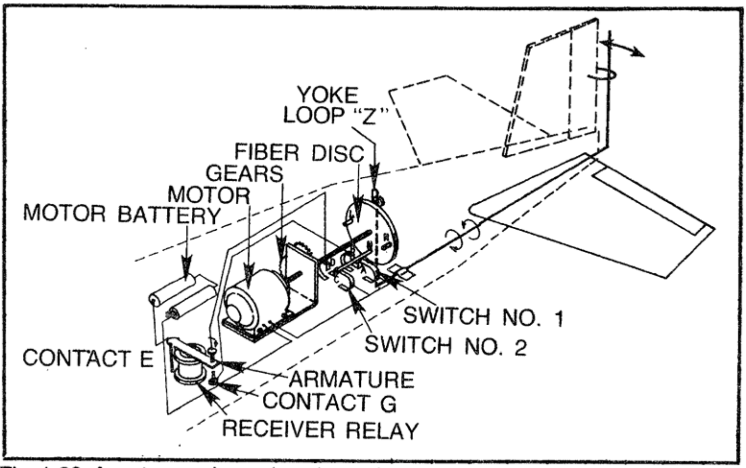


Fig. 1-30. A motor used as a decoder and power unit to provide a single-channel radio system in an airplane.

switch 2. In this position, the loop Z and the rudder are again at neutral.

The third command of "on-off-on" and "hold" causes the following action: The first "on" signal causes the motor to turn as before—to the right. It moves rapidly enough so that when the off part of the signal comes, it is just in time to keep the circuit closed and cause the fiber disc to keep turning. Now the second "on" arrives at the receiver. The relay is energized again, and the circuit is completed through switch 1. Shaft L is turning toward the switch and now opens the circuit by breaking the contact through switch 1. Loop Z is not held in the left position and through the linkage produces left rudder. It will hold it there as long as the signal is kept on. When another neutral or no signal command is sent, the motor again turns around to the neutral position.

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

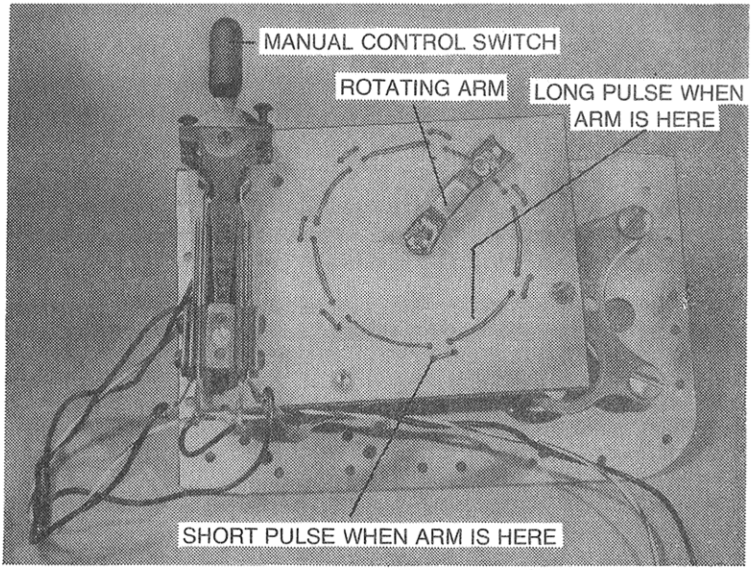


Fig. 2-1. A mechanical coder.

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

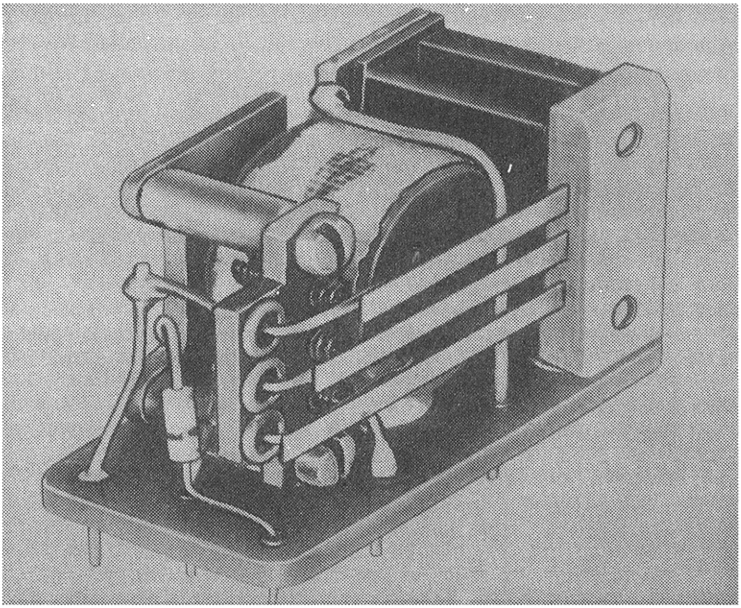


Fig. 2-2. Each reed vibrates to a different tone, usually spaced 50 hertz from the first. Intermittent contact at the points is a disadvantage.

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

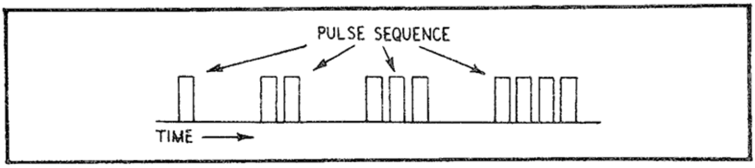


Fig. 2-3. Each group of pulses represents a separate command. The entire sequence might be used to key four separate functions.

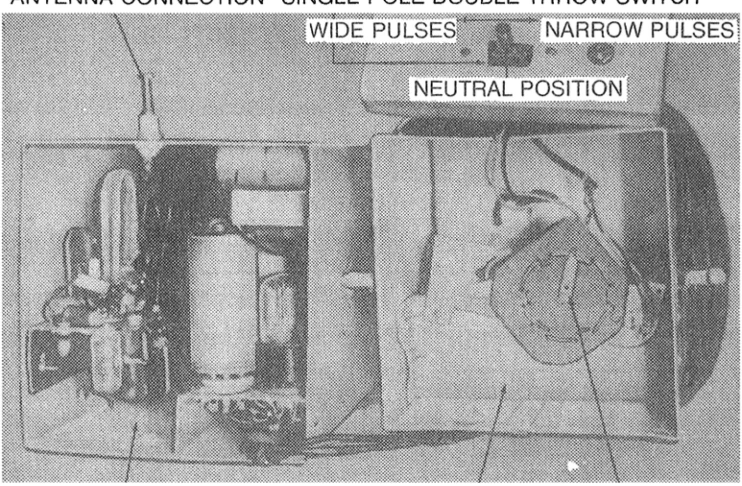
others following. If four commands were sent, one after another, they would appear as shown in Fig. 2-3.

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

ANTENNA CONNECTION SINGLE-POLE DOUBLE-THROW SWITCH



TRANSMITTER CODER ROTATING ARM

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

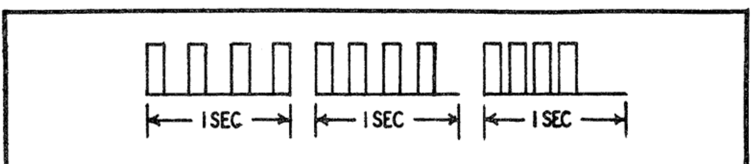


Fig. 2-5. A series of pulses of equal duration. Notice the variation in spacing.

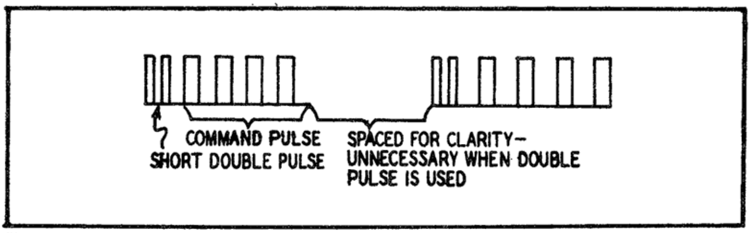


Fig. 2-6. The short double pulse preceding the command pulses separates the commands from each other.

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

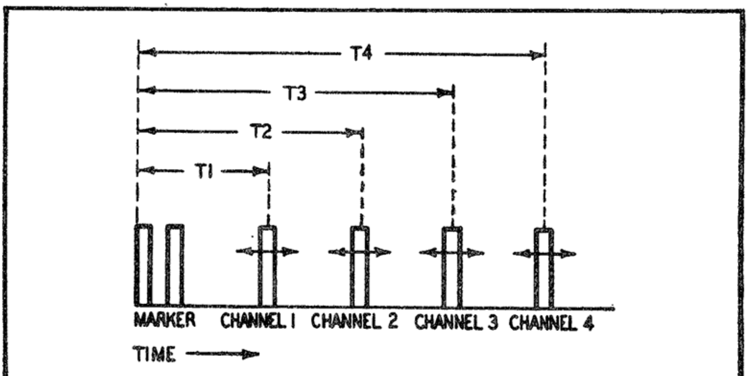


Fig. 2-7. Time modulation of the pulses is often used when a great many commands are to be sent in a short period.

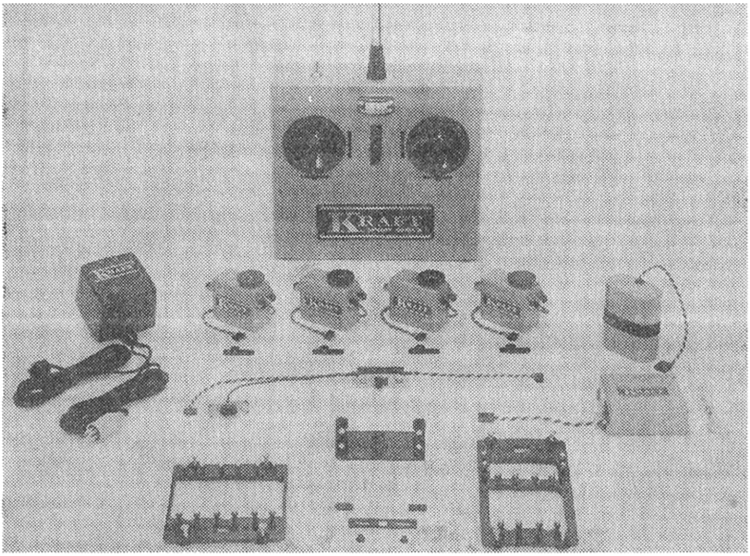


Fig. 2-8. A modern digital transmitter and system.

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

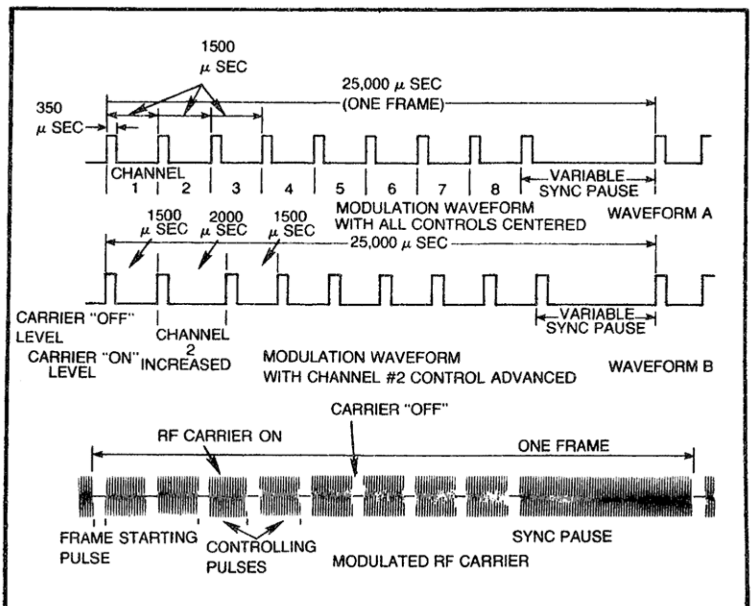


Fig. 2-9. A modern digital control code, in this case Heath's. The pulse width, or carrier on time varies.

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.

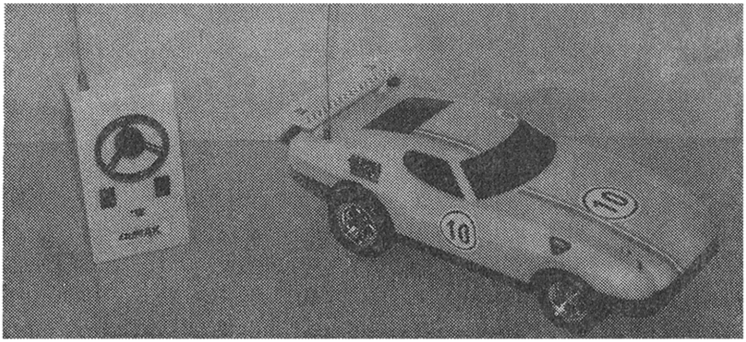


Fig. 2-10. This model radio-controlled race car uses an electric drive motor.

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.

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.

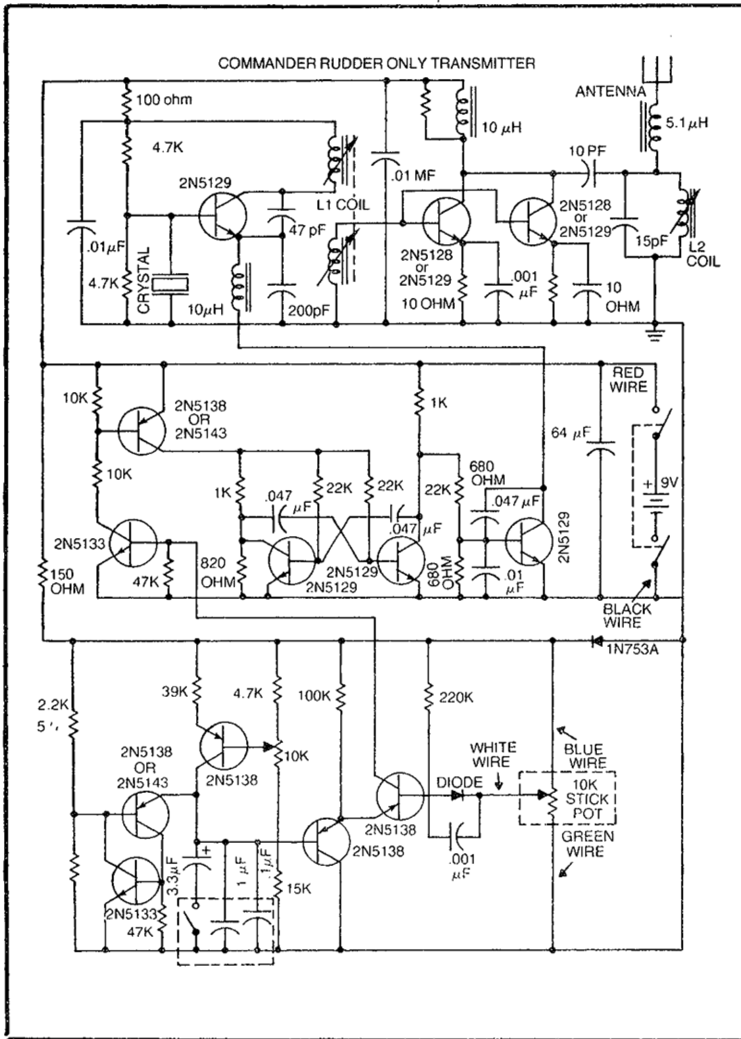


Fig. 3-1. A typical transmitter circuit for radio control using a crystal oscillator and power amplifier. A multivibrator-type modulator turns the crystal circuit on and off with variable timing controlled by the stick pot. This varies the width of the carrier pulses. These are slow pulses and can activate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

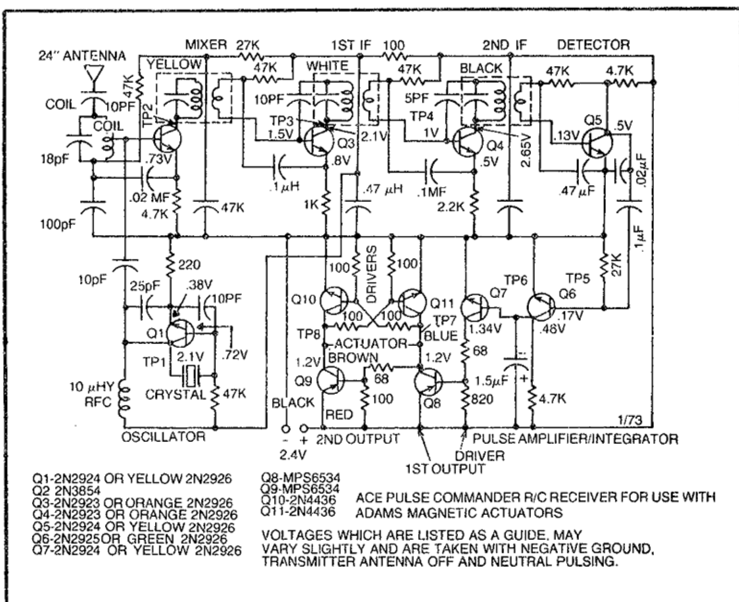


Fig. 3-2. A superheterodyne receiver for single-channel R/C operation.

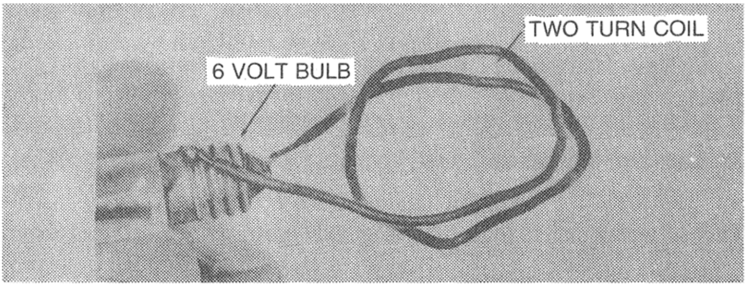


Fig. 3-3. A simple transmitter performance indicator using a brown bead bulb.

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-

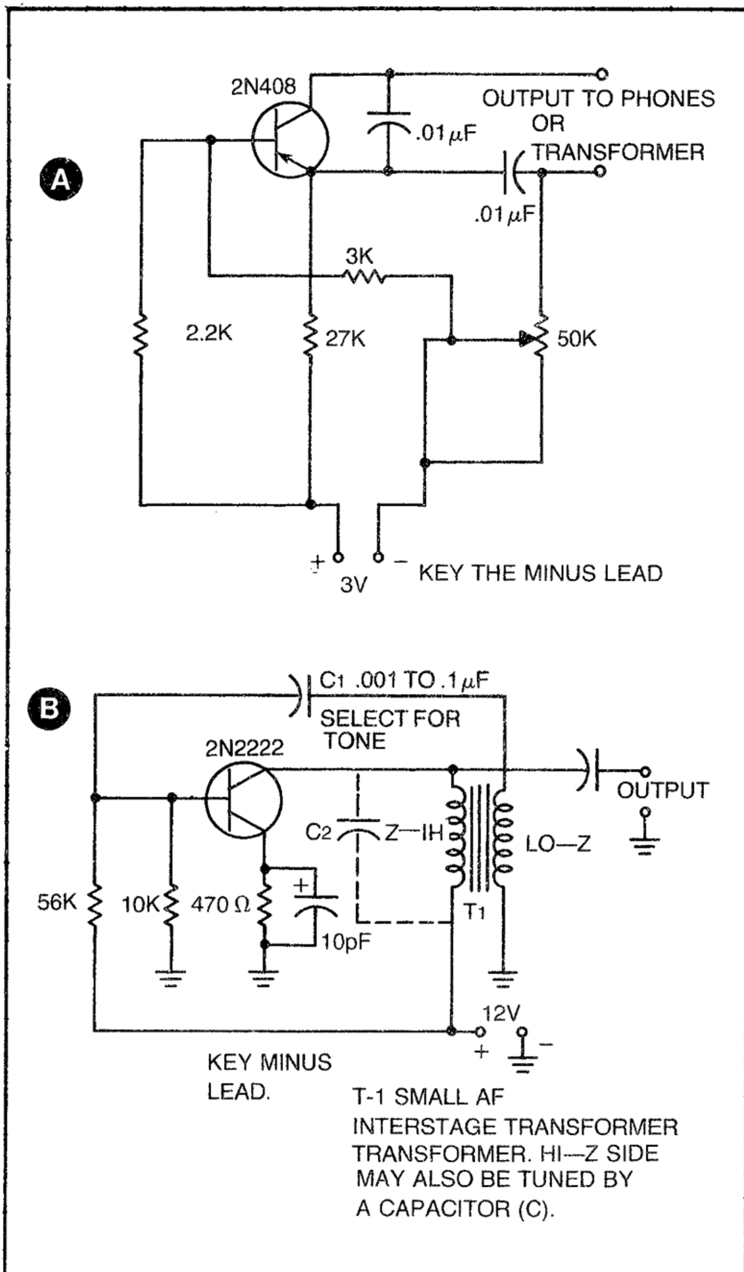


Fig. 3-4. Two simple tone-generating circuits. Suggested circuit values for earphone inductances are listed in (A); in (B), C1 and C2 need adjustment to affect the tone output.

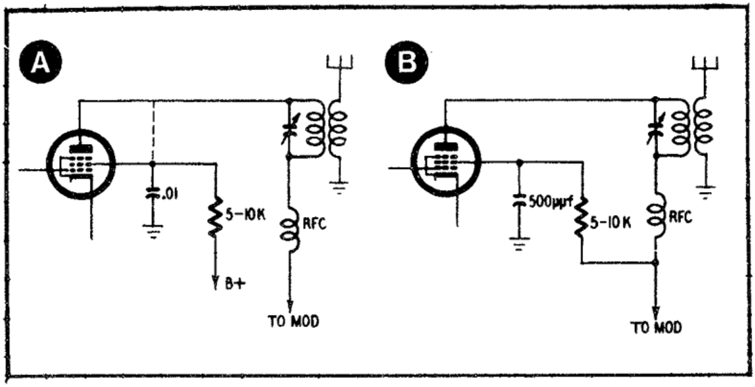


Fig. 3-5. Methods of using plate and screen modulation. At (A), if plate modulation only is used, connect as shown by the dashed lines. At (B), when plate and screen modulation are required, use a small-value screen bypass capacitor.

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 $0.005 \mu f$ 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

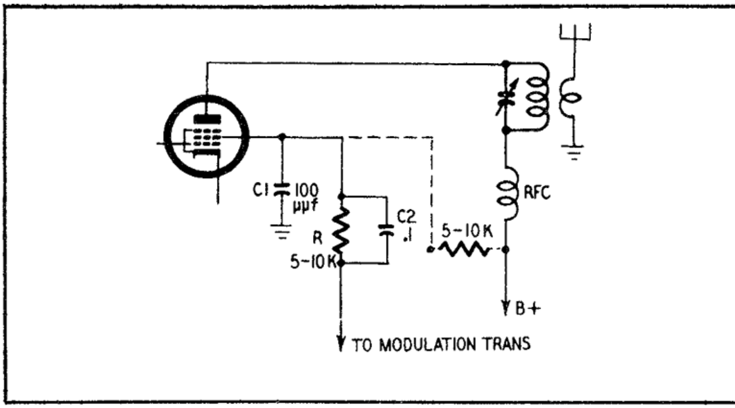


Fig. 3-6. Normally, the screen is connected as shown by the dotted line. To screen modulate, connect R and C2 to the modulation transformer or the plate of the modulator tube.

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.

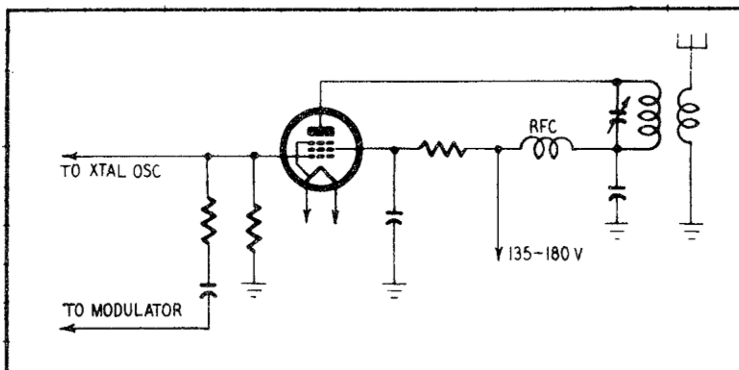


Fig. 3-7. Typical grid-modulated circuit.

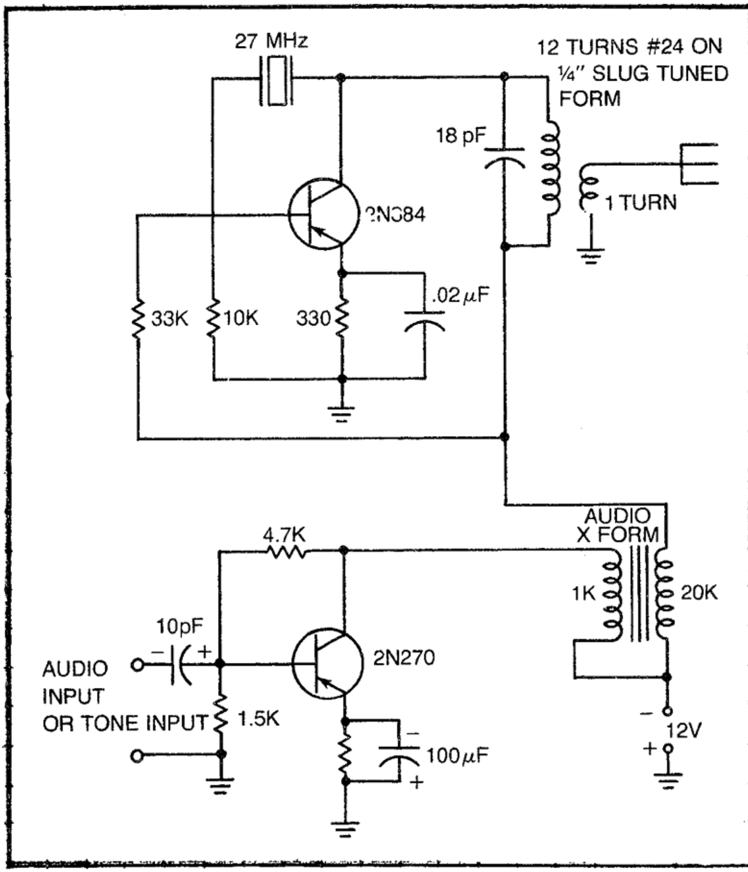


Fig. 3-8. A collector-base-modulated oscillator.

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

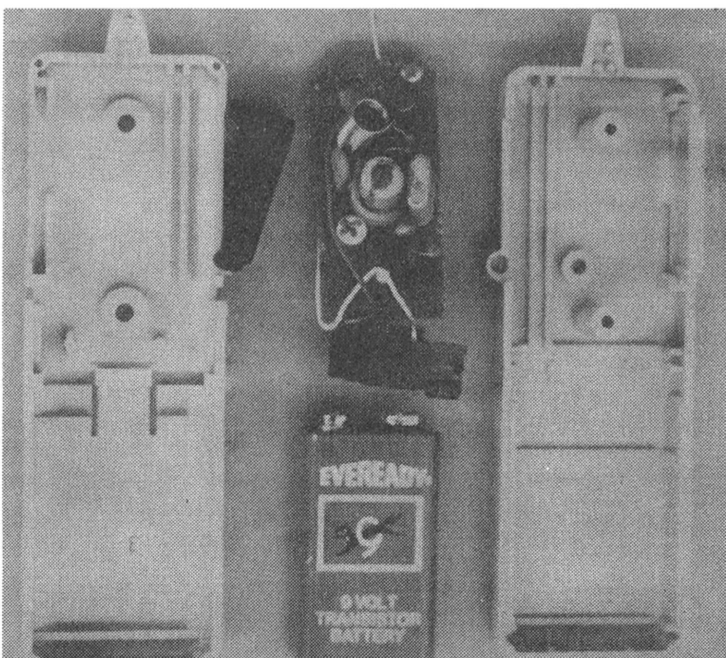


Fig. 3-9. A small hand-held transmitter. This is not a tone-modulated type.

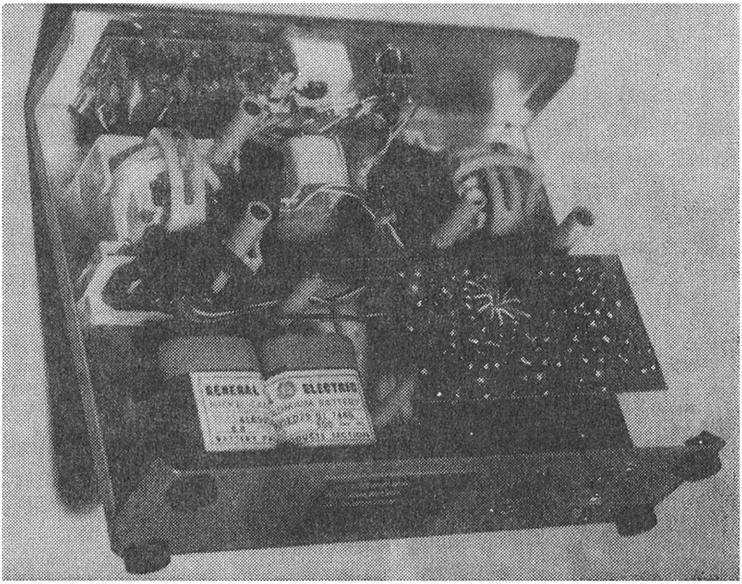


Fig. 3-10. A long-range digital transmitter for control of airplanes.

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

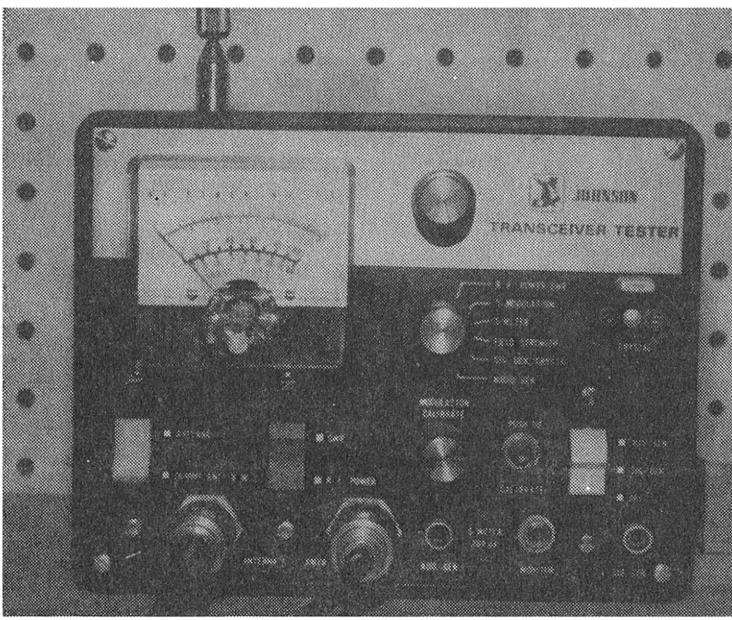


Fig. 3-11. A transistor transceiver tester.

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

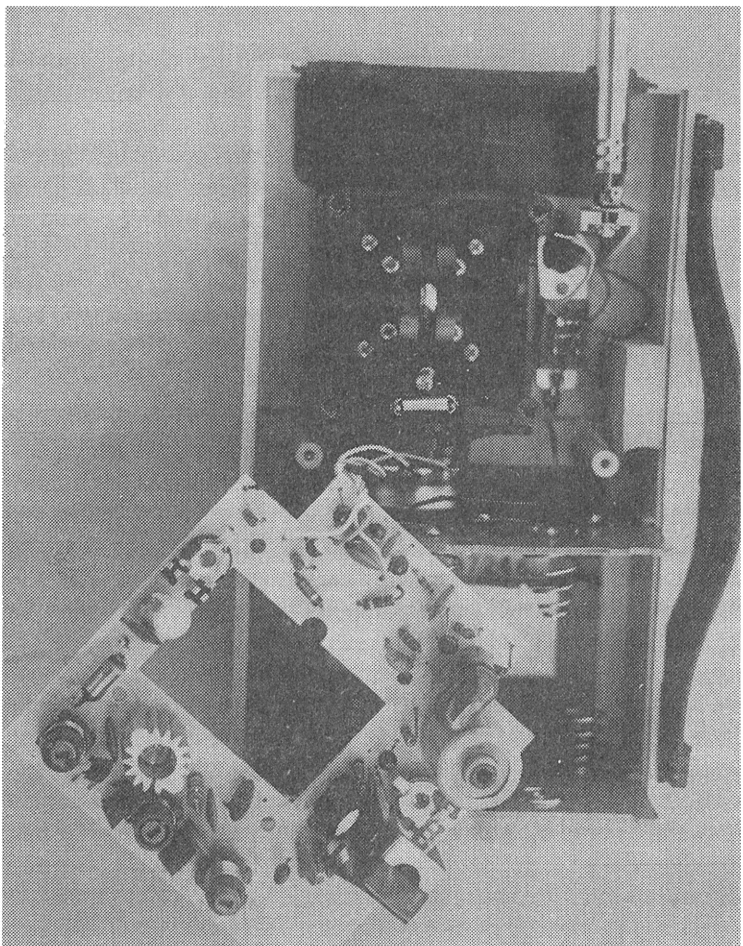


Fig. 3-12. A dry battery-operated, single-channel transmitter.

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

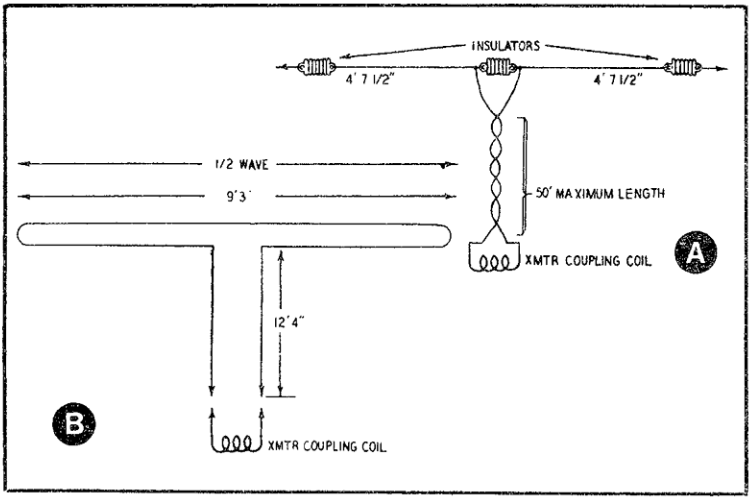


Fig. 3-13. Single (A) and folded (B) dipoles are easy to construct. The dimensions shown are for 50-54 MHz. Double them for 27.255 MHz.

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

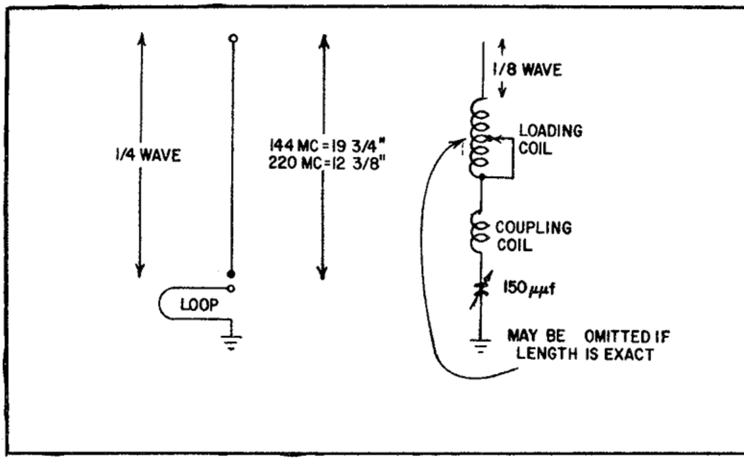


Fig. 3-14. Whip antennas are used in R/C work.

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

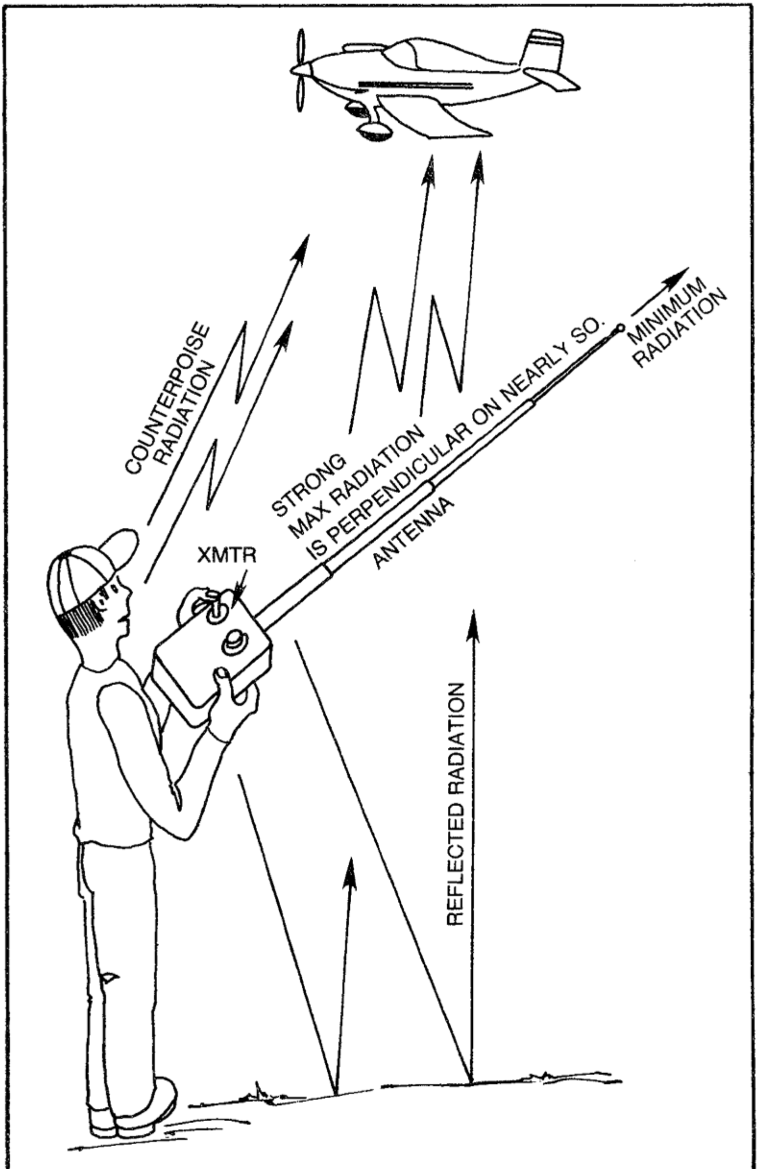


Fig. 3-16. The radiation pattern of a one-eighth to one-quarter wavelength antenna.

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.