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RADIO CONTROL MANUAL—Systems, Circuits, Construction—3rd Edition

How model radio control systems work, and how to build and modify them!

by Edward L. Safford Jr.

RADIO CONTROL MANUAL—
Systems, Circuits, Construction—3rd Edition

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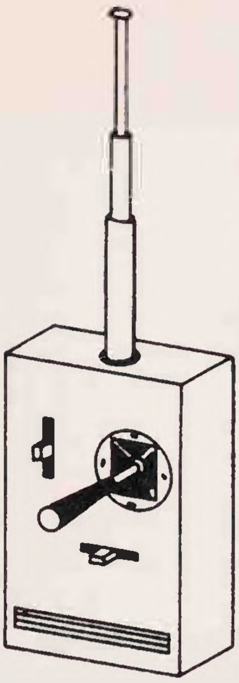

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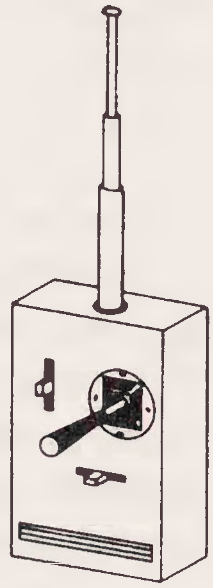


Preface

This is a third revision of this work on Systems, Circuits, and Construction of electronics and physical devices to be used in radio-control systems. It is an update of the material previously contained, the addition of new information and ideas and construction hints which are appropriate to the advancing technology of our most fascinating hobby.

This book is for the more experienced radio-electronics fan, yet we do have some projects in it which will appeal to the beginners as well as the most advanced old timers. And for those who are computer buffs we have some digital ideas and systems which will make interesting reading and study during your evening hours, if that is when you, like ourselves, like to sit back and read and study and examine intellectually challenging concepts.

We need to give you some explanations here. There are so many current transistors and integrated circuits that we just cannot list all types applicable to the circuits presented. Therefore we direct your attention to the many fine substitution manuals available from radio-parts stores for information in this regard. You may find that voltages might have to be adjusted slightly to fit the requirements of some integrated circuits, which certainly might be used in substitution for some circuits presented, so be careful of this. Relays are available in various current operating values from such stores as Radio Shack, or hobby houses and R/C parts suppliers, although many radio-control supply houses such as Ace R/C no longer stock relays as so much modern equipment works directly from the transistor output.

That a transistor is a relay type device is well known. It can be biased to cutoff and then caused to draw quite a bit of current when a signal is fed to it. A relay does just this also. So you will see transistors used as motor-driving devices, and servo-powering units as well as relays, and aside from the smallness and lightness, the operation of the two are quite similar. That means that sometimes you can substitute a relay for a transistor to get a circuit to work, and vice versa.

In this revision we will keep all that is appropriate and good and useable and try to delete that which is obsolete or too large or too bulky or for which parts are no longer available. Of course, we may mention some obsolete items as a matter of interest, as these do have a fine fascination and do bring back memories to those of us who are Old Timers in the radio-control field.

We have stated in other works (*Flying Model Airplanes and Helicopters by Radio Control*, TAB No. 825) that we believe that in so many cases it is better to buy a kit and build from that rather than to try to assemble all the parts required for a system and build that way. Kits have good instructions and if you are careful, you can get magnificent results from the building of a kit. But in this work we feel that there may be areas where original experimentation is one of the objectives of putting together radio-control systems of various kinds. And so it is to that end we think that the information presented herein is very useful. Of course to those of you who just like to "build the whole thing," model, control system and all, we say that is one of the most rewarding experiences of all. To see something *you* have completely worked out and put together operate as it should gives one real satisfaction and pleasure.

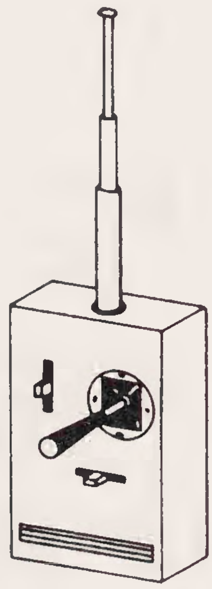
But it takes a little more knowledge and patience and willingness to work at it to get a system completely operating the way you want it to. So there are some who want to fly, or sail, or race models who want to get the control system operating and behind them as soon as possible. They might want to buy a kit or a completed system from the store. They have much fun and pleasure also concentrating on the models rather than the R/C end of the system. For these, reading of this work will give insight and understanding and perhaps provide a little more out of the systems than before. We earnestly hope this will be the case.

We are reminded of a recent experience we had with a fine hobby enthusiast whose passion is sailboats, and what beautiful models they are. He didn't want to spend the time with the radio equipment but instead he wanted more time with the model. So he bought a completed three-channel system to use from Heath Company. It worked out just fine. But then he found that in sailing he wanted the trimming of the sails to be a little different that was possible with the original equipment. So he set out to modify it somewhat in its servo operation. He needed the background information and experience of the kind we present here and in our book *Model Radio Control*, TAB No. 74, and he got it. He made the changes to the servos and got the system to do just what he wanted it to do. And he began to enjoy his hobby even more because *he* put some of his own ideas and inventions into it. You might want to do the same. So knowledge such as presented here could be invaluable to you.

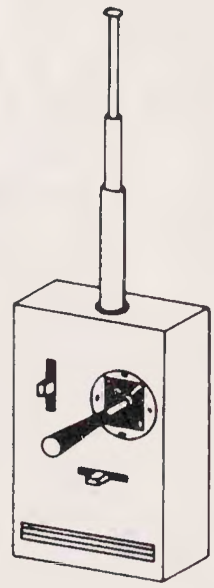
We hope you will accept this revision as you have accepted our other books, and we thank you very much for your consideration of our past efforts. To those of you we have met before in our written pages, its always nice to meet you again. And to those we have not as yet met in our writings, hello, and thank you for looking into this volume. Our thanks to all those who have contributed to our knowledge and understanding of radio control and to the multitude of friends we have made at flying fields, in clubs, at the bayshore, at the model-car race tracks, and elsewhere. May your equipment and models always perform the way you want them to.

Edward L. Safford Jr.

Contents



1
How Radio Control Systems Work



A manual on radio control should list and discuss each type of radio-control system in use. So this first chapter is devoted to an explanation of the various types of radio-control systems and how they work.

Model radio control means sending signals to a model by radio, and, by properly selecting these signals, being able to steer the model, change speeds, operate brakes, light, winches, flaps, bomb releases and a variety of other functions or accessories on the model. *Model radio control means being able to do these things from a distance, and without wires.*

Radio-controlled models are for the most part model airplanes of every size and description, including gliders, but there are also many model enthusiasts who radio-control model tanks, model cars for racing or sport driving, and model boats. The boats may be electric-powered, sail-powered (and aren't they beautiful?) and model glow-plug-motor racing boats. Unusual models offer the model enthusiast a real challenge.

Shown in Fig. 1-1 is a model sailboat. It is about 6 feet in length, and the sail is about 5-feet high. The rudder, jib, and mainsail can all be adjusted by radio signals, and you really have to know your marine principles to sail her smoothly and successfully, as shown here.

The Federal Communications Commission has allocated some spot frequencies in three bands which can be used for radio control. The bands are from 26.995 to 27.255 MHz, A 49 MHz spot for a Part 15 of the FCC regulations operation, which says that the transmitter

Fig. 1-1. A radio controlled sailboat.

must be under 100 milliwatts output power and where many of the toys which use radio control are operated, a band from 51.200 to 53.500 MHz which required an amateur license, and a band from 72.080 to 75.640 MHz.

Some of these spot frequencies are shared with other kinds of public operations. For example, the CBers operate on 27.255 MHz also, and at the highest band there are some frequencies restricted to model-airplane operation only. We call your attention to Table 1-1 to give you the exact frequency allocation situation as of this writing.

It was explained to me at a model-car race track that there is some interference from CBers at times but mostly only when the CBers use linear amplifiers for high-power operation. Of course this is illegal, but some do it. But ordinarily the cars race under full and complete control of their drivers. Airplanes, of course, cannot tolerate interference because that could mean a disaster, so they mostly operate at the 50- or 72-MHz frequencies.

The power input for class C stations is 25 watts at 27.255 MHz, and from 26.995 to 27.197 is 4 watts, while at 72 to 75 MHz the power output is 0.75 watt. Frequency tolerances are 0.005%.

Now let us examine some requirements for radio control and bear in mind that eventually there may be spot frequencies in the higher range useable for the R/C operation that we will discuss in this work. At the higher frequencies the directivity will be better; this could mean less interference, but ranges might be less unless more power is used, and there is always a chance the model might get away if the range is too far and the directivity too great, and you cannot easily keep the model airplane or boat on the beam.

We will examine a very basic diagram to show you what is required in a radio-control system and we will try to give you some basic of the control operation. Later on in this work we will indicate some simple experimental control systems you might make from a small broadcast receiver and a wireless microphone transmitter available as a kit from Radio Shack; or you might use a small walkie talkie which has a button for some kind of tone (it may not be nice and

Table 1-1. Radio-Control Frequency Allocations

<table>
<tr><th colspan="2"></th><th>Freq. MHz</th><th>Flag Color</th></tr>
<tr><td colspan="2">For remote control of objects or devices, or remote activation of devices which are used solely for attracting attention, if they cause no interference.

(May use Superhet or Regenerative Receivers)</td><td>26.995
27.045
27.095
27.145
27.195
27.255</td><td>Brown
Red
Orange
Yellow
Green
Blue</td></tr>
<tr><th colspan="2">Amateur License Required</th><th>Freq. MHz</th><th>Flag</th></tr>
<tr><td colspan="2">Superregenerative type receivers may operate on 51.200 and 52.040 MHz.</td><td>51.200
52.040
53.100
53.200
53.300
53.400
53.500</td><td>Light Blue & Black
Violet & Black
Brown & Black
Red & Black
Orange & Black
Yellow & Black
Green & Black</td></tr>
<tr><th colspan="2">Any Hobby Device (Vehicle)</th><th colspan="2">Model Aircraft Only</th></tr>
<tr><th>Freq. MHz</th><th>Flag</th><th>Freq. MHz</th><th>Flag</th></tr>
<tr><td>72.160
72.320
72.960</td><td>Light Blue & White
Violet & White
Yellow & White</td><td>72.080
72.240
72.400
75.640</td><td>Brown & White
Red & White
Orange & White
Green & White</td></tr>
<tr><td colspan="4">Model Race cars use mostly the 27 MHz spots for racing. This is because they like to race up to six cars at a time.</td></tr>
</table>

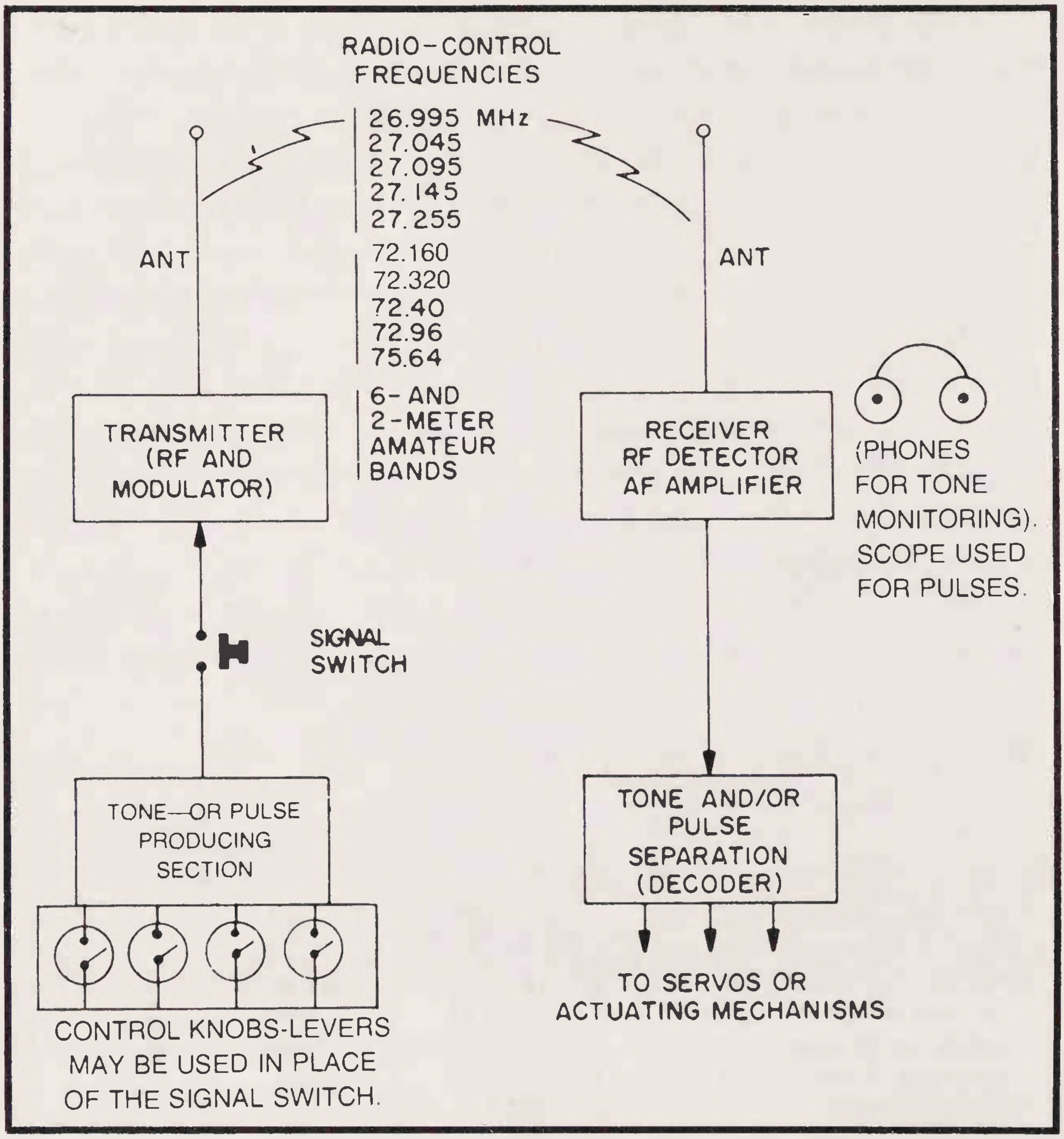


Fig. 1-2. The basic communications link in radio control. The receiver is connected to various motors and other devices which produce mechanical motion.

clear but will buzz loudly) transmission. Adding a relay output can give you the basics of an R/C system. Also, of course, there are many toys now available which use radio control for their operation, although the functions may be limited. You might get one of these and elaborate on the amount of control you can get over the model. We hope to show you in later pages how to get more controls.

FIRST REQUIREMENTS FOR RADIO CONTROL

The first requirement for radio control is a transmitter and receiver capable of sending and receiving tone signals—one or many, constant or pulsed or changing in frequency—over the distance that the model will be required to operate. This communications link should be as nearly 100% reliable as possible, as immune to extraneous signals as possible, lightweight, small, and as economical of battery power as possible.

The tones transmitted are the commands to the model, and changes in these tones (either a change in the tone itself, perhaps frequency, or a change in its width and spacing, or even a change in the sequence in which it is transmitted) can represent specific commands. Also the carrier itself may be pulsed at some rate or in some specific coded manner so that it produces what is commonly called a digital-code signal which can cause mechanisms in the model to perform different functions. We examine in Fig. 1-3 a push button which can be used to send a code manually to the model.

And we see in Fig. 1-4 a later type of transmitter which sends out tones using a pulse-width/pulse-spacing code to operate the actuating mechanism shown just behind the tiny superheterodyne receiver. The unit is available from Ace R/C.

In the tone systems the receiver must be capable of separating the tones or recognizing the types of tone pulses and then causing various mechanical devices, such as small electric motors, to operate when a specific tone or tone pulse width or rate is received.

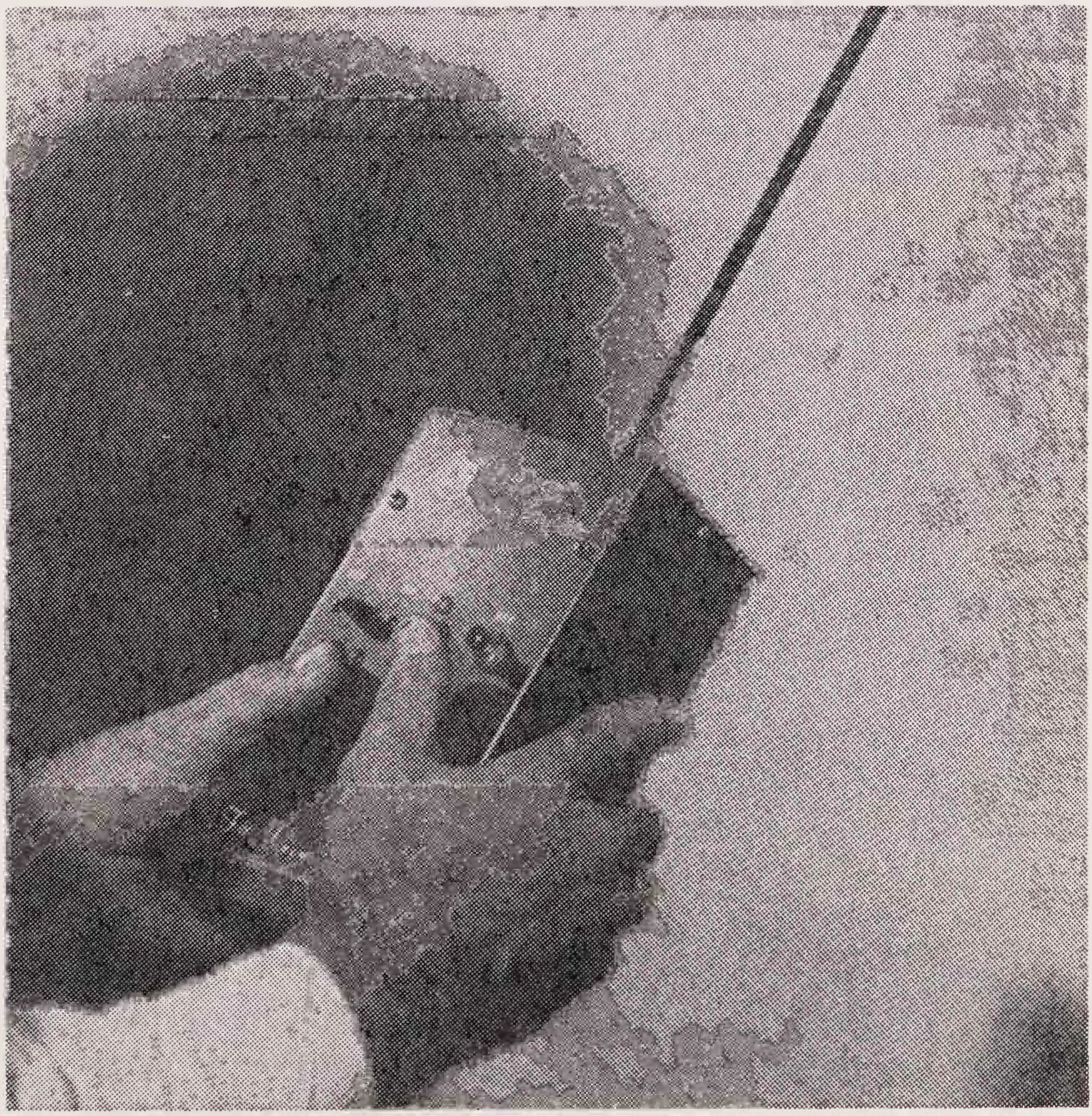


Fig. 1-3. Operating the signal switch on an R/C transmitter.

We mentioned that the carrier might be pulsed. That is the basis for the most modern R/C systems to date. Figure 1-5 shows one such system made by EK-Logictrol. Note that the receiver is packaged together with some of the servo mechanisms, the larger units directly in front of the transmitters.

The battery package is on the extreme right below the transmitter and in the center, lower row. How nice and neat the current packages are. Notice the difference in the two transmitter controls; the right one has a rotating knob, such as you might want to use with a model race car or boat. The left transmitter has two lever controls for rudder and elevator and aileron and motor control of a model aircraft. There are called little-red-brick (LRB) systems because of the packaging used.

THE SIMPLEST COMMAND SIGNAL

To understand how commands are sent to the model, consider first the method used when the commands are represented by a single tone which is turned off and on in some specific manner. We might say the tone is "interrupted," which is simply a way of saying that we can turn the tone-transmit switch on and off quickly. A switch on the transmitter is used to send these commands. We shall refer to it from now on as the SIGNAL SWITCH to distinguish it from the normal transmitter on-off switch. Fig. 1-2 shows the location of this switch in a block diagram of the transmitter.

The receiver operates very much like a regular broadcast receiver in that it will reproduce the tone as its output whenever the tone-modulated carrier is received, and there is no output otherwise. The simplest command signal is simply TONE-ON to cause the model to steer right, TONE-OFF for straight ahead or *neutral* steering, and TONE-ON a second time to give left steering. You press the SIGNAL-SWITCH button with your thumb to send these commands. If you push the button down to steer the model right and its starts to turn left, you simply let up on the pushbutton and press it down a second time, holding it for as long as required to make the model turn as much as you want it to. Figure 1-3 shows the operation.

To understand what takes place in the model when you send this tone, examine Figs. 1-6 and 1-7.

Figure 1-8 shows how to construct a motor-driven escapement. If you trace the circuit, you will see that when the relay armature is in the de energized position (labeled NC, for normally closed) there is a connection from the negative side of the battery (–) to the metal-surface-board and also to tabs 2 and 3. Since the

Fig. 1-4. A pulse-width-pulse spacing control systems.

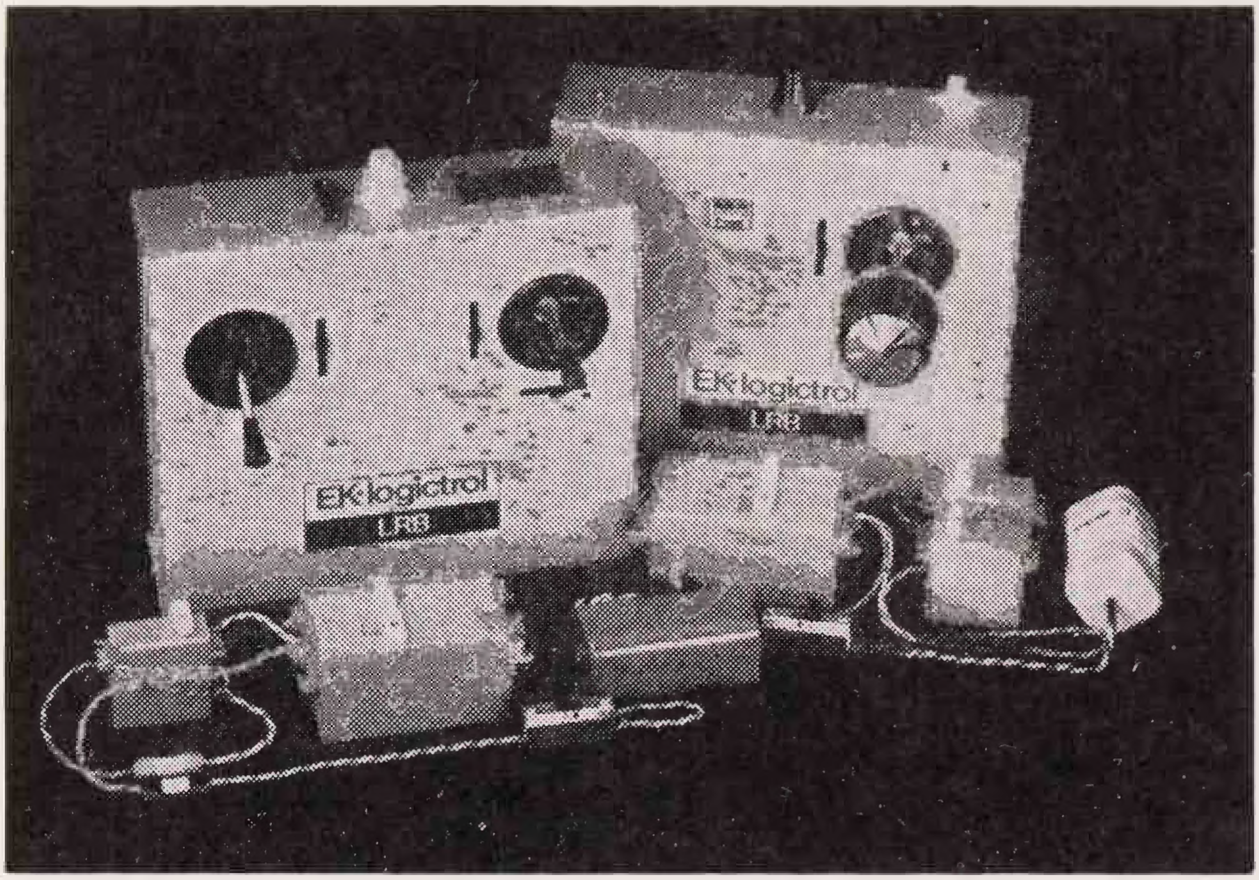


Fig. 1-5. Modern Digital RF pulse systems. (Courtesy EK-LOGICTROL)

wiper arm is connected through the motor shaft to one side of the drive motor, and the other side of the drive motor is connected directly to the positive (+) side of the battery, the motor will run until the wiper is on tab 1, where the circuit is broken. This is the neutral position of the rudder. So you see that when no command signal is sent, the rudder automatically neutralizes itself. When the relay is energized and held that way by sending a tone continuously, tap 1 is connected to the battery and tabs 2 and 3 are disconnected. Since the metal plate is always connected to the battery, the motor will now run until the wiper reaches tab 2, where it will stop. This is

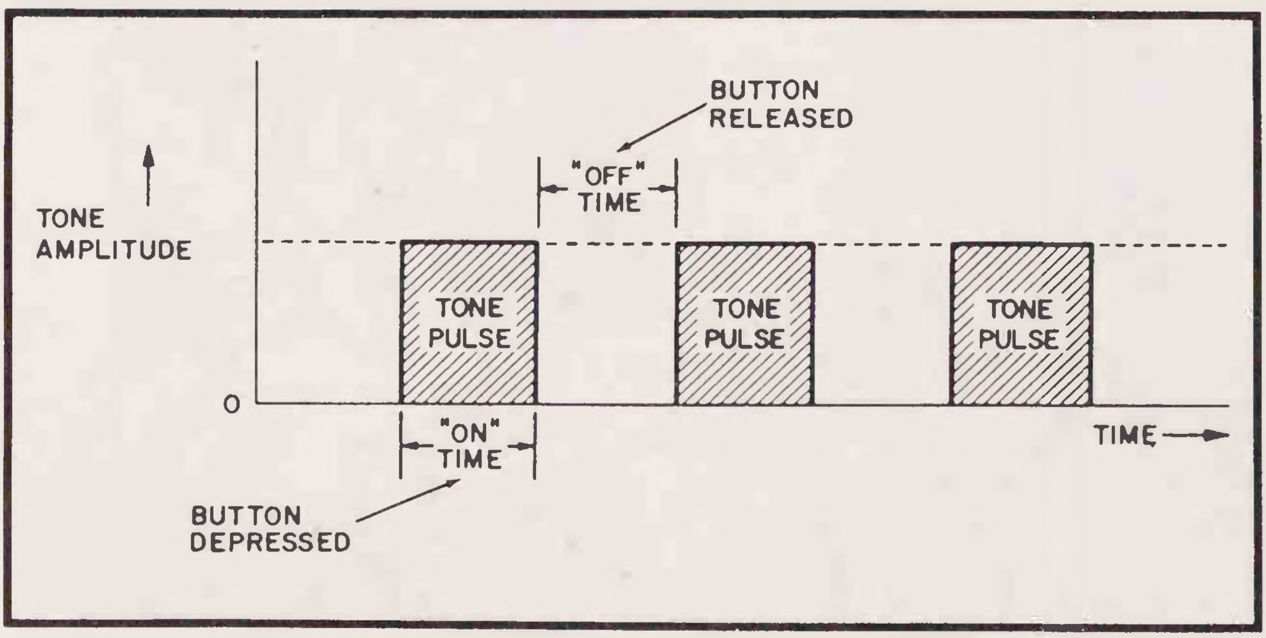


Fig. 1-6. The graph illustrates tone pulses produced by operating the signal switch.

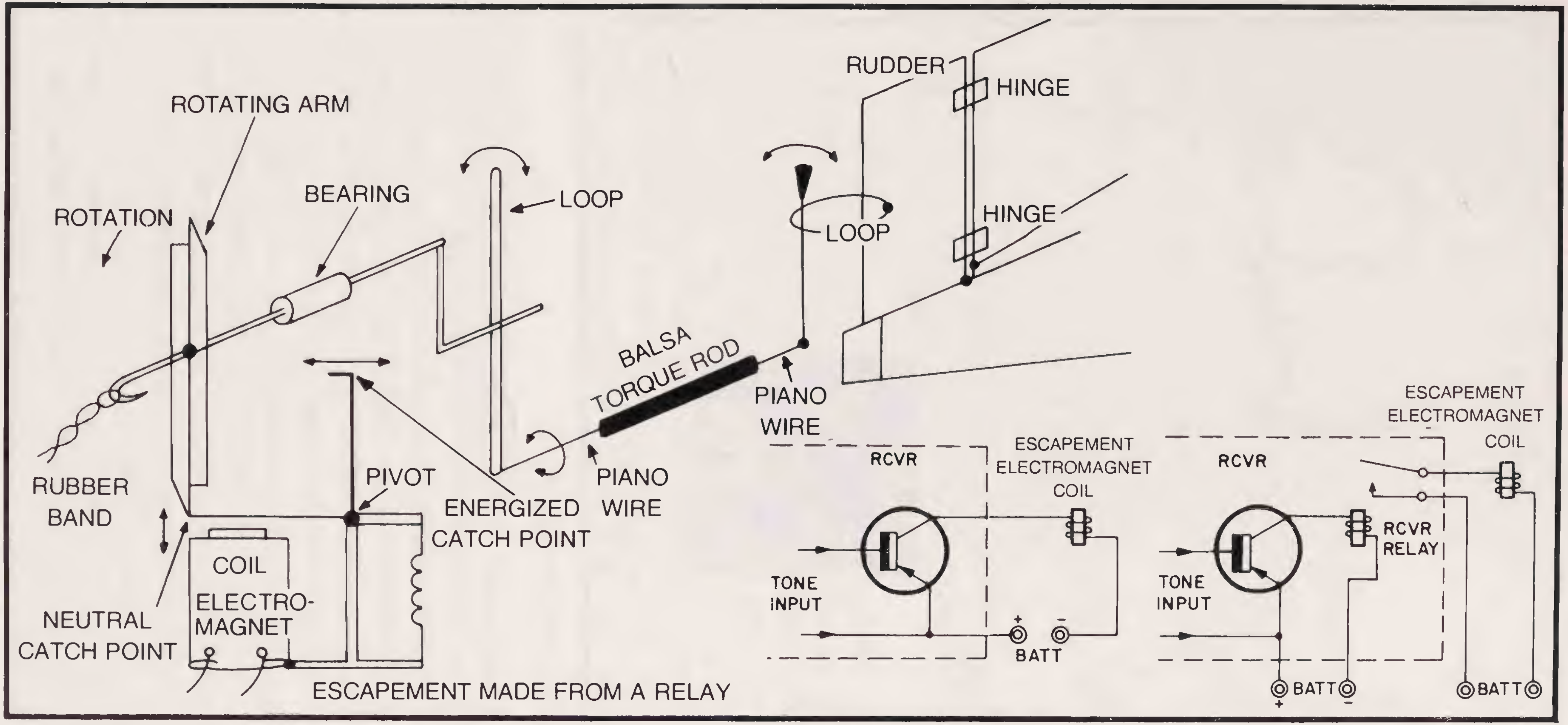


Fig. 1-7. Some steering devices are powered by rubber bands, springs, or by electric motors but all operate in the same way. In 1-7(a) we see an escapement, as the coil is energized it lets the arm rotate one-fourth turn giving steering in one direction. Off is another quarter turn, and on again is another quarter turn for right steering. Notice the cycle that the device completes going from neutral to left to neutral to right to neutral. Note how the escapement coil can be energized directly by a transistor (b) or via a relay (c).

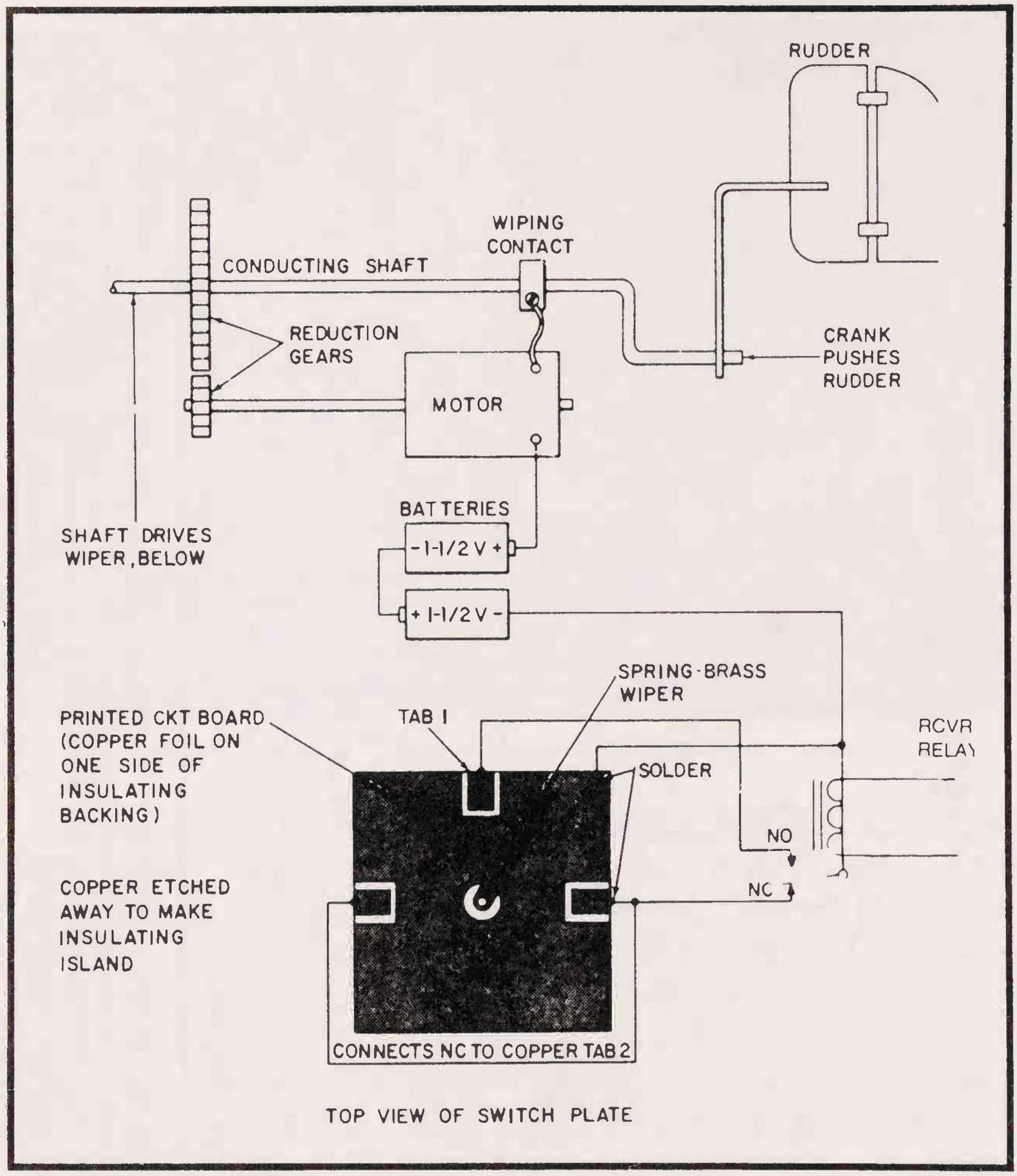


Fig. 1-8. A motor driven escapement.

left rudder. Momentarily we stop sending the tone and then send it again. This allows the wiper to move from tab 2 onto the metal plate and the motor will drive it until it reaches tab 3, where again it will stop. This is right rudder. Thus, with the proper tone commands, the rudder can be positioned left or right and the arm will automatically return to neutral when no tone is received.

You must realize that with this type of control the steering wheel or rudder is always deflected to its maximum position, either left or right, each time a tone is received. To steer the model in a gradual turn, don't hold the rudder too long in one postion, but rather hold it for a short time, release it, then position it in the same direction again for a short time. The model then executes a series of short turns which when put together make a large gradual turn as shown in Fig. 1-9.

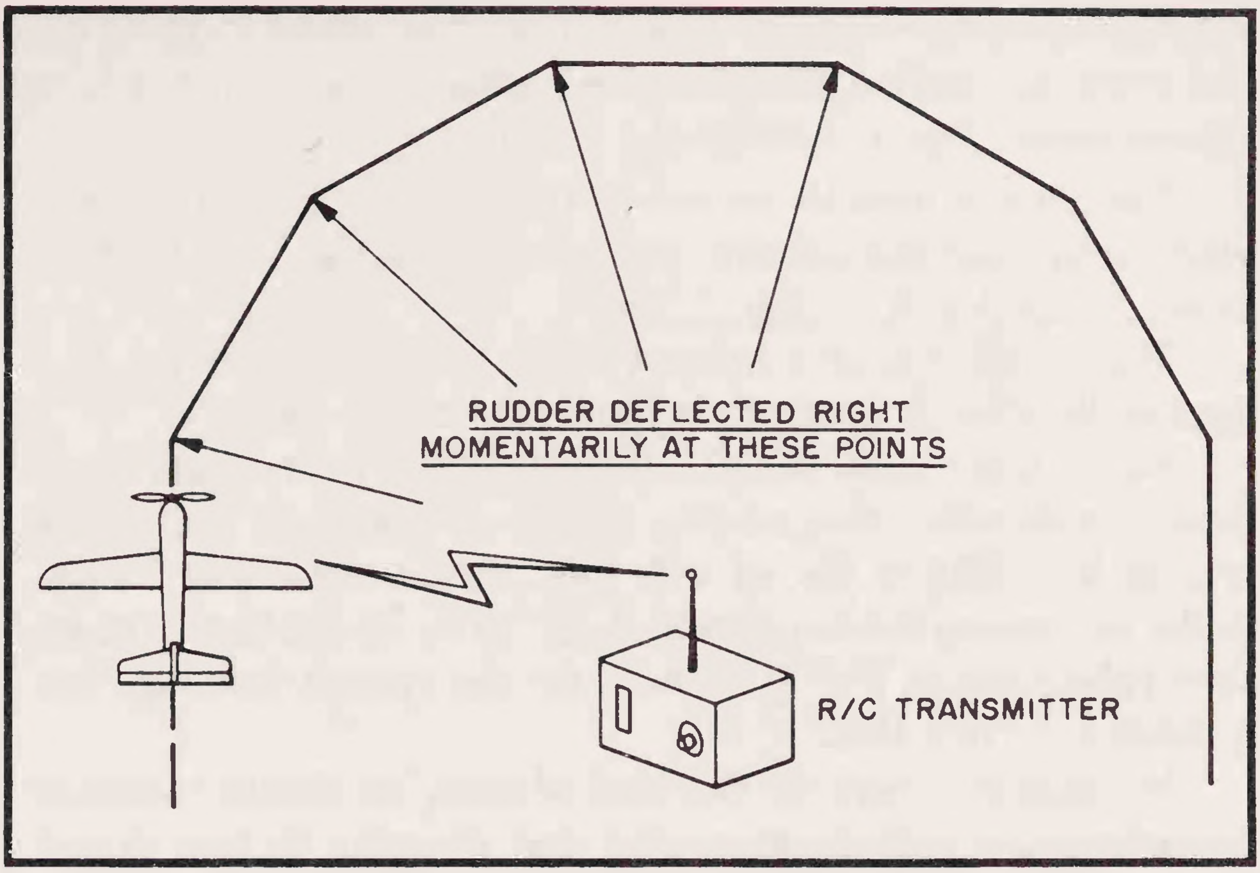


Fig. 1-9. The concept of a gradual turn by controlling the time that the rudder is deflected to its maximum position.

You will also realize after a moment's thought that to repeat a command with this system you must release the tone button, depress it and release it quickly and then depress it and hold it down. The first time you depress, the signal switch would give left, the second time right, and the third time would be left again. So, to repeat a command you must release, depress, release and depress and hold. With a little practice this becomes automatic. It is the same sequence used with an escapement of the single arm type shown in Fig. 1-7.

THE SIMPLEST PROPORTIONAL-CONTROL SYSTEM WITH MECHANICAL DECODING

Proportional control means deflecting the rudder a small amount for a gradual turn and a large amount for a fast or sharp turn. The steering is accomplished by making a signal switch such that rudder movement is directly proportional to a small deflection of a lever or steering wheel. It is now necessary to vary the duration of the transmitted tone and to make the tone pulses automatically and continuously for as long as the button is down. If the time that the tone is transmitted is longer than the time the tone is off, then the model will be steered left. The maximum left occurs when the tone is on steadily. If the time the tone is off is longer than the time it is on, the model will be steered right. Maximum right results from no tone. Notice how this differs from the previous method where "no tone" was neutral. In this system, neutral or straight-ahead steering occurs when the time length of the tone is the same as the time length *between* tones. Figure 1-10 graphs the idea.

This code is used in the Ace R/C pulse Commander system, which uses a magnetic actuator, such as shown in Fig. 1-12. It can be obtained from Ace R/C (Fig. 1-13).

The installation of a pulse-width/pulse-spacing system in a small model aircraft is shown in Figs. 1-14 and 1-15.

Notice that this is all there is to it. Three items make up an airplane installation, not counting the off-on switch. Of course you have to be willing to put up with the "nervous twitching" of the rudder as it moves continuously back and forth. To see how it causes turns refer again to Fig. 1-10. And, for the system, see Fig. 1-4, available from Ace R/C.

In summary, then, for this kind of code, an electric motor or magnetic acutator is so connected that it wants to turn in one direction when a tone or signal is received, and in the opposite

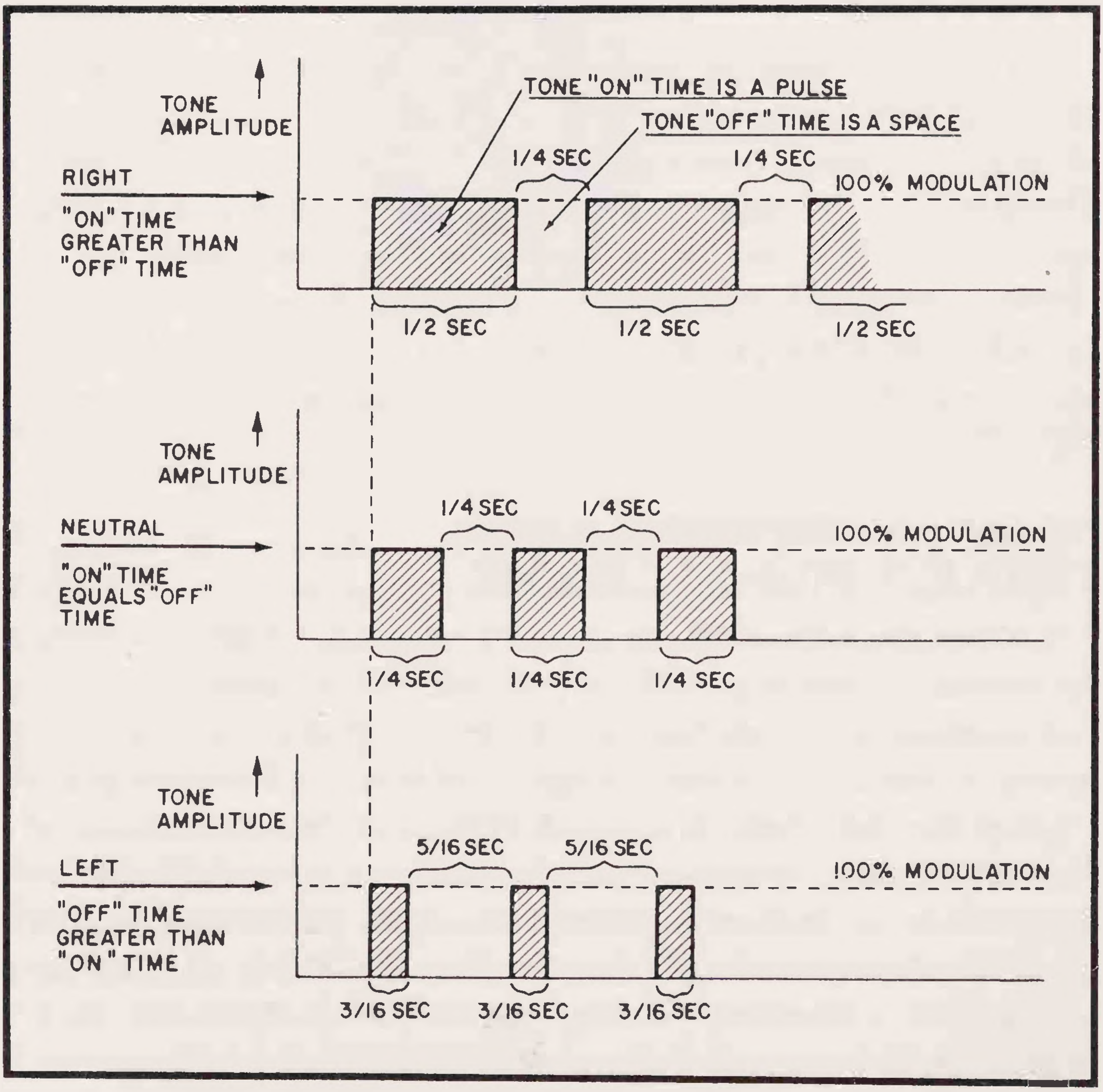


Fig. 1-10. Neutral is equal pulses and spacing. In the receiver, an electronic "fail-safe" circuit disconnects the steering controls if there is a system failure.

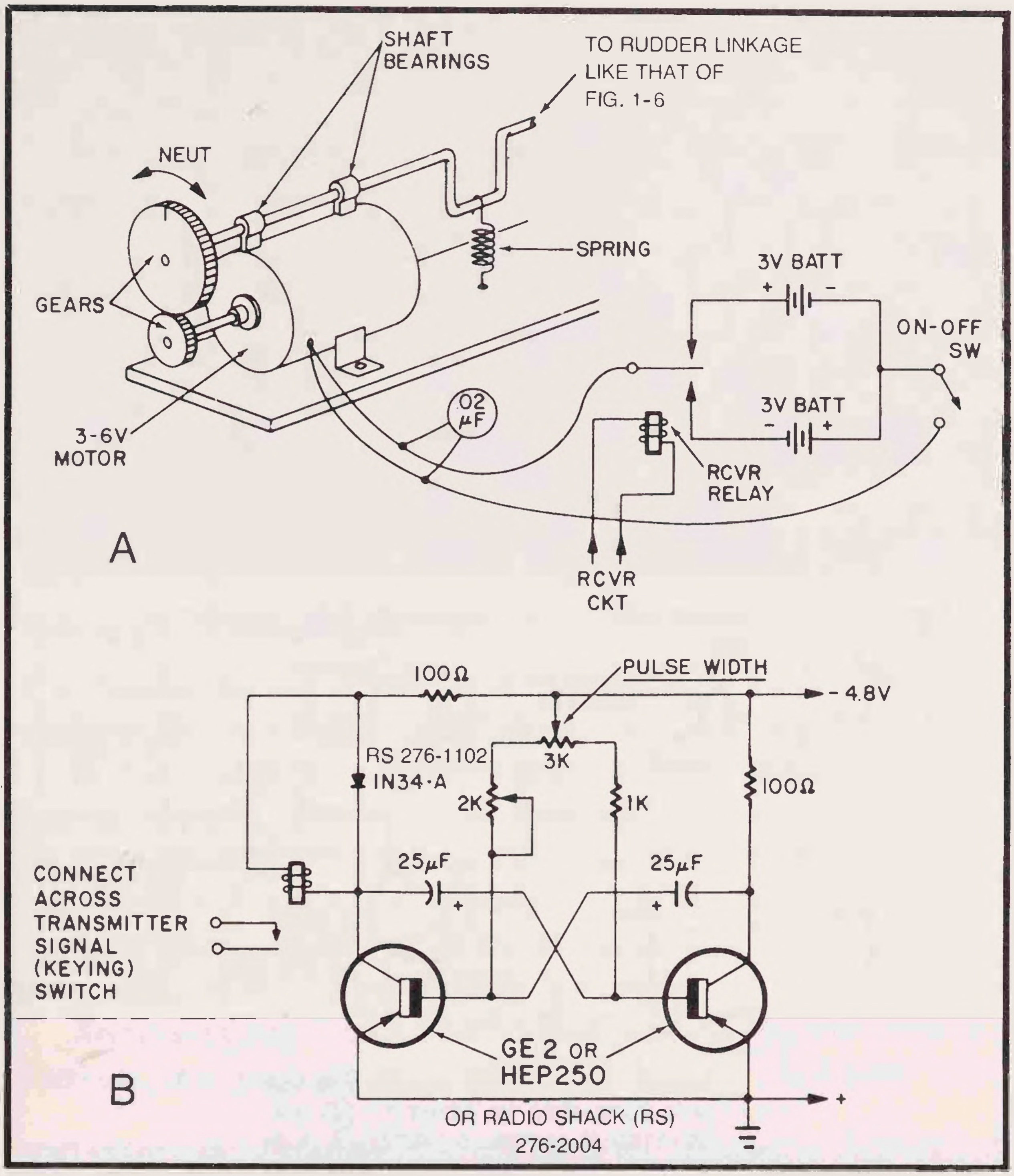


Fig. 1-11. The basic pulse-width, pulse-spacing decoder (a). If the spring is weak, the motor rotates the output shaft in one direction on no-tone, and in the opposite direction on full-tone. If an arm is geared to the output shaft it can be made to move back and forth with this rotation to position a model-aircraft elevator. One might also put switches at the limits and let these operate an elevator positioning servo. A suggested transmitter-pulsing circuit for this decoder is shown at (b).

direction with no tone. A centering spring on the motor keeps the shaft at neutral when equal pulse-width-pulse spacing commands are received. Mechanical stops are often included to prevent the rudder or steering wheels from turning too far, or the motor shaft may be allowed to rotate completely, cycling the steering element and giving straight-ahead steering if the rotation is fast enough. Figure 1-11a illustrates the arrangement.

Two circuits for transistor servos of this type for use with relayless receivers are shown in Fig. 1-12. Notice that although the relay is not required, the arrangement of the motor or actuator is the same as in Fig. 1-11a.

SIMPLEST TWO-CHANNEL PROPORTIONAL COMMAND SIGNAL

The command signal of the previous section can be modified easily to obtain a second proportional channel. Normally this would be used to control the model aircraft's elevator. Now the elevator *and* rudder can be moved simultaneously so that you can steer left or right and up or down at the same time. The modification merely calls

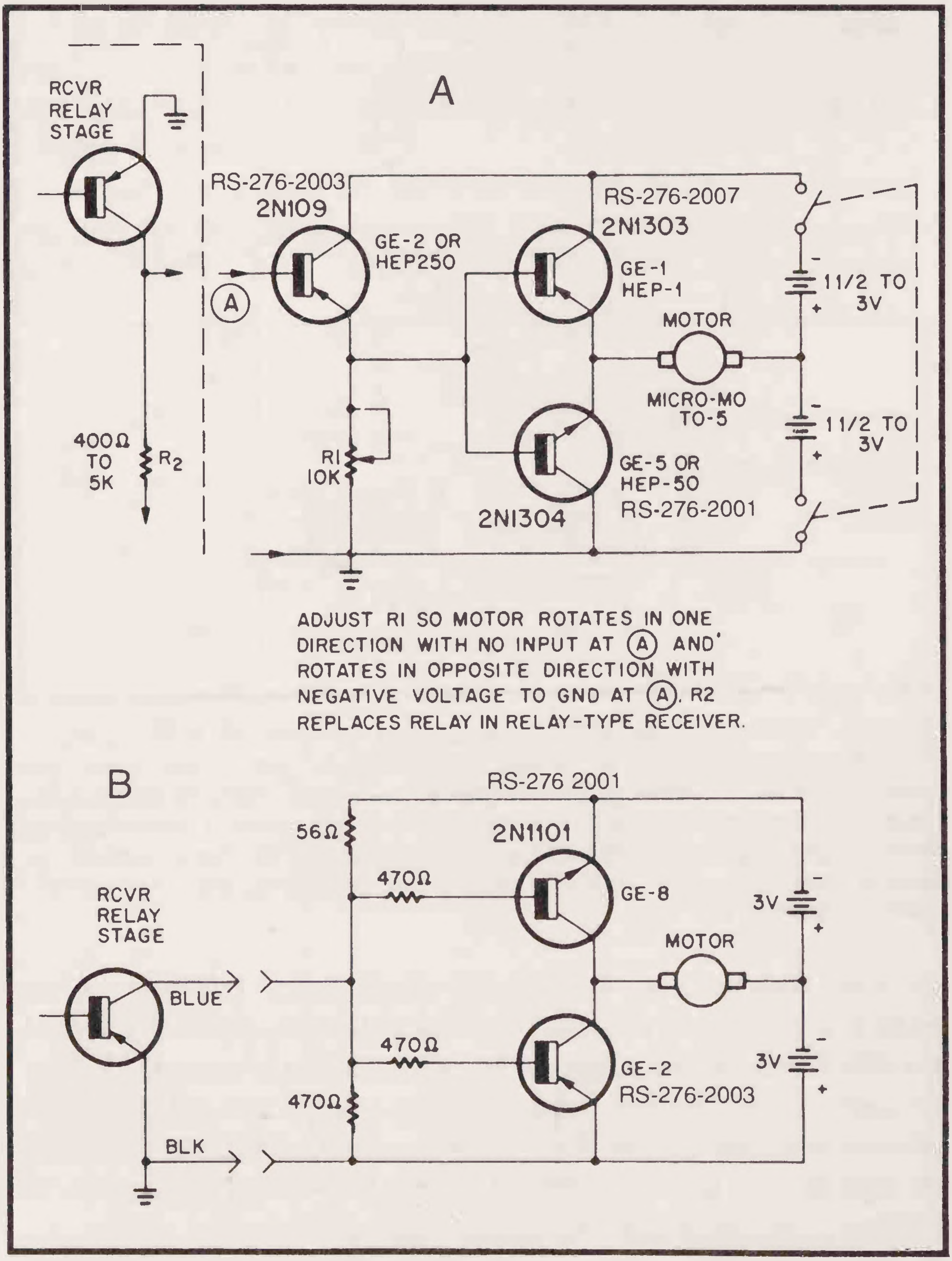


Fig. 1-12. Circuits to operate the servomotor from a relayless receiver. The circuit at (a) is more sensitive.

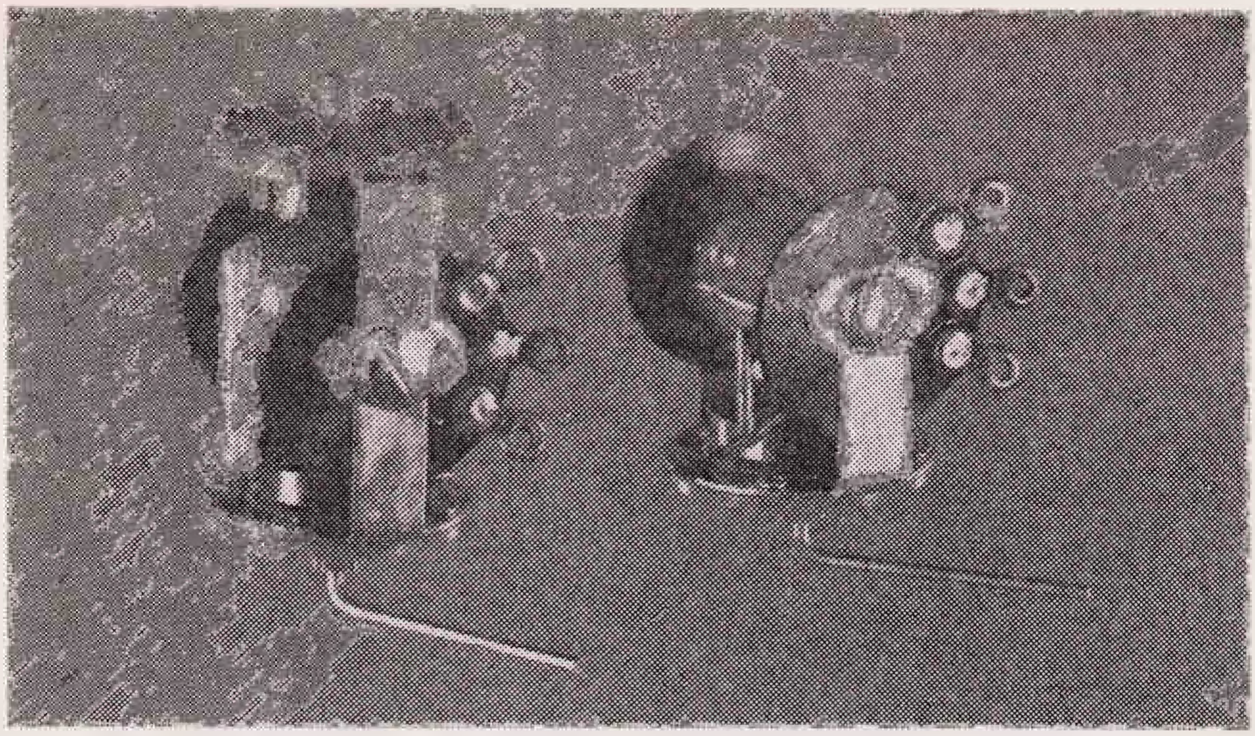


Fig. 1-13. The Adams pulse width-spacing actuator (ACE R/C).

for increasing the *rate* at which the variable-width pulses are transmitted, as shown in Fig. 1-16. Hinges must be free; see Fig. 1-19.

In the model, an auxiliary circuit may be connected to the receiver output to cause a relay to close when it receives a fast pulse rate. This auxiliary relay will not close on a slow or "normal" pulse rate. Figure 1-17 shows two circuits for this. Increasing the pulse rate does not necessarily affect the steering, as long as the width-spacing ratio of the pulses remains unchanged.

To obtain proportional elevator control we use the fact that the steering-motor decoder crank will deflect less on a fast pulse rate

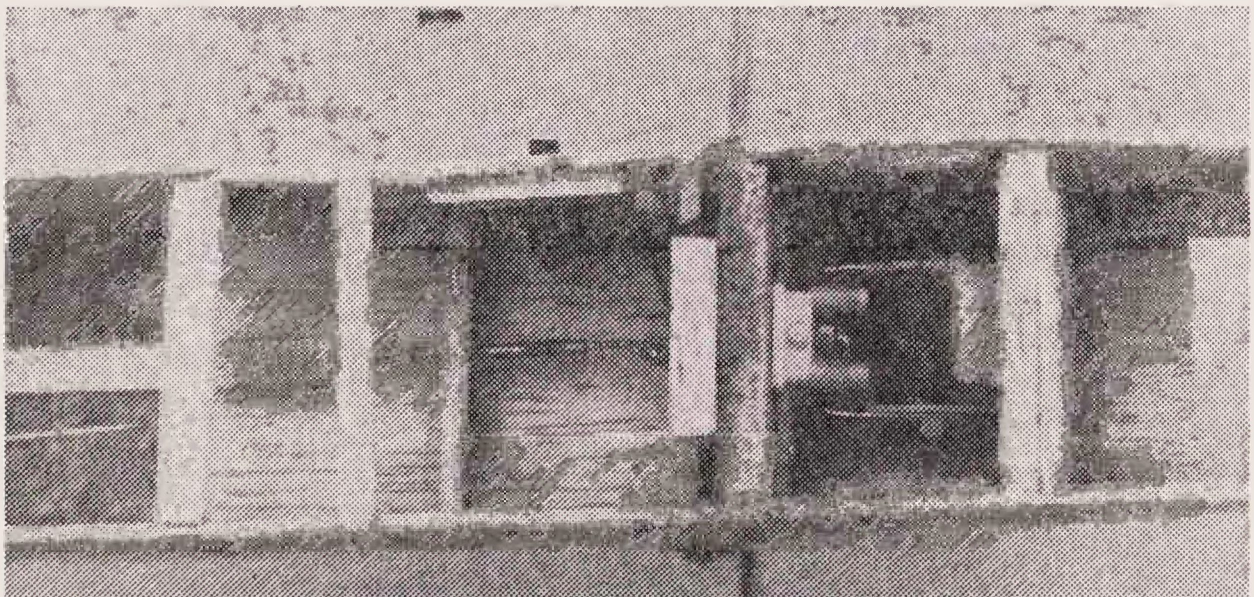


Fig. 1-14. The Adams actuator installed in a model aircraft.

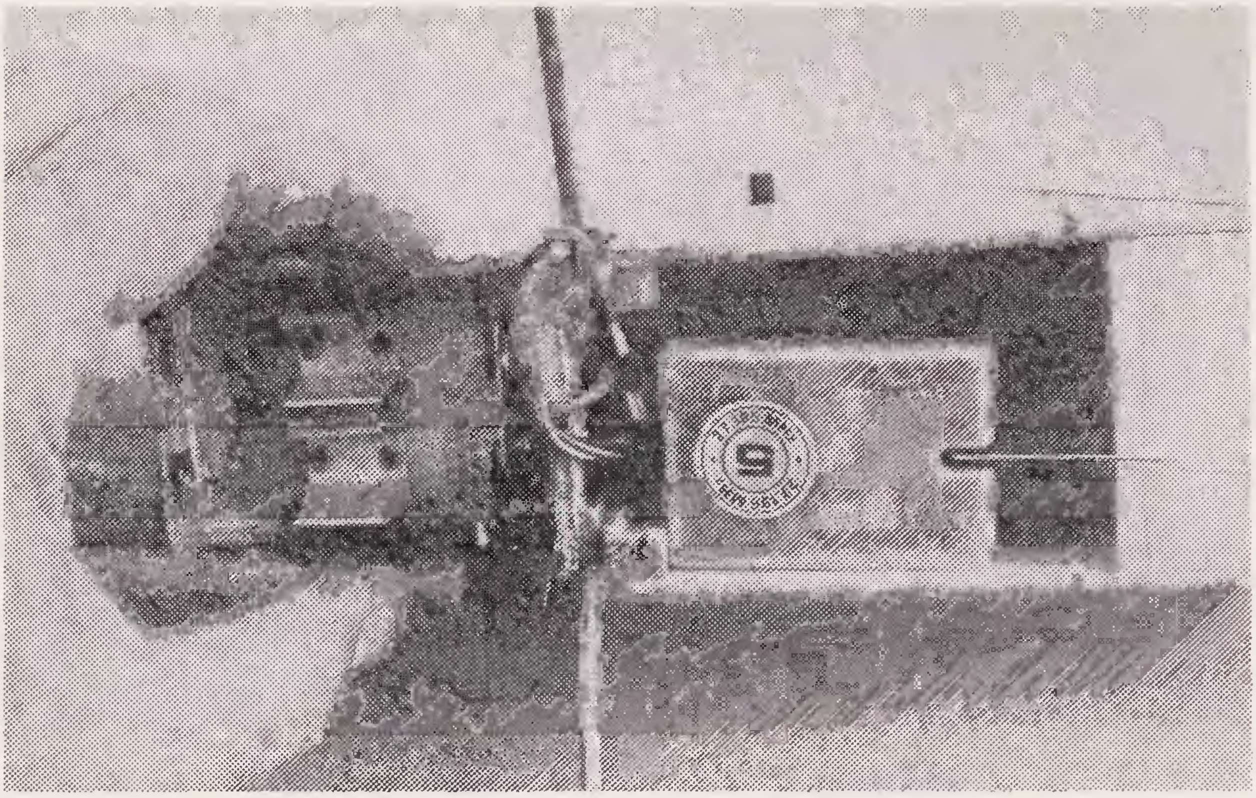


Fig. 1-15. The receiver and battery holder for the pulse width-spacing installation. The receiver may be obtained tuned to the 72 MHz frequencies, from Ace R/C.

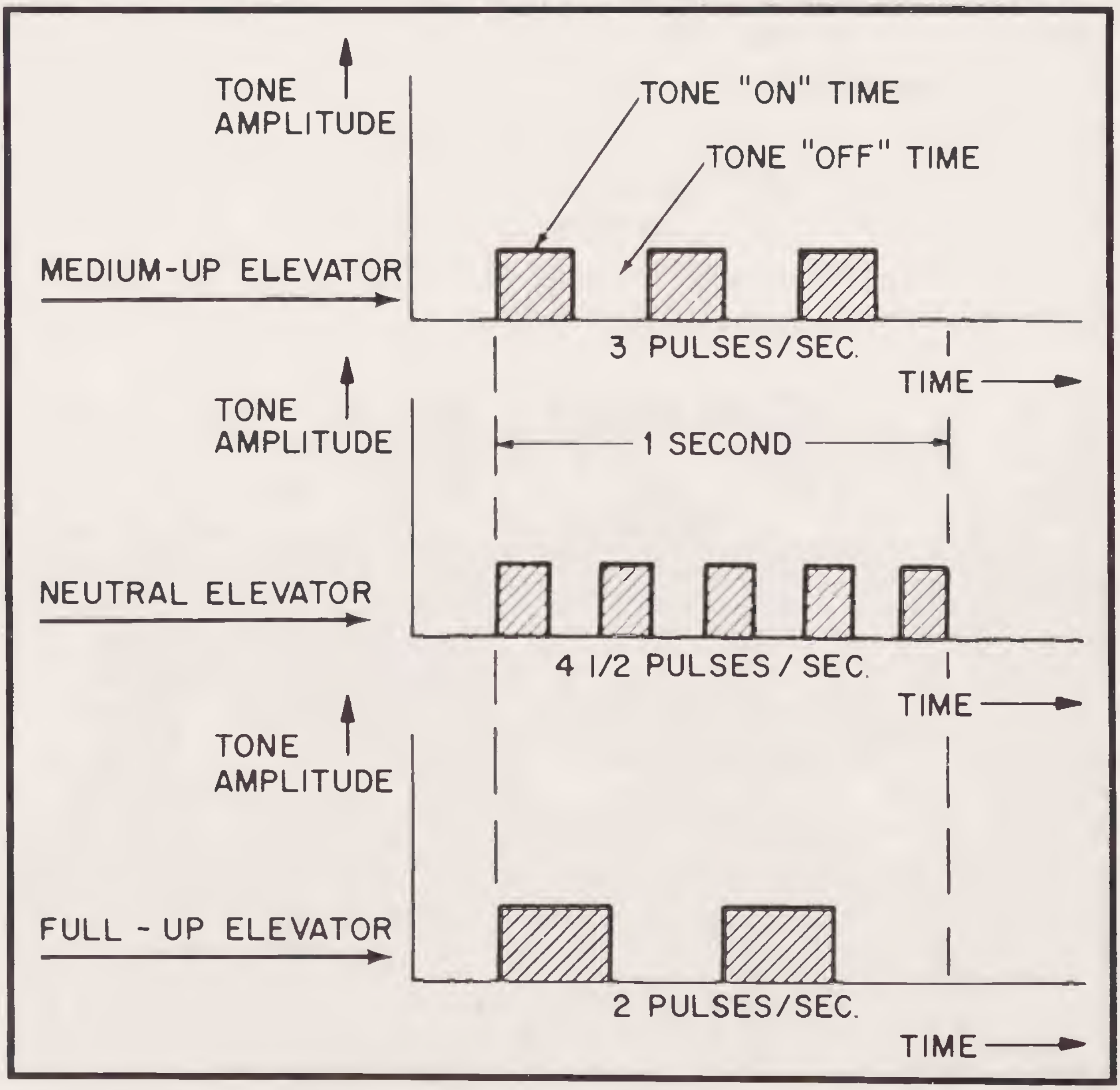


Fig. 1-16. "Pulse rate" means the number of times the tone is transmitted per second. Normally this rate varies between 2 and 40 pulses per second.

than it will on a slow pulse rate. With a special yoke connected to the elevator, the elevator can be deflected to a full-up position by decreasing the pulse rate to minimum. A fast pulse rate would keep the elevator full down (Fig. 1-18).

Thus, as we vary the pulse rate we obtain varying elevator deflection, either up or down. Which one you use depends upon how you want to fly and on the power available. You might want up-elevator for loops and fast takeoffs from the runway. You might choose down-elevator if you plan to dive-bomb targets, and let the model loop with its normal-climb adjustment and neutral elevator as it comes out of its high-speed dive. That's useful, too, if you want to

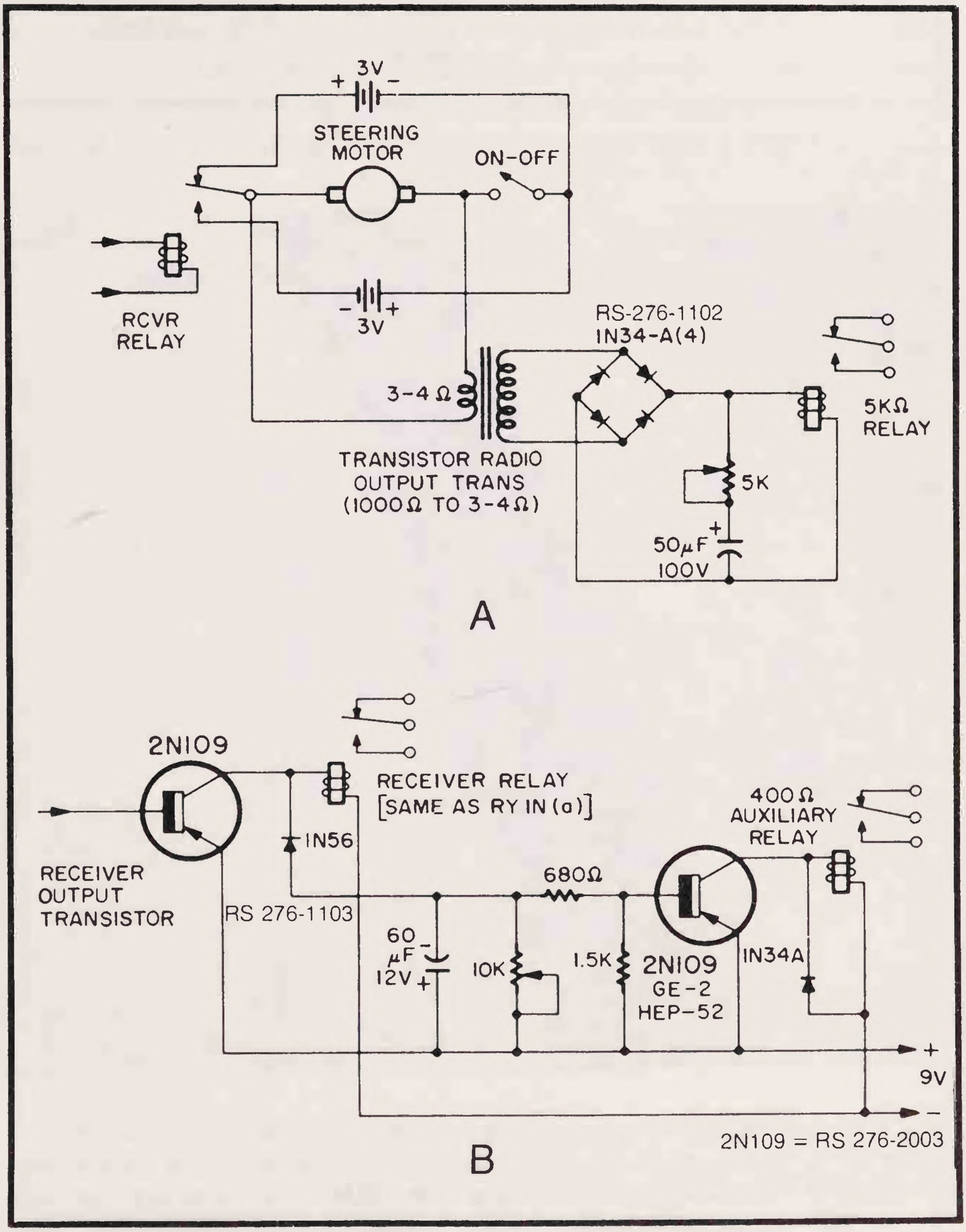


Fig. 1-17. Two pulse-rate decoding circuits.

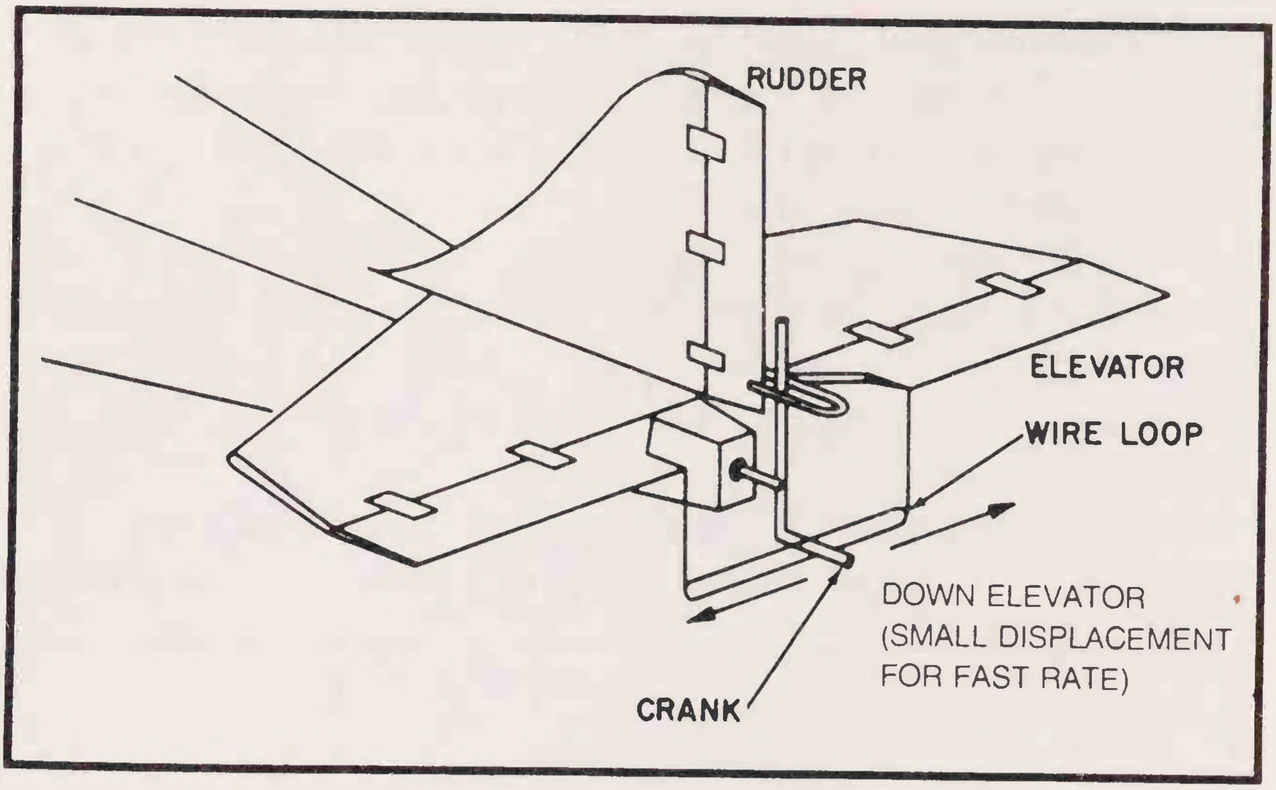


Fig. 1-18. Proportional elevator control by varying the tone-pulse rate. Fast rate is neutral, slow rate means maximum deflection.

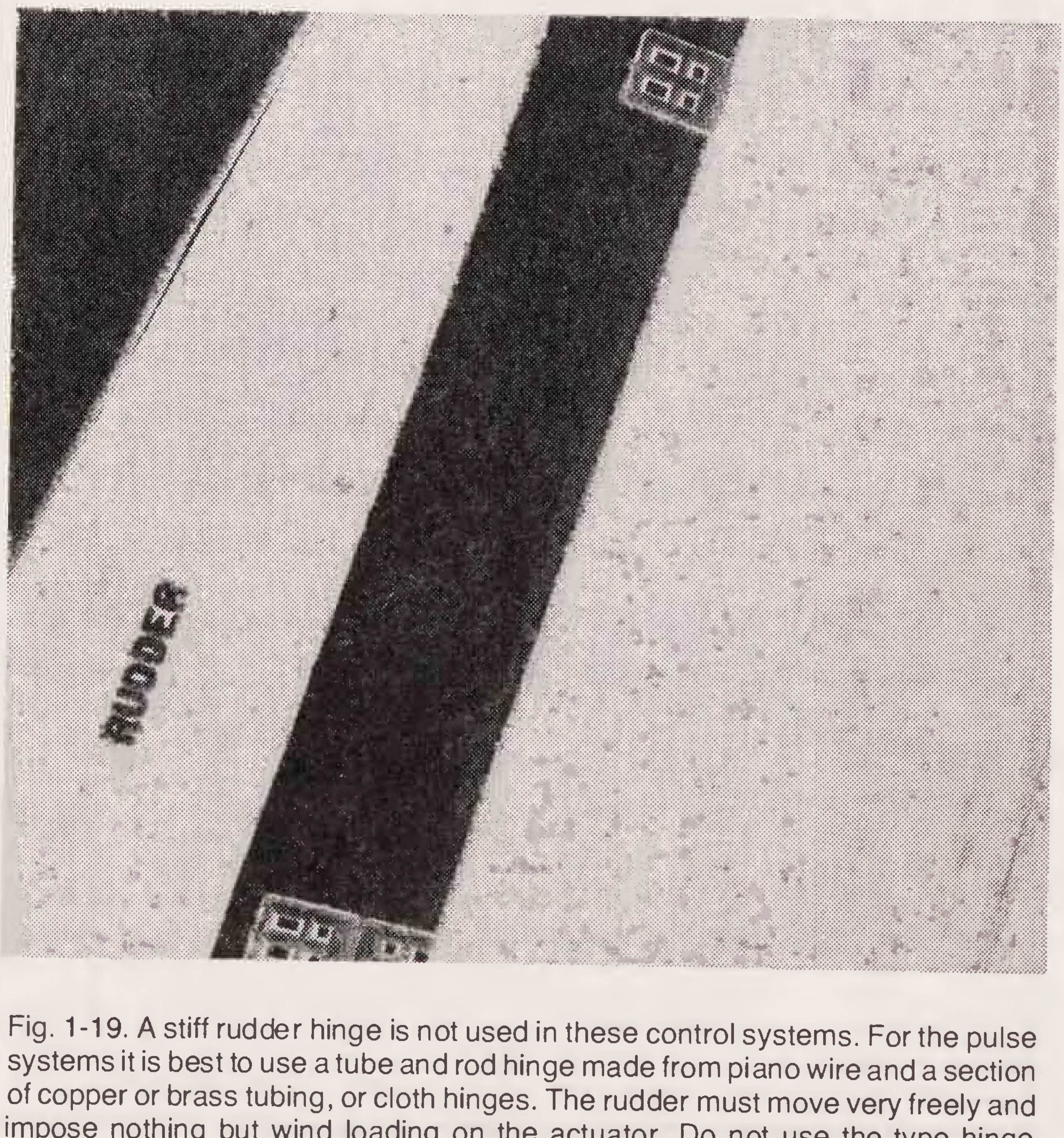


Fig. 1-19. A stiff rudder hinge is not used in these control systems. For the pulse systems it is best to use a tube and rod hinge made from piano wire and a section of copper or brass tubing, or cloth hinges. The rudder must move very freely and impose nothing but wind loading on the actuator. Do not use the type hinge shown here, for the pulse-width pulse spacing systems under discussion.

bring the model down low for touch-and-go landings without changing motor speed. You still have to steer by varying pulse *width* no matter what *rate* you are using.

But the rudder must flop easily in this kind of system. Do not use the hinge arrangement shown in Fig. 1-19, which is used with servos and has some advantage in that it tends to keep the rudder at neutral in those systems. Due to constant motion, strong, free, hinges are a necessity in the tone-pulsed systems we are examining.

Figure 1-20 shows how to construct a simple mechanical coder to vary pulse width and pulse rate.

FAIL-SAFE CIRCUIT FOR PULSING SYSTEMS

Because an absence of the tone signal in the previous systems can mean a full rudder deflection and/or elevator deflection, most such systems use a circuit to disconnect the battery power in case the pulsing stops for a certain length of time. Such a circuit is called a *fail-safe* circuit because in case of failure the model goes straight and does not crash-dive because of locked controls. Such a circuit is

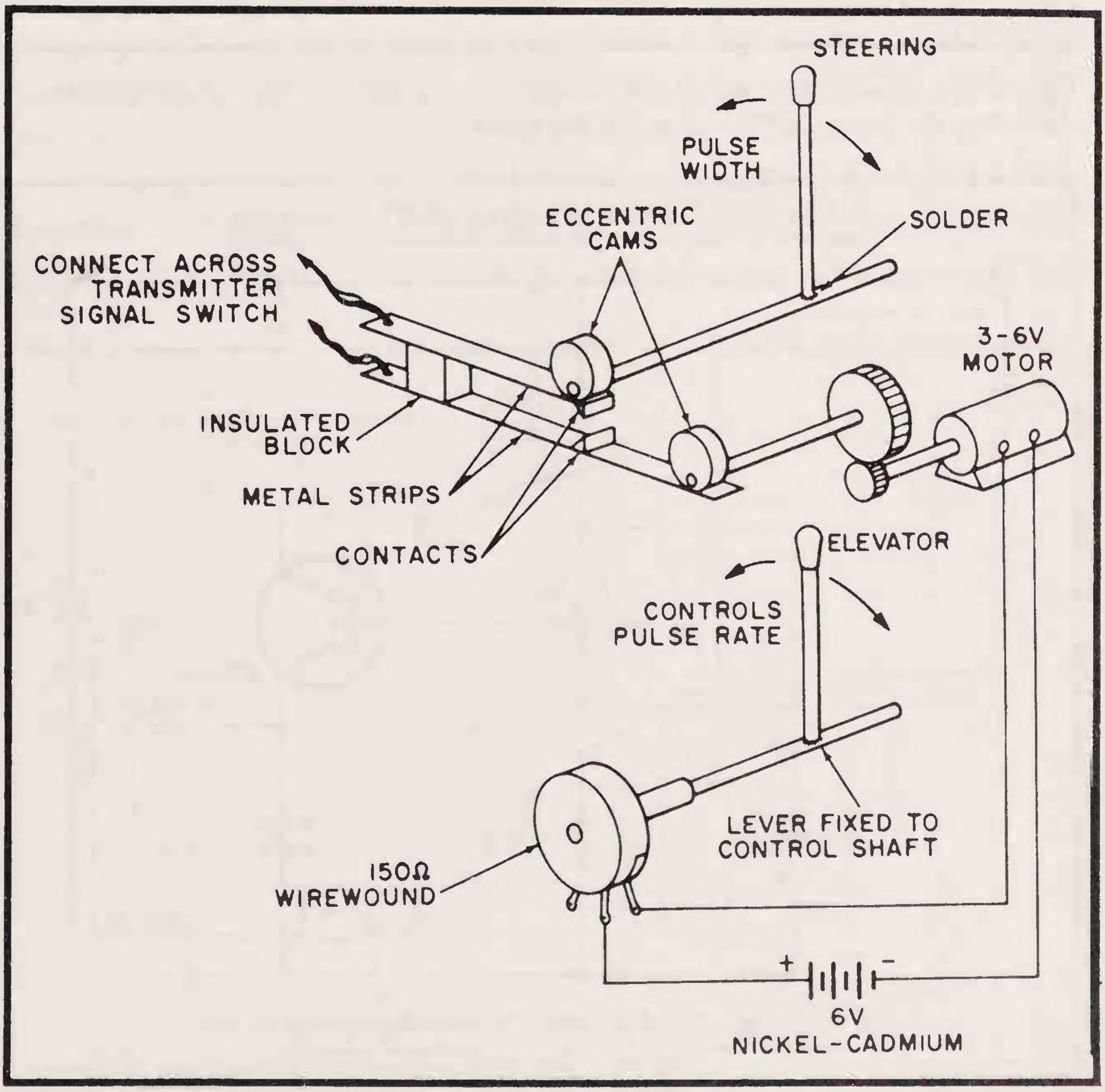


Fig. 1-20. Mechanical pulse-width-rate coder.

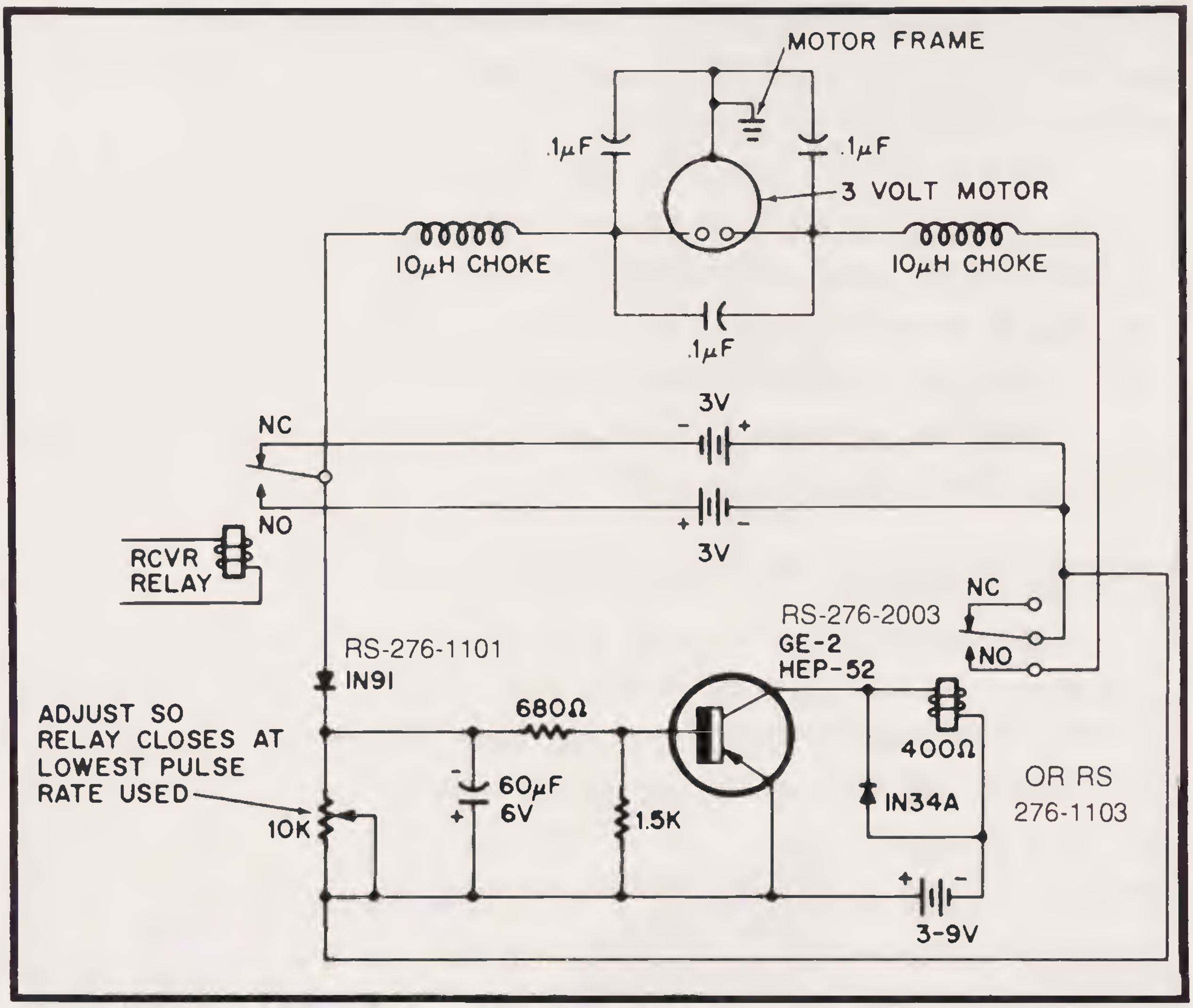


Fig. 1-21. A fail safe circuit for models using pulse commands. Electronic decoding for pulse width—spacing systems.

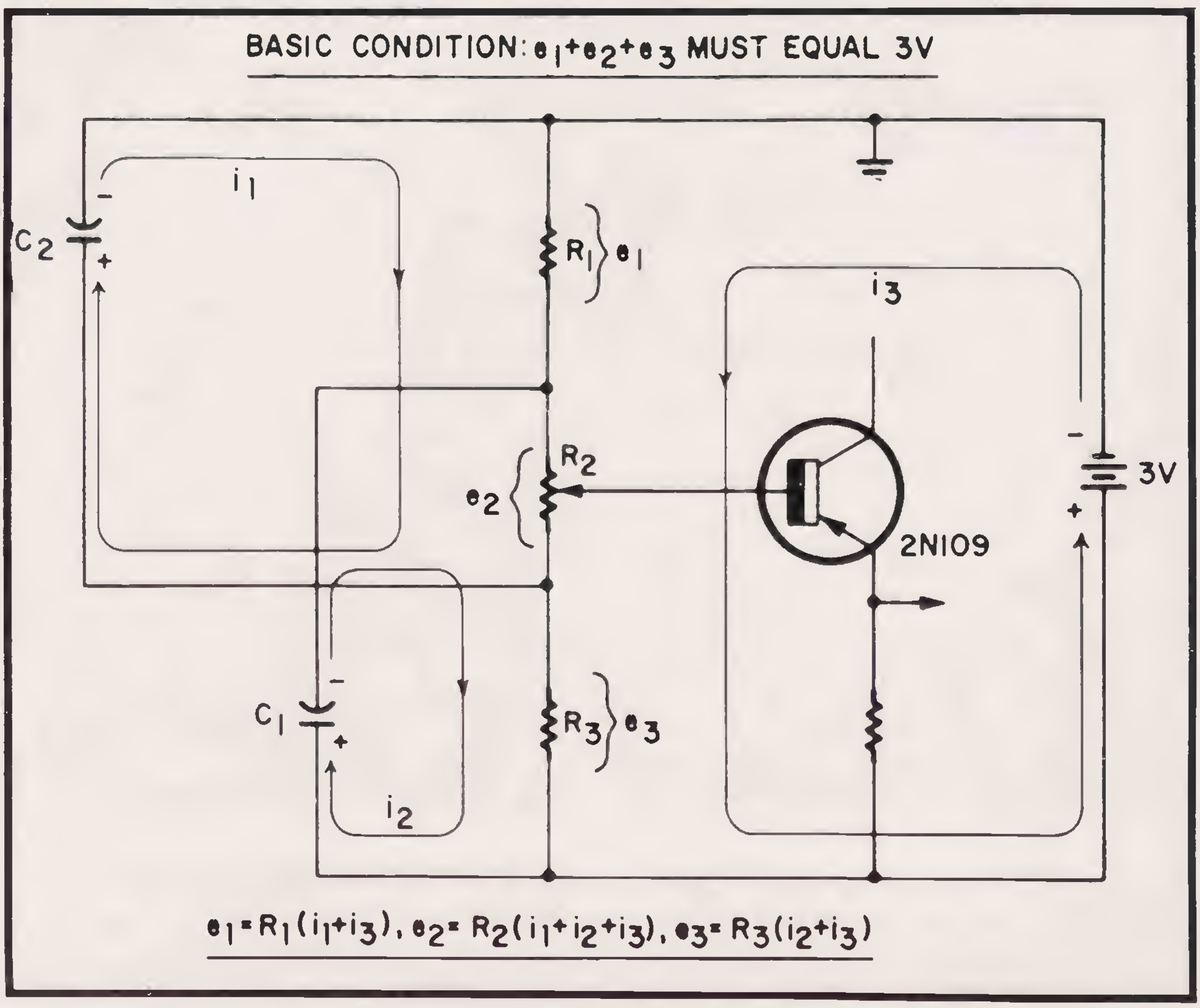


Fig. 1-22. A circuit to explain how currents in the electronic pulse decoder produce voltages.

shown in Fig. 1-21. The power to the rudder-elevator steering motor is connected through the normally-open relay contact. If pulsing stops, the relay opens and disconnects the circuit, and the spring and wind forces restore the rudder and elevator to neutral.

ELECTRONIC DECODING OF PULSE-WIDTH PULSE SPACE CODE

Credit for originating this method of decoding pulse-width and pulse-rate commands goes to Dr. Walter Goode and Gerald Herzog. Others have advanced the basic ideas. The circuit of Fig. 1-22 shows how two currents, I1 and I2, due to voltages on capacitors C1 and C2, can change the conduction level of the input transistor Q1.

Capacitors C1 and C2 are charged by voltage pulses through diode pairs as shown in Figs. 1-23 and 1-24.

Figure 1-23 is a decoder that compares the peak pulse amplitude in the lower half of the input circuit against a voltage proportional to the *rate* at which the pulses are received. This upper circuit is called a pulse counter and its voltage output is proportional to the number of pulses received per second.

Figure 1-24 is a decoder that gives an output based on comparing the width of each pulse (represented by a positive voltage) against the spacing of pulses (represented by a negative voltage). Notice capacitors C1 and C2 in each circuit.

Use of these circuits allows radio control with pulse-width variation and pulse-rate variation, but at a higher frequency than used for the mechanical decoders. The average pulse rate for this

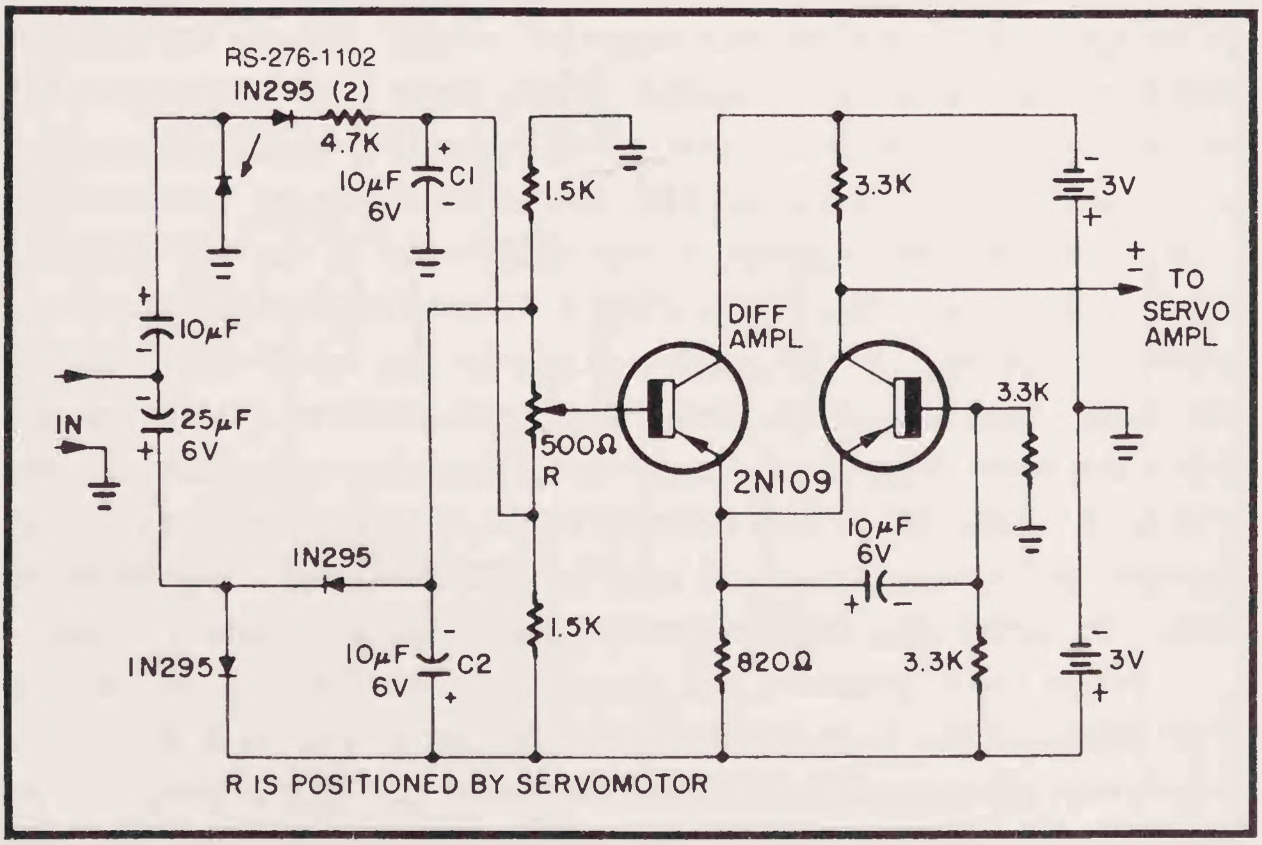


Fig. 1-23. The actual circuitry of a pulse-rate decoder. 2N109 = RS276-2003.

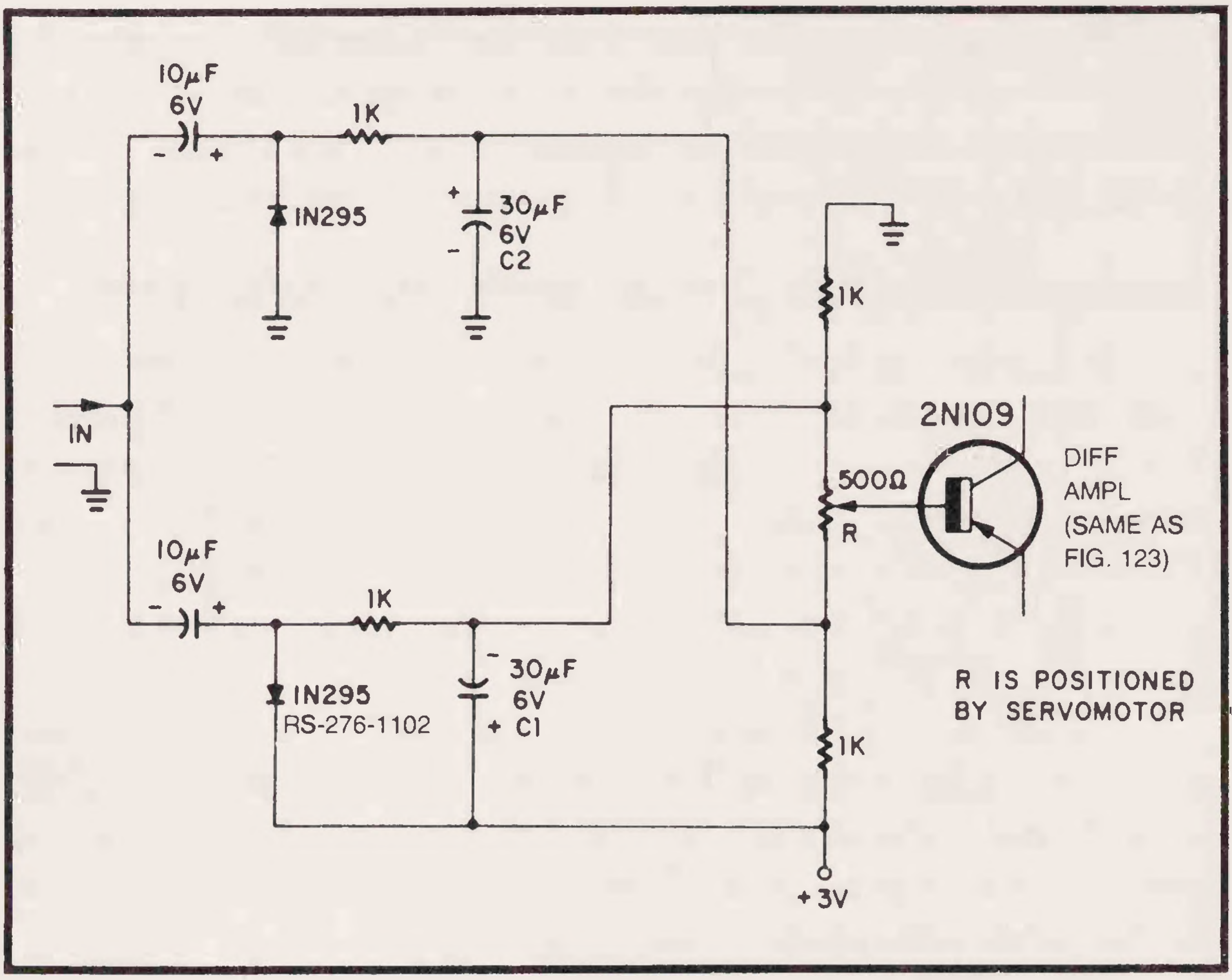


Fig. 1-24. The actual circuitry of a pulse-width pulse-spacing (symmetry) decoder.

system is around 525 pulses per second, but, as we pointed out previously, we can still vary the width of the pulses at this frequency and get rudder steering. Examine the circuit in Fig. 1-25.

In this circuit, part A is normally in the receiver. It is shown here because it performs a very important function: changing the tone signals into positive and negative pulses. Q2 and Q3 and the batteries form a balanced bridge. When there is no tone input, Q1 does not conduct much so there is a high negative voltage to the base of Q2. Q2 conducts heavily and the output at the center, between the two transistors, is negative to the center-tap of the 4.5-volt batteries, which is ground. When there is a tone input to Q1 it conducts heavily, reducing the negative voltage to the base of Q2, so Q2 presents a high impedance from collector to emitter. At this time Q3 looks like a low impedance across its terminals so the common point between Q2 and Q3 is now positive to the battery-common point or ground. In this way the output between Q2 and Q3 can be positive or negative, depending on whether a tone is being received or not.

When these positive and negative pulses, whose widths can vary (because the tone-on, tone-off time can be varied at the transmitter) are presented to the width detector, this circuit produces an output voltage *proportional to the width of the positive pulse* via one

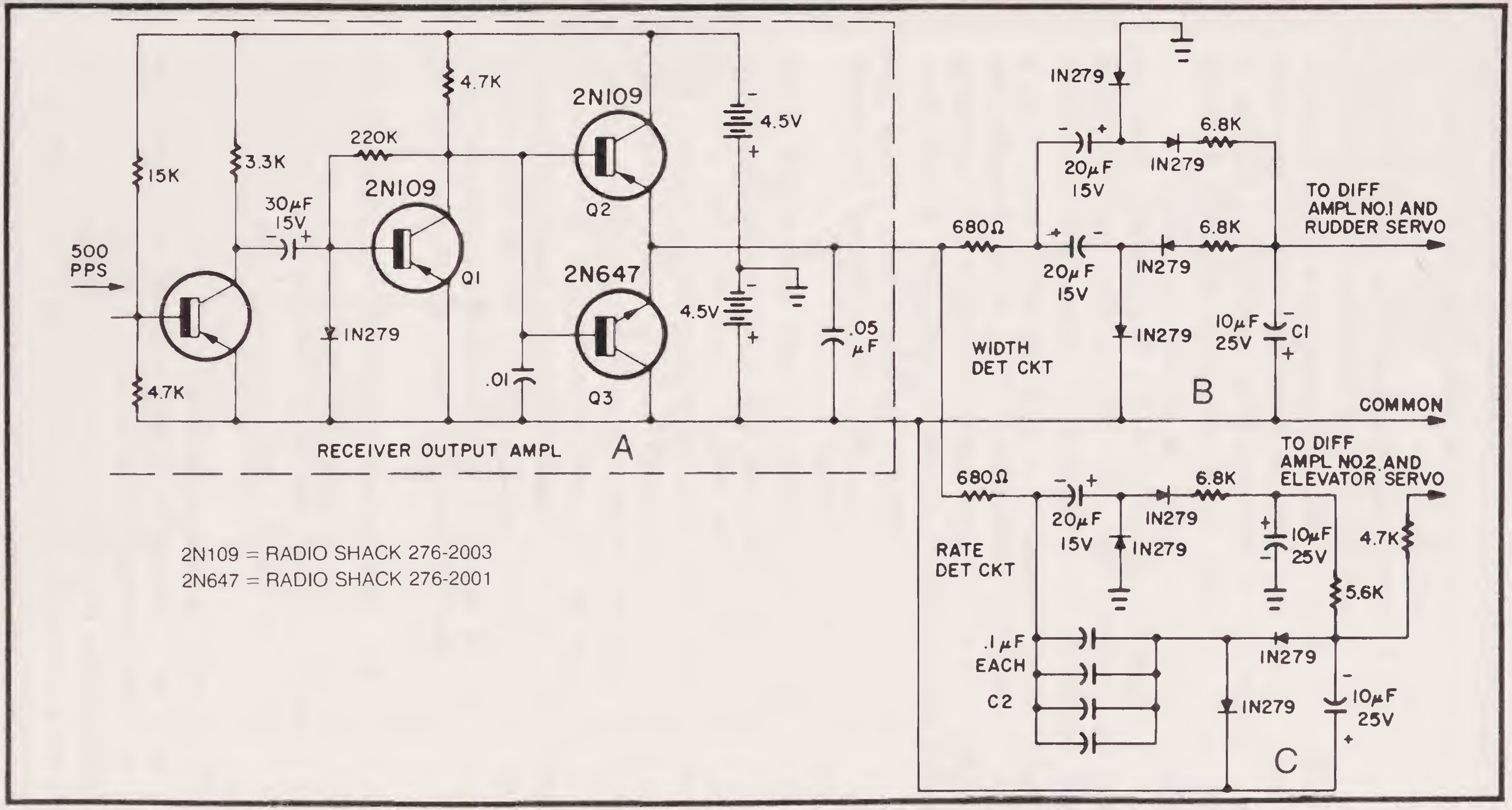


Fig. 1-25. An electronic pulse-width/pulse-rate decoder. The circuit is broken into four sections, part A is normally a part of the receiver, part B and C are the width and frequency decoders, and part D is a typical input to a direct-coupled servoamplifier section showing the feedback potentiometer.

pair of diodes, and another output *proportional to the width of the negative pulse* via the second pair of diodes. The output voltages are plus and minus, correspondingly.

These plus and minus voltages are added together at the detector output so that capacitor C1 has a voltage across it proportional to the *difference* in the pulse-width-pulse-spacing. So the pulse-width-spacing commands have been converted into a DC voltage whose polarity change from a reference level specifies the *direction* of rudder (or elevator) movement, and whose magnitude of change specifies the *amount* of rudder (or elevator) movement.

This voltage by itself cannot operate the *servomotor,* so we use a differential amplifier (Fig. 1-26). This amplifier does two things: First it amplifies the DC voltage from the detector and gives a large DC voltage output capable of running the motor, and second, it receives a *feedback* from the rudder servoarm potentiometer (R). This voltage balances the input voltage when the arm has moved the desired amount, stopping the arm in the commanded position. Note that when the command signal stops, this feedback voltage then becomes the only input to the differential amplifier and thus causes the servoarm to return to neutral.

Section C shows the frequency (or pulse-rate) decoder for this circuit. It is identical to the width-spacing decoder except that the capacitor C2 consists of four 0.1-μF sections to a total of 0.4 μF instead of the 20 μF used in the width-space decoder section. This change makes the circuit frequency-selective. Here, it produces a small output voltage for low-pulse rates, below about 525 pulses per second, and a larger output than its opposite circuit for pulses above this value. Its output is compared to the output of the upper branch. The output of the whole circuit is either a plus or minus voltage depending upon the magnitude and direction of the pulse-*rate* variation from the normal transmitted frequency of 525 pulses per second.

The circuit has been used successfully, but when no signal at all is being received, noise can make the highly sensitive circuits produce an output large enough to drive the servos to their extremes of travel. If this circuit is used, a fail-safe circuit should be built in as before.

The on-the-ground portion of this system is shown in Fig. 1-27.

The circuit consists of a blocking-oscillator pulse-generating circuit with a frequency-control potentiometer. This circuit activates an amplifier with a variable time constant, so that the width of the pulses can be varied. The output of the circuit connects directly to the modulator of a transmitter. Notice the trim adjustments, used to

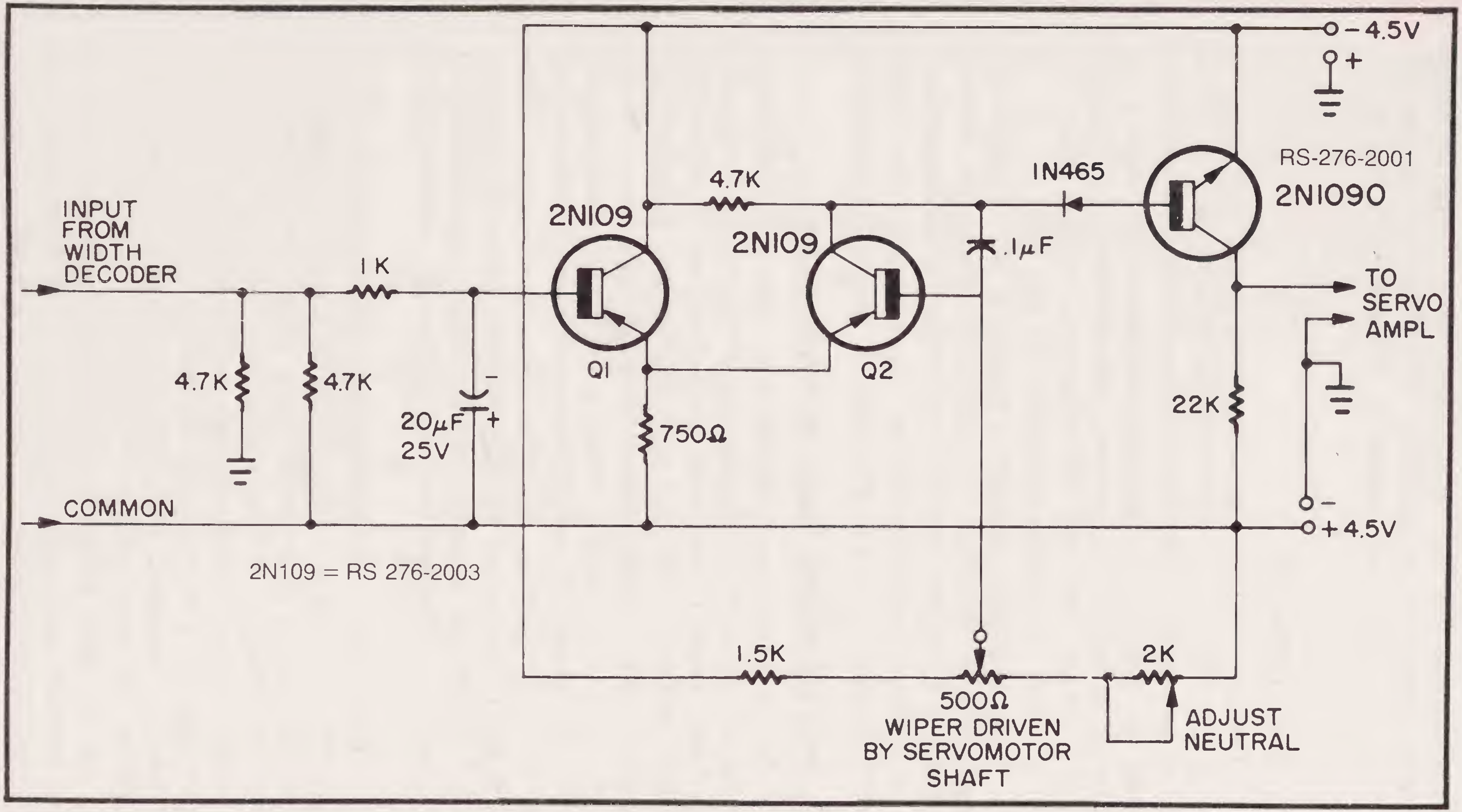


Fig. 1-26. Differential servoamplifier. Note that Q2's input is the voltage from the feedback pot (R).

keep the control stick (a lever attached to the shaft of the frequency control) centered for straight flying. These trim pots can compensate for drift pulse rates caused by changes in the transistors' conduction.

THE SERVO AMPLIFIER

The servo amplifier that would be used with the preceeding circuits would be a direct connected type such as a Darlington or an operational amplifier, available as an integrated circuit in most parts stores. It might also be a comparison amplifier, which compares the input to the feedback signal from a potentiometer. This amplifier then would drive PNP and NPN transistors, which in driving the motor causes it to reverse directions. See Fig. 1-28.

If the operational amplifier is capable of both a positive and negative output, then these two outputs specify direction of motor rotation by energizing the proper transistors. We will discuss more about servo systems a little later on. You might adapt one of these servo-amplifier systems to work with the circuits just presented.

MULTIPLE CONTINUOUS TONES AND FILTER SYSTEMS

You can transmit more than one tone. Two, four or even eight tones may be transmitted separately or simultaneously. In this case each tone represents a command. These tones may be generated by simple oscillator circuits and combined (through resistance networks to minimize interaction) as shown in Fig. 1-29.

The output of the tone section is fed to the transmitter modulator (see modulation methods for transistor transmitters in Chapter 2). In the receiver, the tones are fed to a series of filters composed of inductances, which separate the tones and cause different relays to close, or transistors to conduct as each different tone is received. Thus one tone is left, a second is right, a third tone is up, etc.

The closing of the *relay* (or conduction in the transistor) when a tone is received causes a servomotor to deflect a control surface to its limit if the tone is sent continuously. Thus one has to beep the tone (by tapping the button rapidly several times) to get gradual steering. Self-neutralizing servos are used for rudder, nonneutralizing or neutralizing servos are used for elevator. Figure 1-30 shows a circuit for a two-tone LC filter decoder operating two relays, which could give left-right steering.

The LC-filter type of decoder has fallen in popularity over the past several years because these filters are quite broad in response compared to other decoders. If one considers sending six tones for

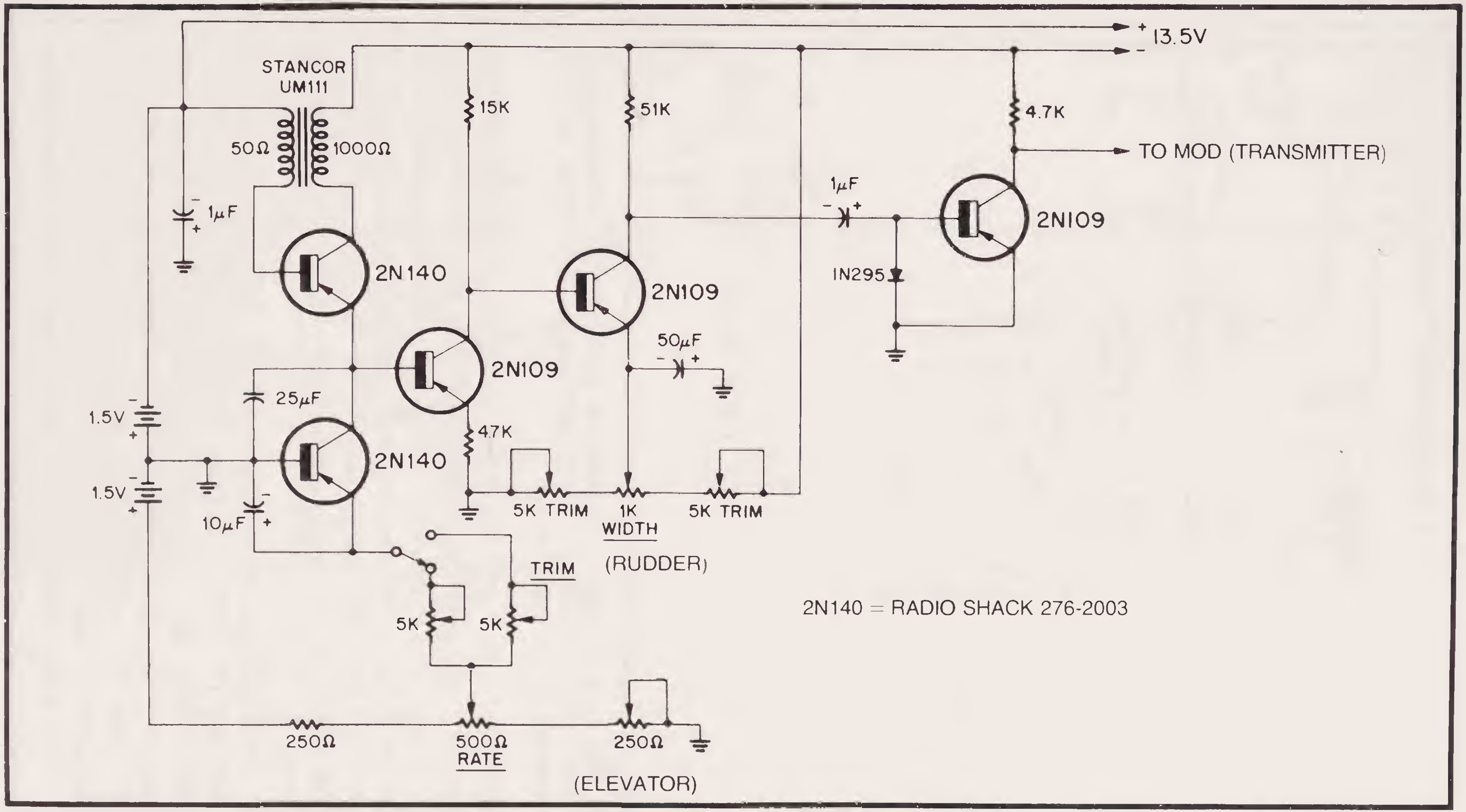


Fig. 1-27. A rate-width pulser for the electronic pulse-rate-width decoding circuit.

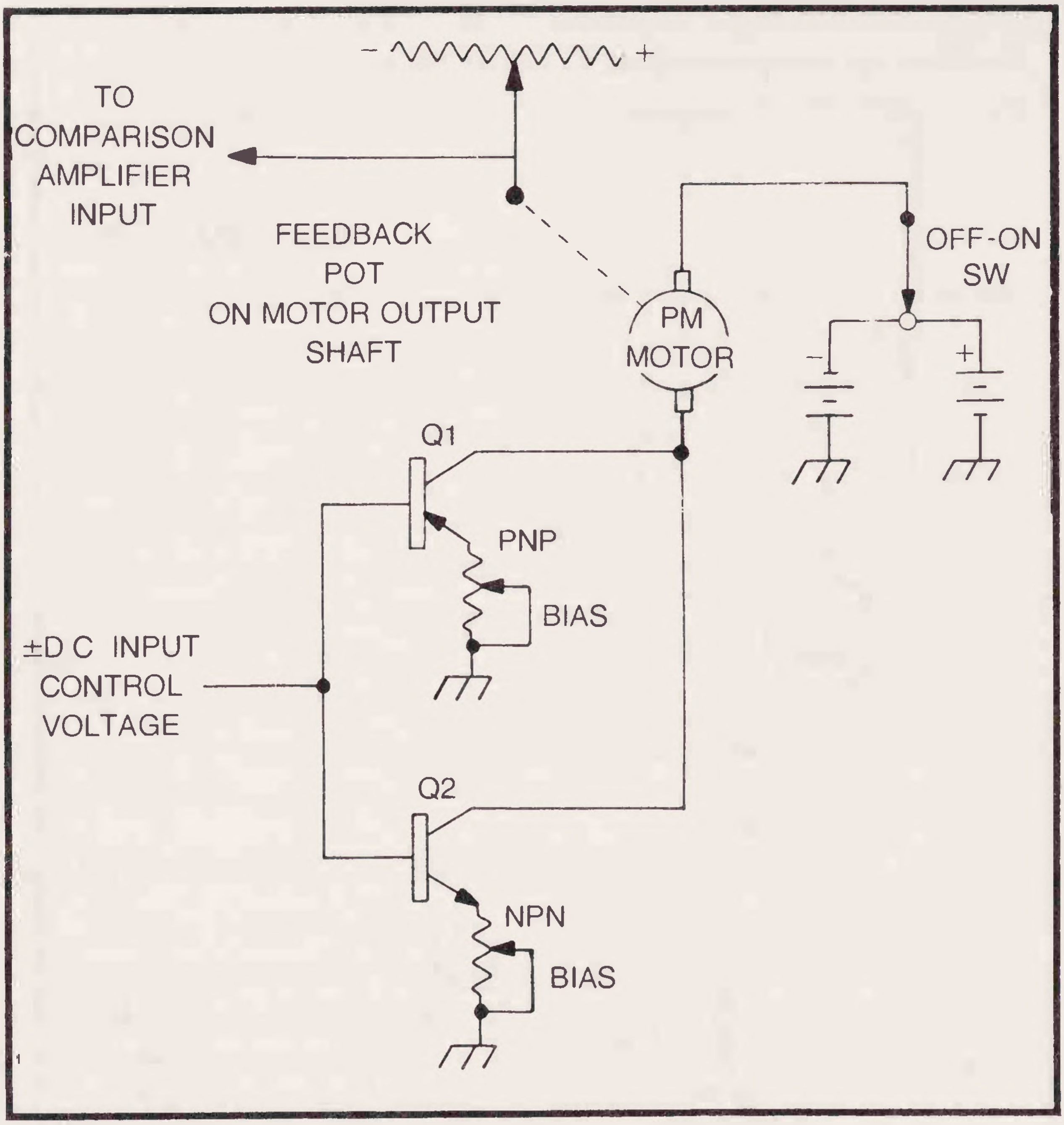


Fig. 1-28. A possible direct drive amplifier for a PM motor. Q1 and Q2 are biased so motor will not run unless a + or – signal is presented to bases, you must experiment with this kind of circuit.

commands of up, down, left, right, motor fast and motor slow, the frequency band required would probably be from 300 Hz to about 6,000 Hz—tones at 300, 550, 1,000, 1,400, 2,500 and 6,000 Hz. It is possible to narrow this tone separation by incorporating more elaborate filters than the ones shown. So the use of tone filters for all commands is not too popular—now. However, this is a very reliable system.

One variation of this idea *is* interesting. That is to use, say, two tones and two filters and pulse each tone with the pulse-width pulse-spacing idea. Thus you get proportional control over four functions. These functions could be the rudder, elevator, ailerons and motor of a model aircraft. You might even control all four simultaneously with this idea.

Two tones allow adequate band separation with simple filters (as in Fig. 1-30) so that no interference or beat problem occurs

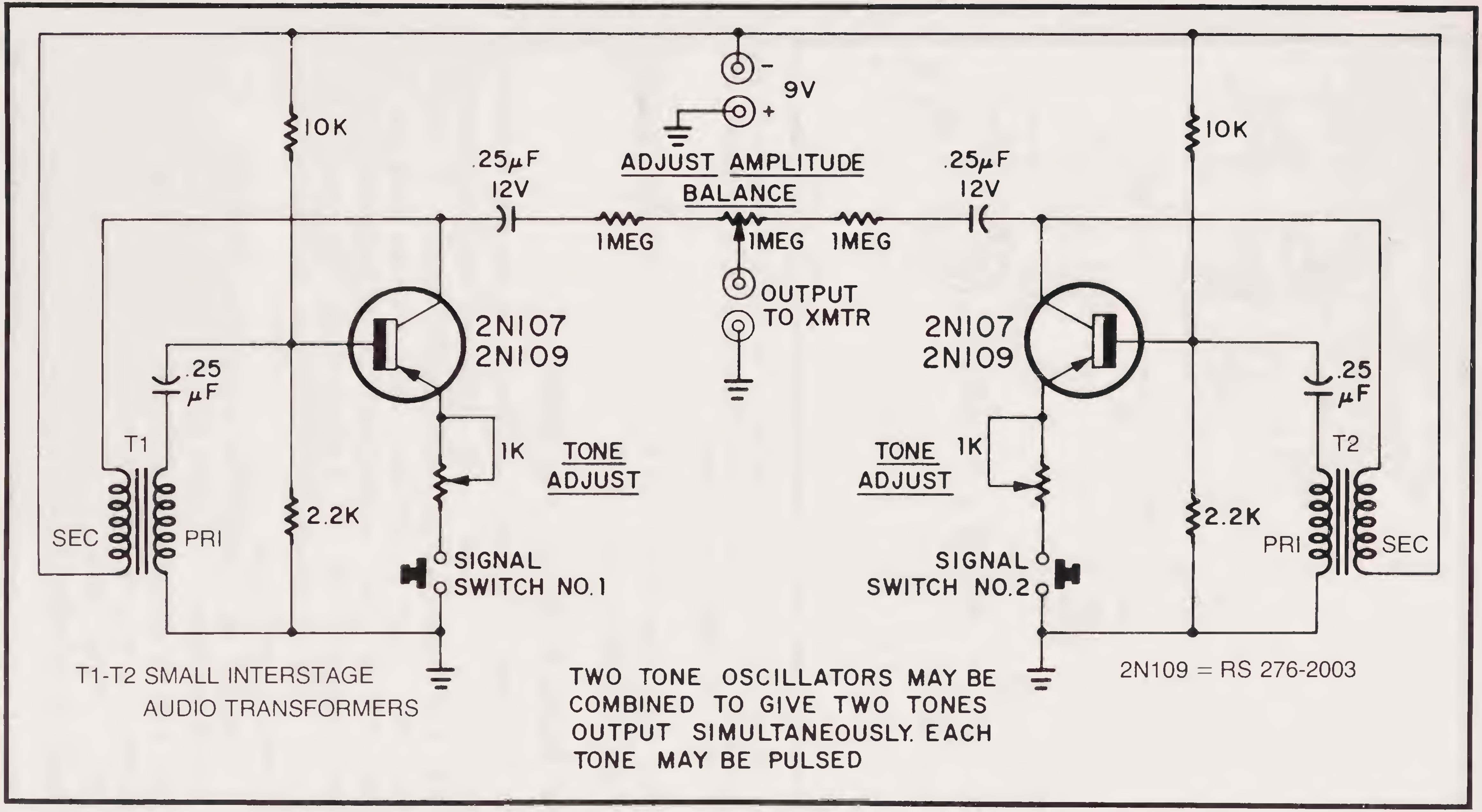


Fig. 1-29. Two tone oscillators combined for either separate or simultaneous transmission.

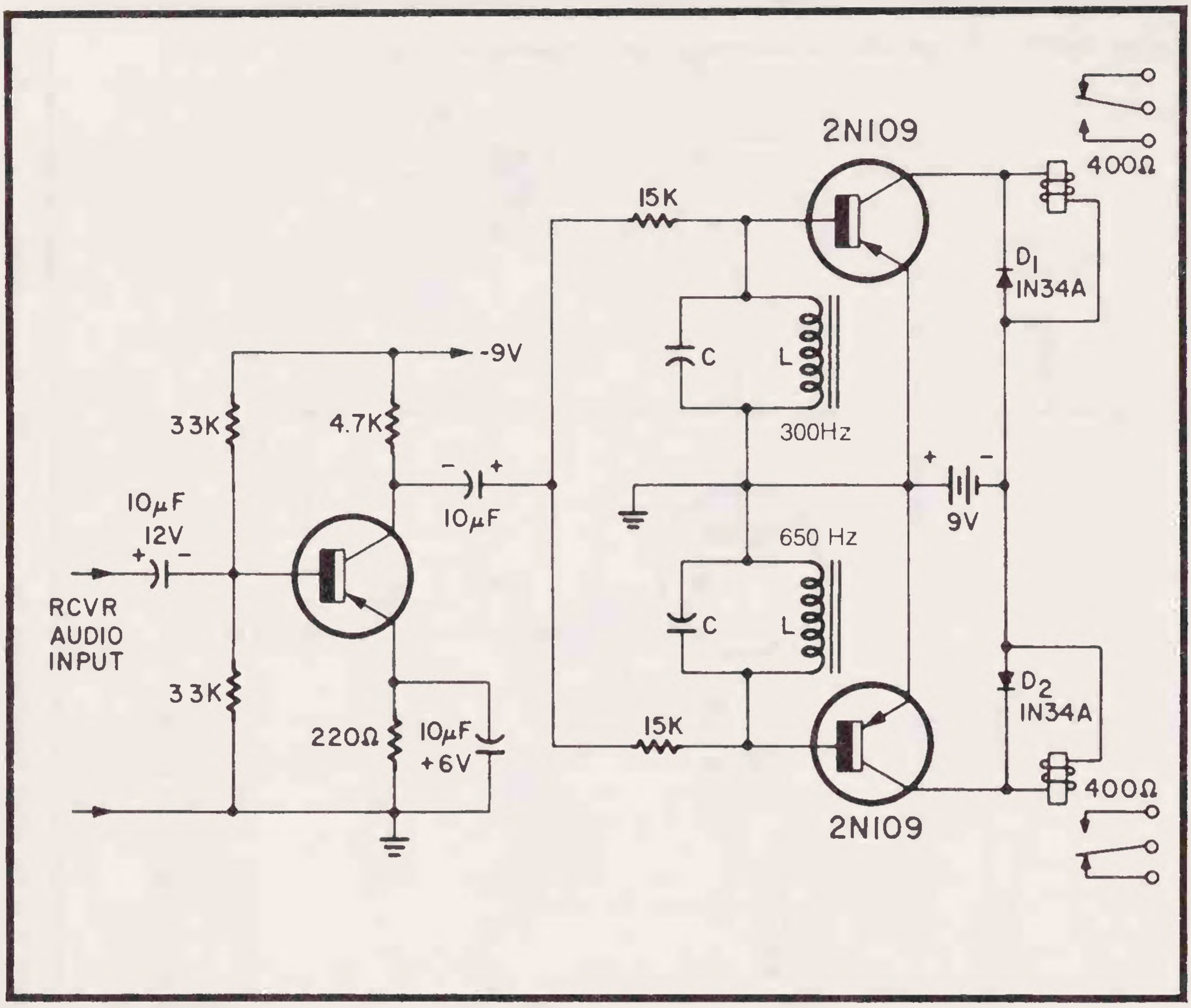


Fig. 1-30. A typical L-C filter decoder circuit for two tones. The inductances should have a low DC resistance. More filters can be used for more channels. L and C tune to the desired tone frequency.

between the tones. A beat, recall, is the sum or difference between two tones or their harmonics.

THE INTEGRATED-CIRCUIT TONE FILTER

A method of providing tone filters using integrated circuits is one possibility to update of this method of sending commands. Figure 1-31 shows active filters designed around the 741 amplifier which "passes" around 1400 and 850 Hertz and not much else. The values of R and C_1 and C_2 determine the bandpass and might be adjusted experimentally for other frequencies. The units overall are small and adaptable to modern control devices. One filter is required for each tone command.

A possible relay amplifier is shown at (c).

With the modern integrated circuits you will find that an examination of them will reveal possibly other methods of making small, compact, and very effective tone filters, which you might use as decoders for tone-control operations such as the 567IC. We encourage such examinations and research.

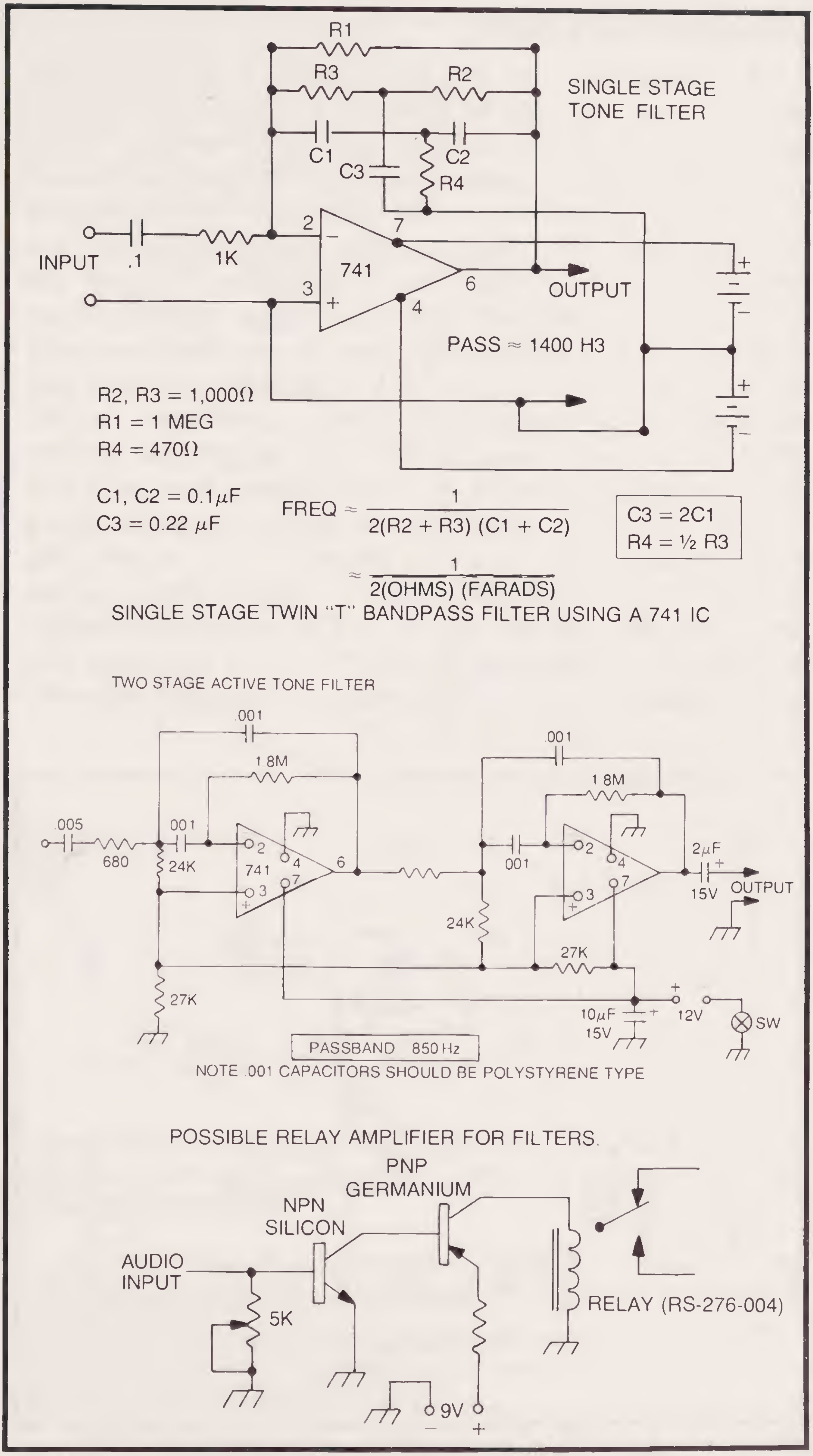


Fig. 1-31. Active IC tone filters.

THE RESONANT-REED FILTER

In a harmonica many tiny reeds vibrate to produce various notes. The same idea can be applied to a vibrating reed decoder using a magnetic coil, like that of an earphone, to furnish a varying magnetic field to vibrate a spring steel (very thin and relatively short) reeds. If contacts are placed so that when these reeds vibrate they touch the contact at the extreme of their vibrating movement, you have the basics for a reed decoder. These used to be popular and were available commercially. They are no longer available and are considered obsolete as a decoding method because they have a very narrow bandpass—on the order of 3 to 4Hz; they also make only intermittent contact on each vibration are somewhat heavy, and the audio band is not large enough for wide ranges of operation. But they are interesting, and so we include mention of them. If one made such a decoder and used it to supply control voltage to a transistor bank, a lot of previous troubles would be eliminated, and certainly, this device would give good, tight tone separation. It used to be that tones of 200, 250, 300, 350, etc. Hz could be used without interference, except from harmonics or beats. We show a circuit used with such a decoder in Fig. 1-32. You might use this circuit with other switching devices, replacing the reeds.

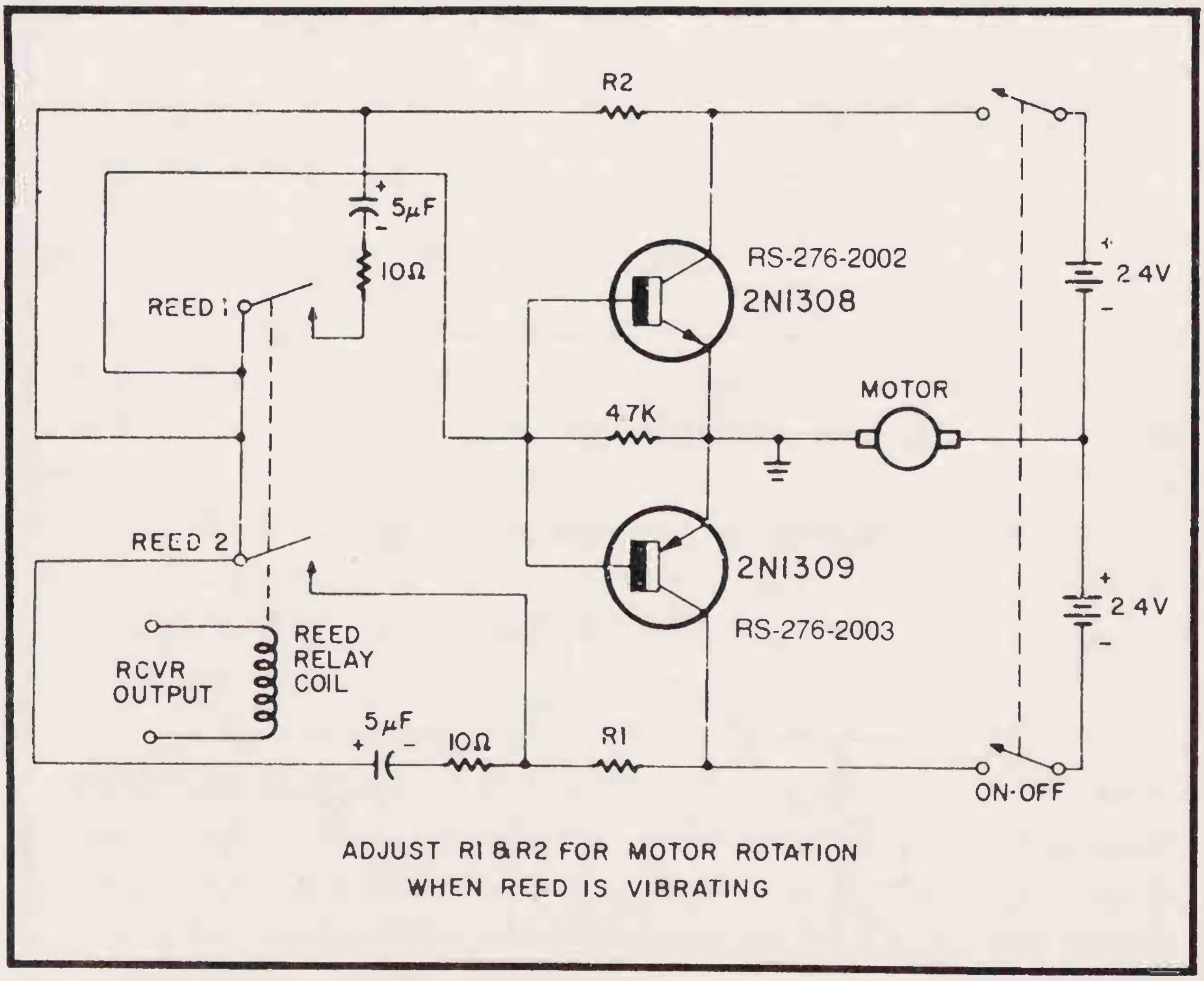


Fig. 1-32. Basic reed-operated servo system. Close 1 for clockwise rotation with tone 1, close 2 for counterclockwise rotation with tone 2.

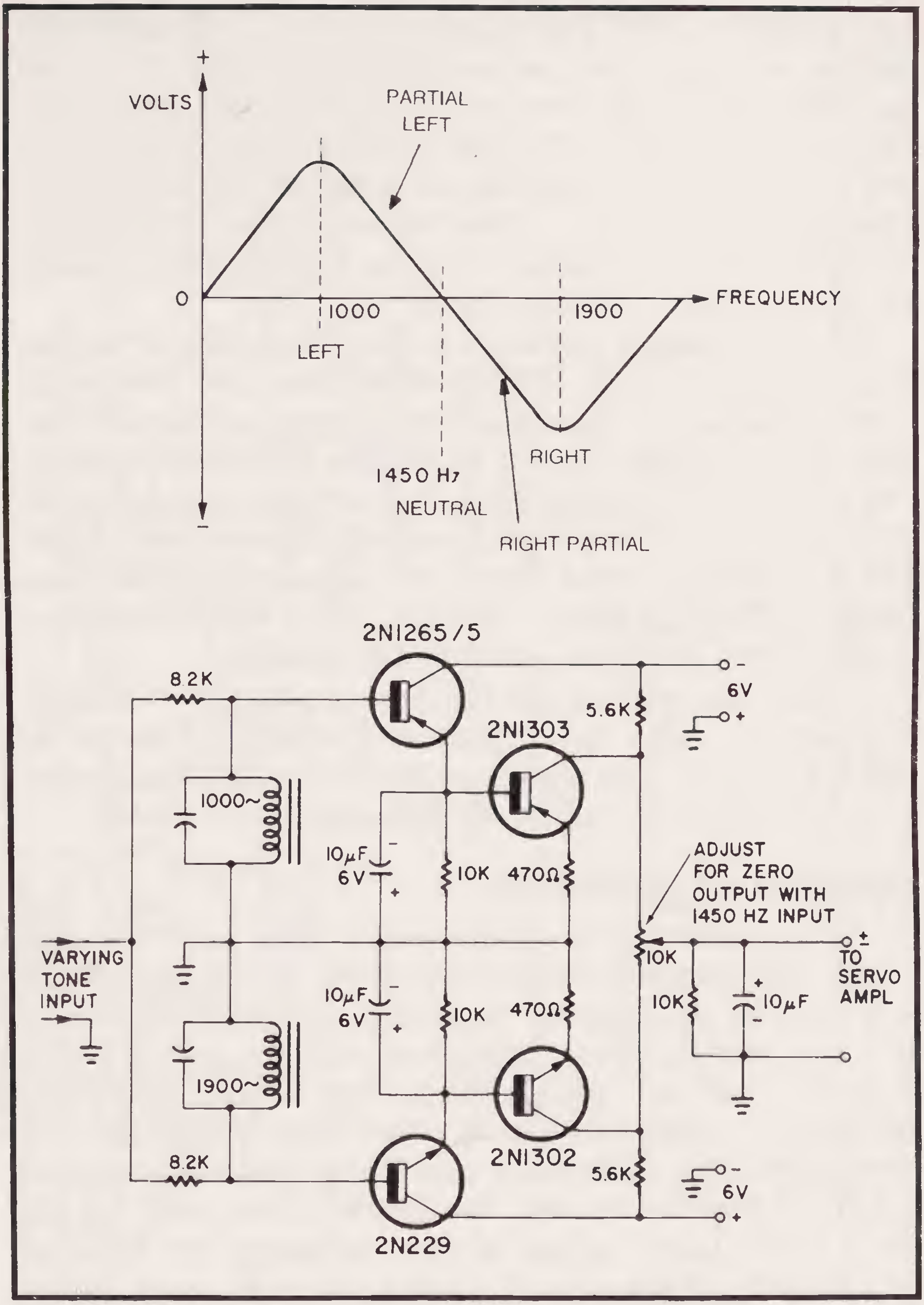


Fig. 1-33. A typical tone discriminator circuit. Other tone separation filters may precede the discriminator.

Or, you might adapt the transistor motor-control part of this circuit to operate as the servo amplifier of Fig. 1-28. It would be worth the experimentation to see what you could come up with.

VARYING-TONE COMMAND SYSTEM

As another approach to control, we might change the frequency of a tone above and below some neutral frequency, as in the pulse-rate system, to obtain proportional control. This is done with *discriminator circuits*, which can be built from the filter circuits just described. Since the filter response is relatively broad, you can vary the tone slightly around the filter resonance and still have good output. This output can be made positive or negative or zero depending upon whether the tone is above, below or on the filter frequency. A possible discriminator circuit is shown in Fig. 1-33. It is essentially a balanced bridge.

The simultaneous transmission of two tones quite far apart in frequency, each capable of being varied above and below some "rest" frequency, can give proportional steering and elevator control. Three such tones would be required for proportional control of rudder, elevator and motor. Normally in a system such as this the motor would be an on-off type function for high-low motor rather than proportional control. Thus two changing-frequency tones would be used for steering and elevator, and the third set as a pulse would produce fast motor or slow motor cyclically.

Of course it might be possible to use a single-tuned circuit or equivalent, and use a slope detector to give control. With this the neutral is when the tone is halfway to the peak of the resonant rise. Lower tone gives one control and higher tone gives another.

TONE-SEQUENCE TRANSMISSION

One problem with the transmission of tones is that beats are produced between them when more than one tone is transmitted at a time. A second problem is that the maximum available modulation of the transmitter must be divided among the tones; thus no tone is transmitted with full 100% modulation. That reduces reliability. In the Sampey system (courtesy of Grid-Leaks) this difficulty was overcome by using an electronic commutator to allow the transmission of each tone one at a time, but sampled at such a rate that the model doesn't know that the tones are interrupted. The control is essentially simultaneous for all channels, yet each tone modulates the carrier 100%. Four tones are sampled and sent by this method in the system shown in Fig. 1-34.

The receiver would have four relays, say, each one operated by a different tone. You could use integrated circuit filters to separate the tones in this case. Then you could have one tone for left, one for right, one for up, and one for down in a very reliable control operation. Since all tones are pulsed at a very fast rate, you would get the effect of simultaneous-proportional control over these functions, all at the same time.

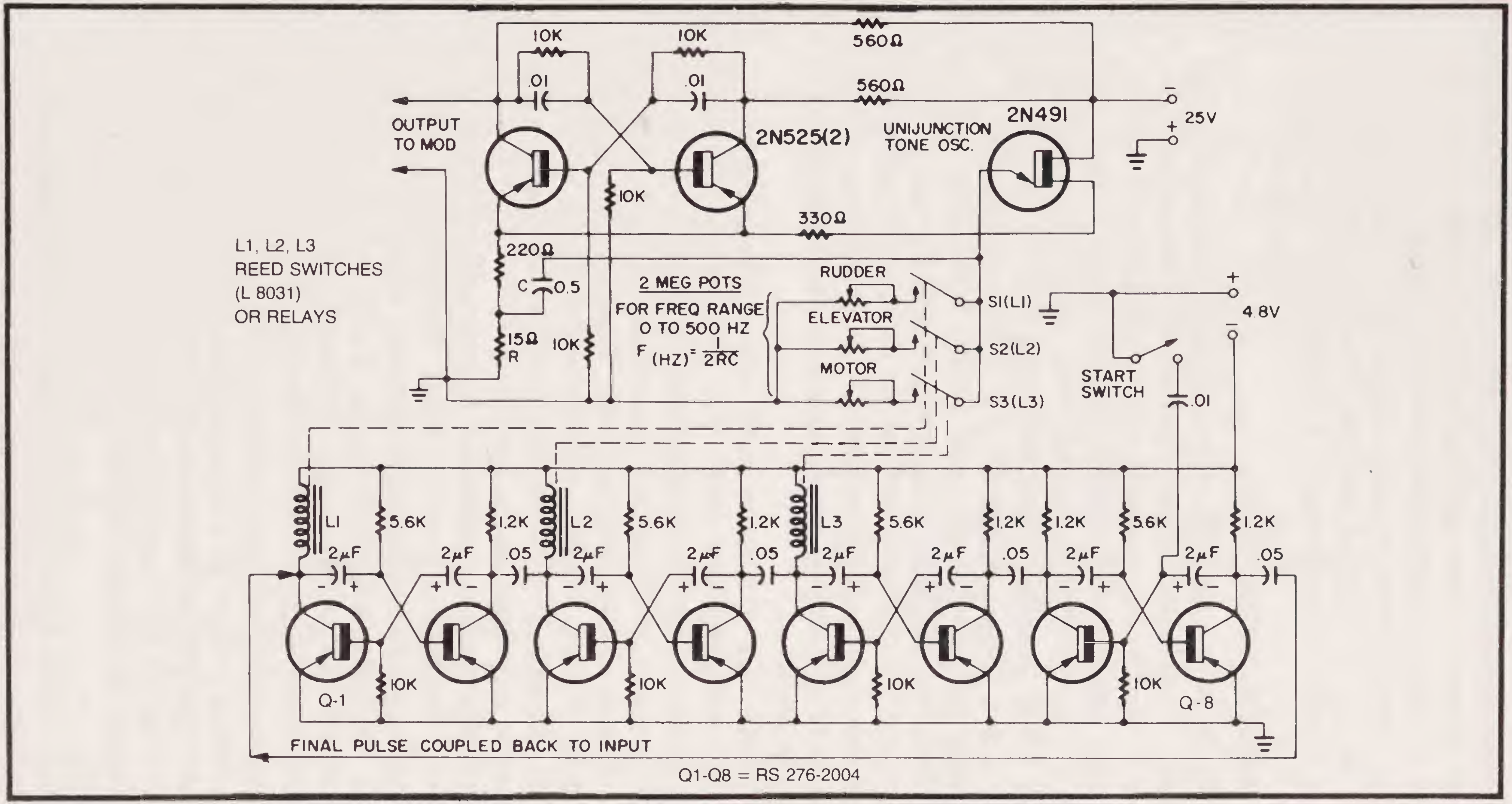


Fig. 1-34. In sequence, the ring commutator selects the tone-circuit elements required for each tone. The operator can vary each tone with a control lever. The receiver would use tone filters. Reed relays are often advertised in radio magazines.

In the ring commutator, flip-flop multivibrators are coupled so that one triggers the next and the last triggers the first. As each operates, it causes a reedswitch in one collector of each pair to close, causing a tone of a certain frequency (generated by the unijunction) to be transmitted. Note that this type of reed relay closes on DC. Arc suppression of relay contracts is required. See Fig. 1-35.

HOW A DIGITAL SYSTEM WORKS

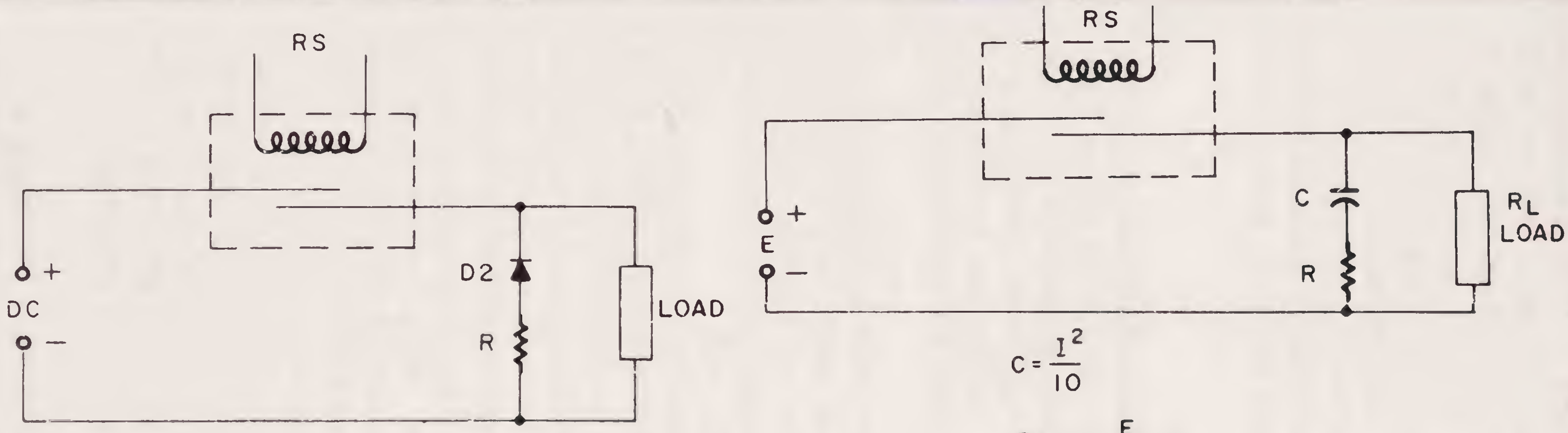
Modern radio-control systems are digital. Many brands are on the market, in both completed and kit form. Heathkit, for example, offers a good kit for the somewhat experienced electronics builder. But others include Kraft, Logictrol, Expert, Futaba, Cannon, and Ace R/C; they are all good systems which will give excellent performance in simultaneous and proportional control over as many as eight channels. Some systems will even have more channels.

These systems all use small servos which have built-in integrated-circuit amplifiers of the feedback type. The size of these servos varies from the very small bantam to the larger and huskier types required for big aircraft and boats. You can usually specify the size servo that you want. It is customary to use the smallest possible size for airplanes.

Because they all operate on the same basic principle, the variation of radio-frequency pulses, there is *some* interchangeability among systems of the various manufacturers. Ace R/C, for example, makes a servo which works with quite a number of systems and has an adapter to change from a positive pulse input to a negative pulse input. But you must be careful trying your servos with other systems. Be sure they are compatible before you connect parts together, or you might ruin the system.

Digital systems are available in from two to eight channels, and some even have more channels than that. Each channel is proportional, and although they operate sequentially, they do so at such a fast rate, due to the millisecond duration of pulse transmission, that you can operate all eight channels of an eight-channel system. As far as practical, movements all operate simultaneously. Thus you can vary engine speed, elevator position, and rudder position of an airplane model in flight, all at the same time. It's the real thing all right, and wonderful experience to boot for that person who always wanted to fly, but didn't get the chance to do so. And there are no crash dangers for the pilot. This has great appeal to the lady folk of the family.

Now, to fully understand digital systems, we will first look at one which has only four channels. This will give us the basics for



$$C = \frac{I^2}{10}$$

$$R = \frac{E}{10\left(1 + \frac{50}{E}\right)}$$

DIODE AND RESISTOR

RS - MAGNETIC REED RELAY OR STANDARD RELAY

D2 - GENERAL-PURPOSE DIODE (IN456)

R - RESISTOR (10 TO 100 OHMS)

RESISTOR AND CAPACITOR

RS - MAGNETIC REED RELAY OR STANDARD RELAY

C - CAPACITOR

R - RESISTOR

I - CURRENT IN LOAD = E/R_L

WHEN SPDT REED RELAY IS USED, BOTH NORMALLY CLOSED AND NORMALLY OPEN CONTACTS MUST BE PROTECTED.

Fig. 1-35. Arc suppression with relays.

examination of a later, up-to-date system following this first discussion. The four-channel system was developed some years ago, but it is still valid, still will work, and its "truths" are still "self-evident" if you want to try to build one from "scratch," We find that many electronics experts like this challenge, but for those not quite so expert we advise getting a good kit, where all parts are furnished, test procedures are specified, and you can be assured of a satisfactory product. Kits, of course, are more economical than the finished product, and you usually have factory assistance and service if desired.

SOME DIGITAL CONCEPTS

Probably the first concept to understand is that the digit of the digital system—the name means the same thing as in a digital computer—is simply a pulse such as we have already explained. The difference in this system is that these pulses are transmitted at a very rapid rate—milliseconds apart—and are just a carrier signal from a transmitter. Idea number one, then: The digit is a pulse and it is also called a bit.[1]

The pulses are transmitted in trains—that is, there is a series of pulses, then a time space and then the same series or number of pulses. This process continues and so one transmits information constantly in this type system. These trains of pulse are often called words in digital-control language (Fig. 1-36).

The time space between the words is used to allow the decoding equipment in the model to synchronize itself so that it can transfer the commands represented by the pulses to their proper channels. Note that each pulse is a command channel. In the receiver these pulses are separated, sent to four separate channels where their width is compared to a reference pulse generated or present in each of the four channels (Fig. 1-37). If the incoming pulse is longer than the reference pulse, a negative voltage is produced at the comparison-circuit output. If the incoming pulse is shorter than the reference pulse, the comparison channel output is positive. When the pulses are equal, the voltage output is zero. Understand here that the *amount* of the voltage out of the comparison circuit is exactly proportional to the difference in width, or time duration, of the pulses, so that as we vary the width of the incoming pulse we can get a proportional DC output of either polarity. This voltage can be amplified and used to position a servomotor left or right for proportional steering.

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[1] In computer terms a series of bits make up a digit and a series of digits make up a word. I am taking some liberty in definitions here to simplify the explanation of digital radio control.

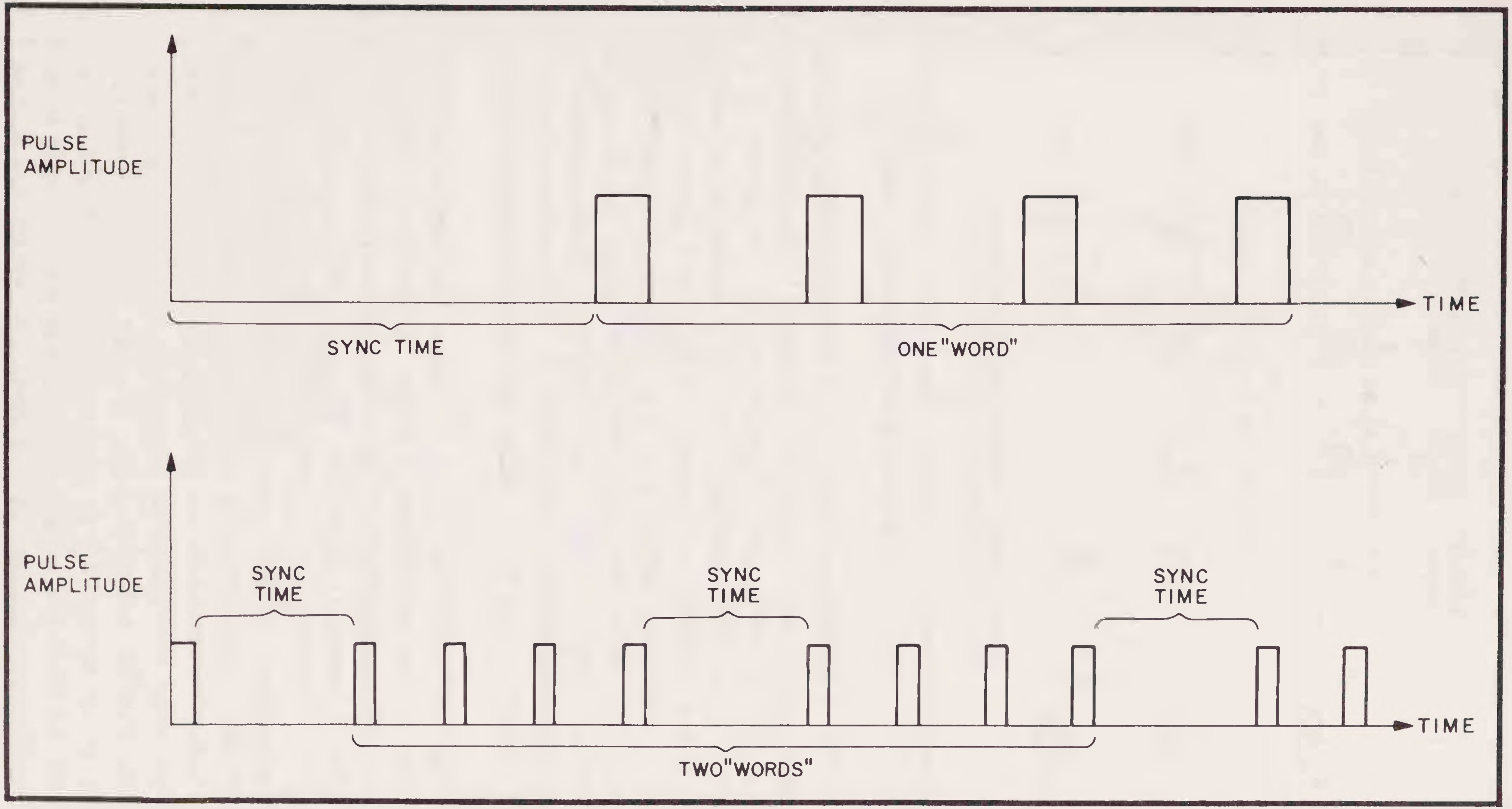


Fig. 1-36. The time-transmission concept of a digital word. Note the time space between words. Each word here consists of four bits, or four command channels.

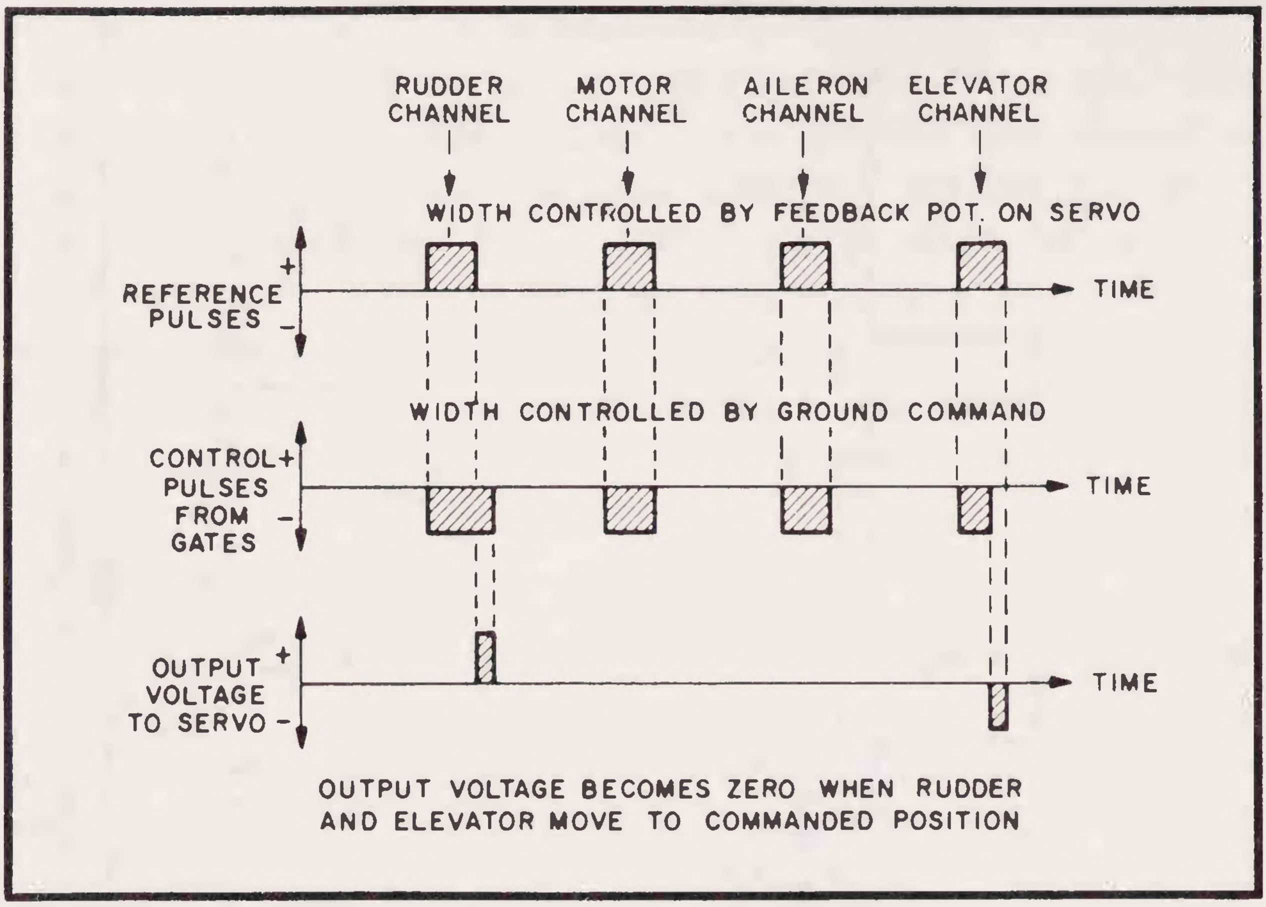


Fig. 1-37. Comparison between the reference and command pulses.

In Fig. 1-37 the basic operation of the pulse-driven servo is explained as far as the comparison of the pulses is concerned. Since we must have a continuous voltage to drive the servomotor, it is necessary to "stretch" these pulses with an averaging circuit, which is a one-shot multivibrator. Figure 1-38 is a block diagram of the system. You also must note that since the difference in pulses can be very small, the circuit may find it difficult to "decide" which way to start the servomotor running. There is therefore a cross-connection between the two channels so that whichever channel starts conducting first effectively blocks the other one until the command signal changes.

Figure 1-39 shows the circuit that allows the pulse differences to be used as servomotor drive voltages. The incoming pulses are sent to a one-shot multivibrator Q1 and Q2 and also to the reference multivibrator formed by Q3 and Q4. The width of the pulse from the reference multivibrator is governed by the position of the servomotor-driven feedback potentiometer Rx. Note that the pulses from the first multivibrator Q1 and Q2 are compared to the pulses from the feedback multivibrator (or reference multivibrator) Q3 and Q4 in the diodes D3 through D6. Essentially, if the incoming pulse is narrower than the reference pulse, one pair of diodes allows one channel to the servomotor to conduct, producing rotation in one direction. As the motor rotates, it repositions potentiometer Rx so that the difference in pulse widths is made zero and the motor stops

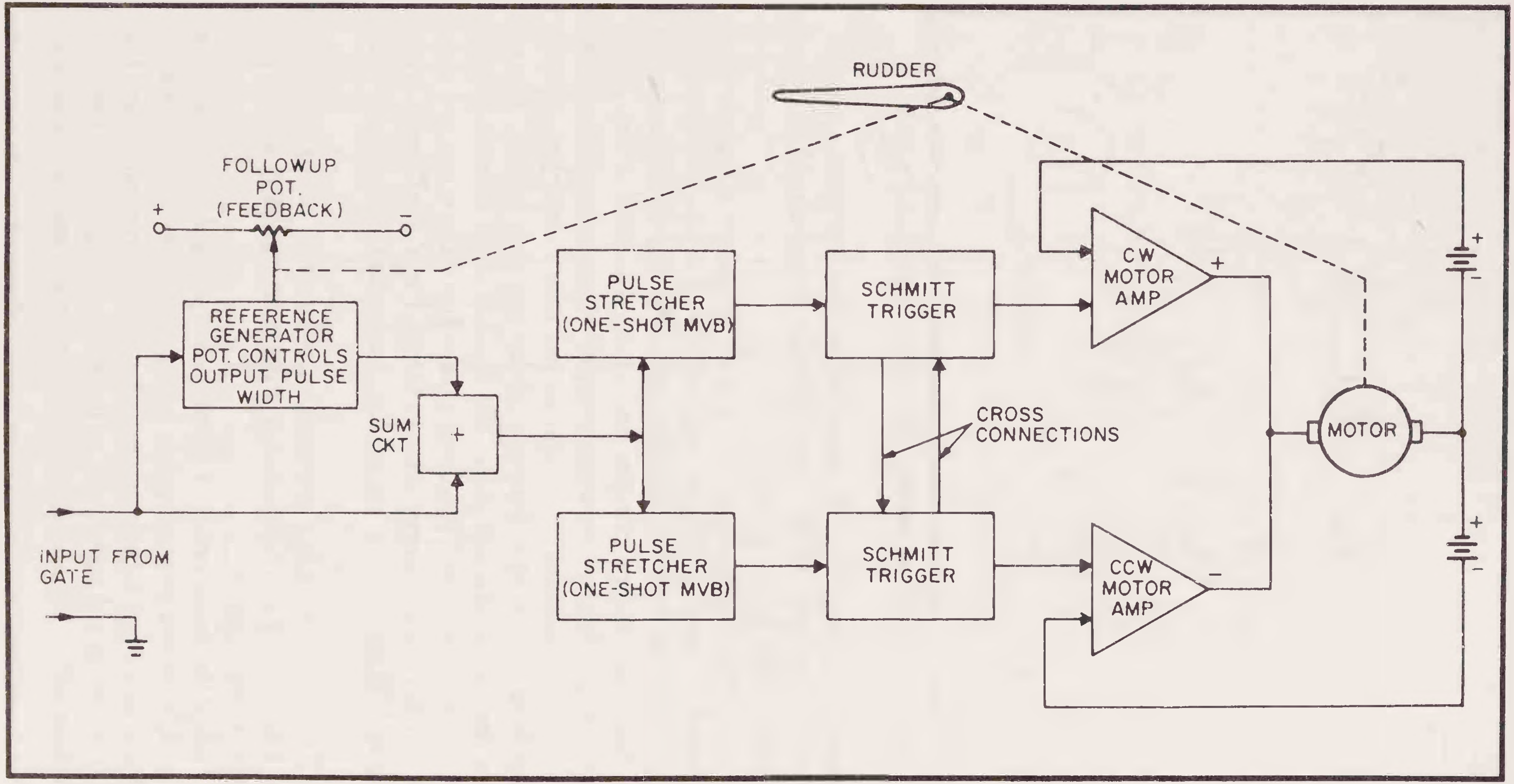


Fig. 1-38. Block diagram of a pulse-driven proportional-servo system used with a digital radio-control system.

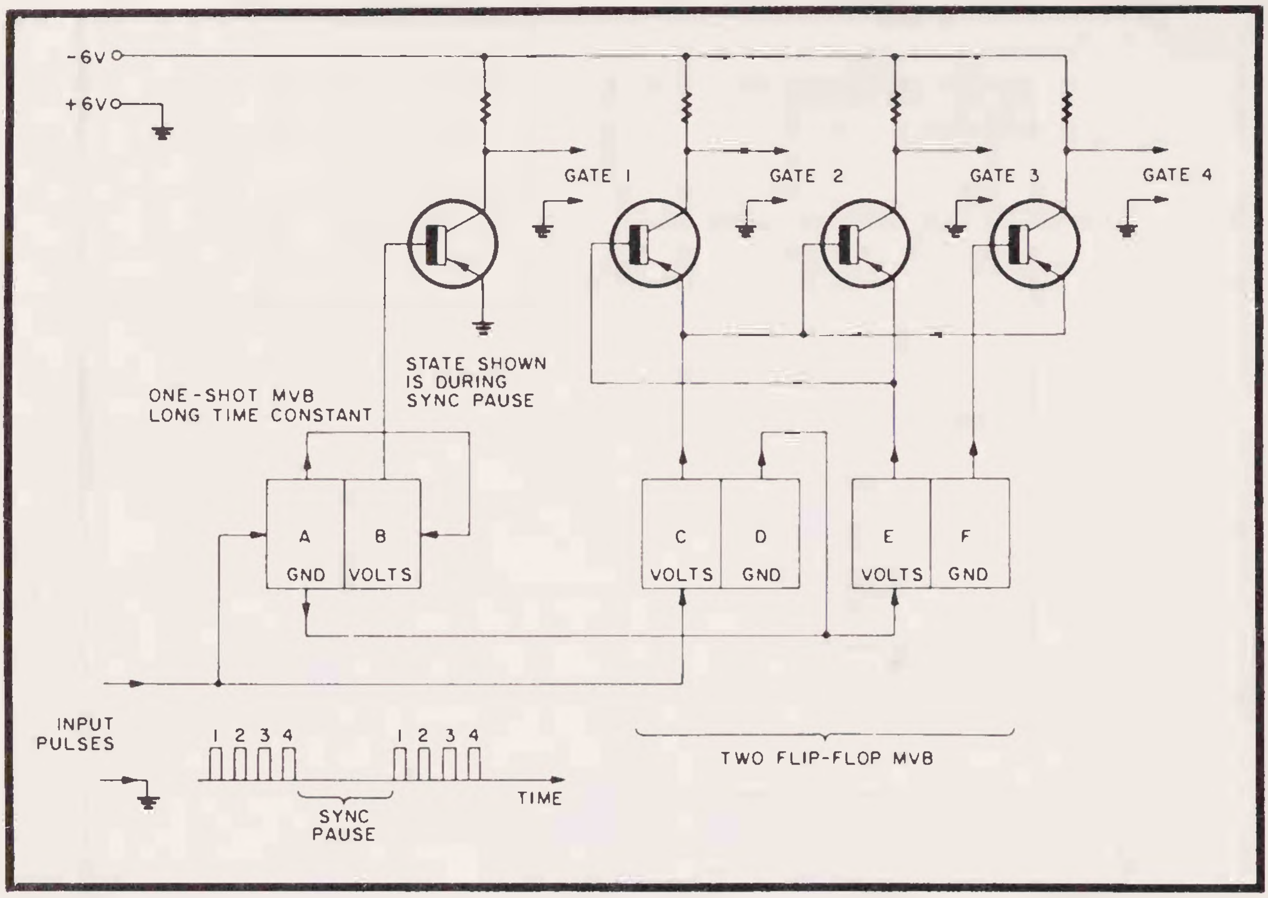


Fig. 1-39. Schematic of the servo decoder for the digital-pulse system.

running. If the pulses coming in are wider than the reference pulse, the motor is caused to run in the opposite direction until Rx causes the pulse width to be the same.

Now examine Fig. 1-40 to see how the pulses that come from the command transmitter are separated in the receiver decoder.

The decoder consists of one-shot and flip-flop multivibrators. A one-shot multivibrator changes the conductive state of two cross-connected transistors only when an input trigger causes the change. The time the transistors remain in the new conductive state is determined by the time constant of the one-shot circuit. Then it drops back to its original state. The flip-flop multivibrator changes state of conduction upon receiving a pulse and stays in the new state until another pulse changes it back. In other words it "flips" on one pulse and "flops" back to its original conduction state on the next, etc.

The one other circuit required is a *coincidence* circuit—a transistor which must have two voltages of the proper polarity applied to it before it will conduct.

When the three types of circuits are arranged as shown in the block diagram and an input pulse train is received, the decoder will produce an output from each gate for each command pulse. The width of the gated pulse will be in direct proportion to the time spacing between the command pulses, as we will see just a little later on.

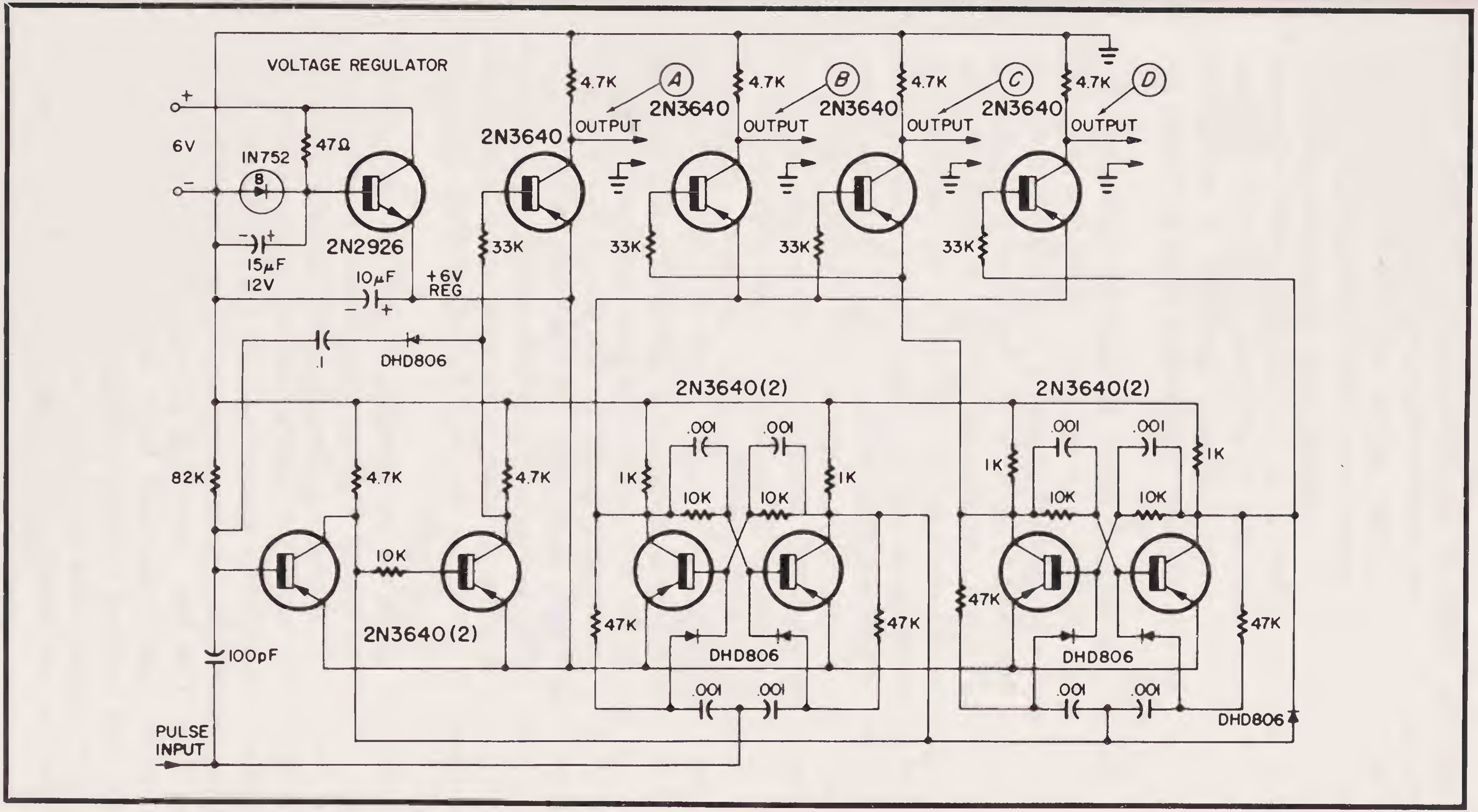


Fig. 1-40. A digital-receiver pulse decoder.

Now, to examine the operation of the block diagram, assume that the decoder is in the condition shown on the diagram. Where we have indicated GND, it means that this side of the multivibrator is conducting heavily and where we say VOLTS we mean that that side of the multivibrator is not conducting, so its collector has a relatively high voltage. The condition shown on the diagram prevails whenever the synchronizing-space time is transmitted, so we call it the sync condition. This is the period between pulse trains or words. The circuit assumes this condition automatically when it receives no pulses for a set period of time.

Now refer to the table below the diagram, which shows the change in output for each pulse received. On the first pulse the one-shot changes its state and remains in its new state throughout the duration of the rest of the word. The first pulse also triggers C and D into the state shown for pulse No. 1, but E and F remain unchanged. Gate 1 is now activated, with the proper voltage applied to its base and emitter to make it conduct. Pulse 2 now arrives. It changes the state of C and D and also the state of E and F so that gate 2 is now activated in the same manner as gate 1. No other gates have the correct voltage at their bases and emitters to make them conduct. Pulse 3 arrives, produces condition 3 and activates gate 3. Pulse 4, the final pulse, closes all the gates, and then the synchronizing time (no pulse reception) begins. Shortly after this time begins, the R/C time-constant of the one-shot multivibrator runs down its charge so that the one-shot returns to its initial condition. This opens gate 4. Now the circuit is ready for the reception of the first command pulse, which closes gate 4 and opens gate 1 as discussed. The actual circuit for performing this operation is shown in Fig. 1-41.

We note then that the width of the pulse out of each gate is proportional to the spacing between the pulses in the command train, as shown in Fig. 1-42.

The other part of this system which we need to examine briefly is the coder on the ground. This unit must generate the pulses and vary them so that we obtain proportional control over the channels we desire. First, though, the actual transmitter and receiver can be the same for nearly every type radio-control system. You can use a regular transmitter as long as it is capable of being pulsed at the rapid rate required for this system, and you should use a superhet to receive the pulses in the model. These two items of equipment are pretty much standard. All that is necessary to transmit digital information is to be sure that the transmitter can send the pulses at the required rate and that the receiver will not distort them seriously.

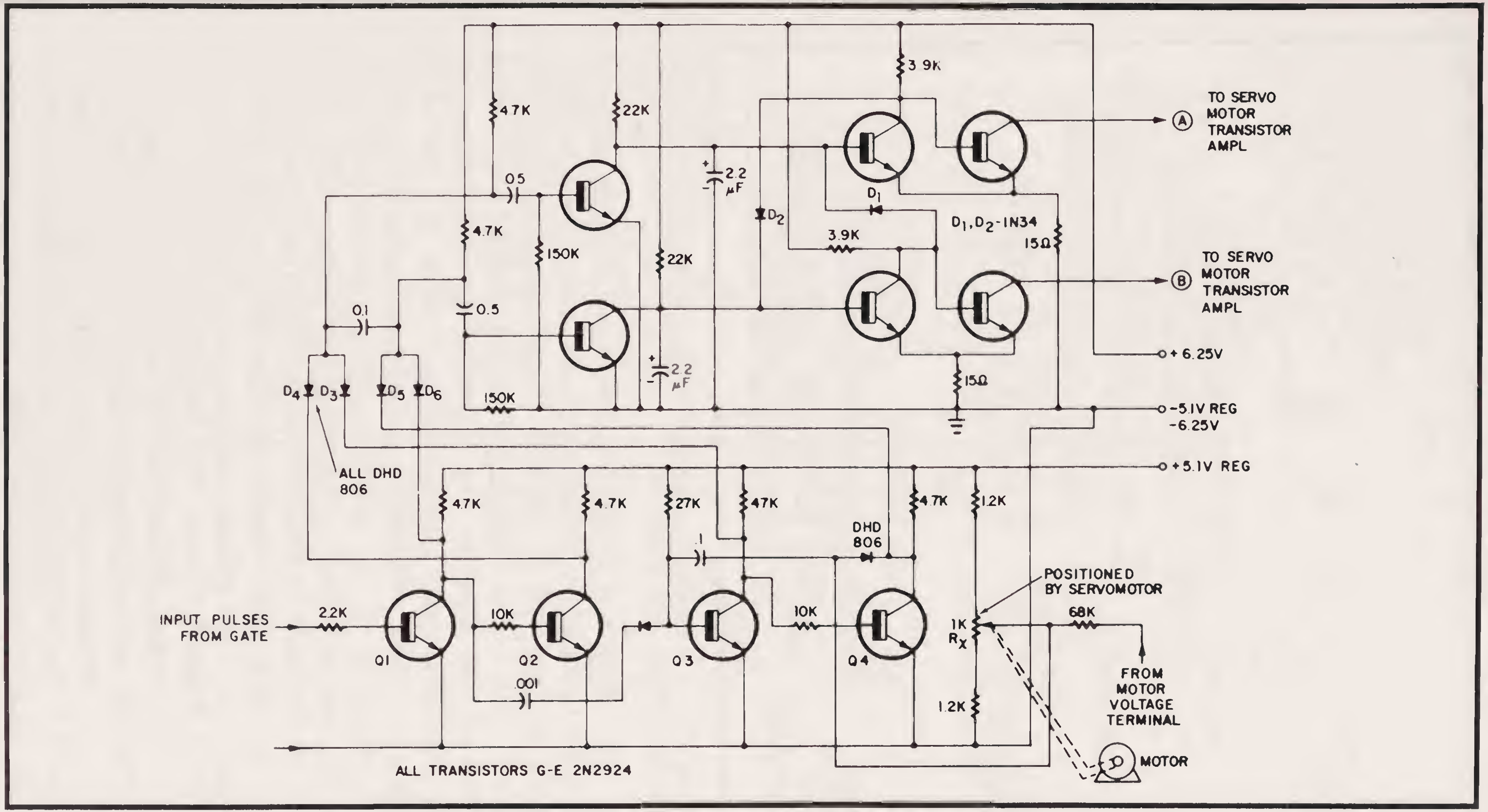


Fig. 1-41. Four-pulse digital decoding circuit of Tomlinson. (Courtesy Radio Control Modeler)

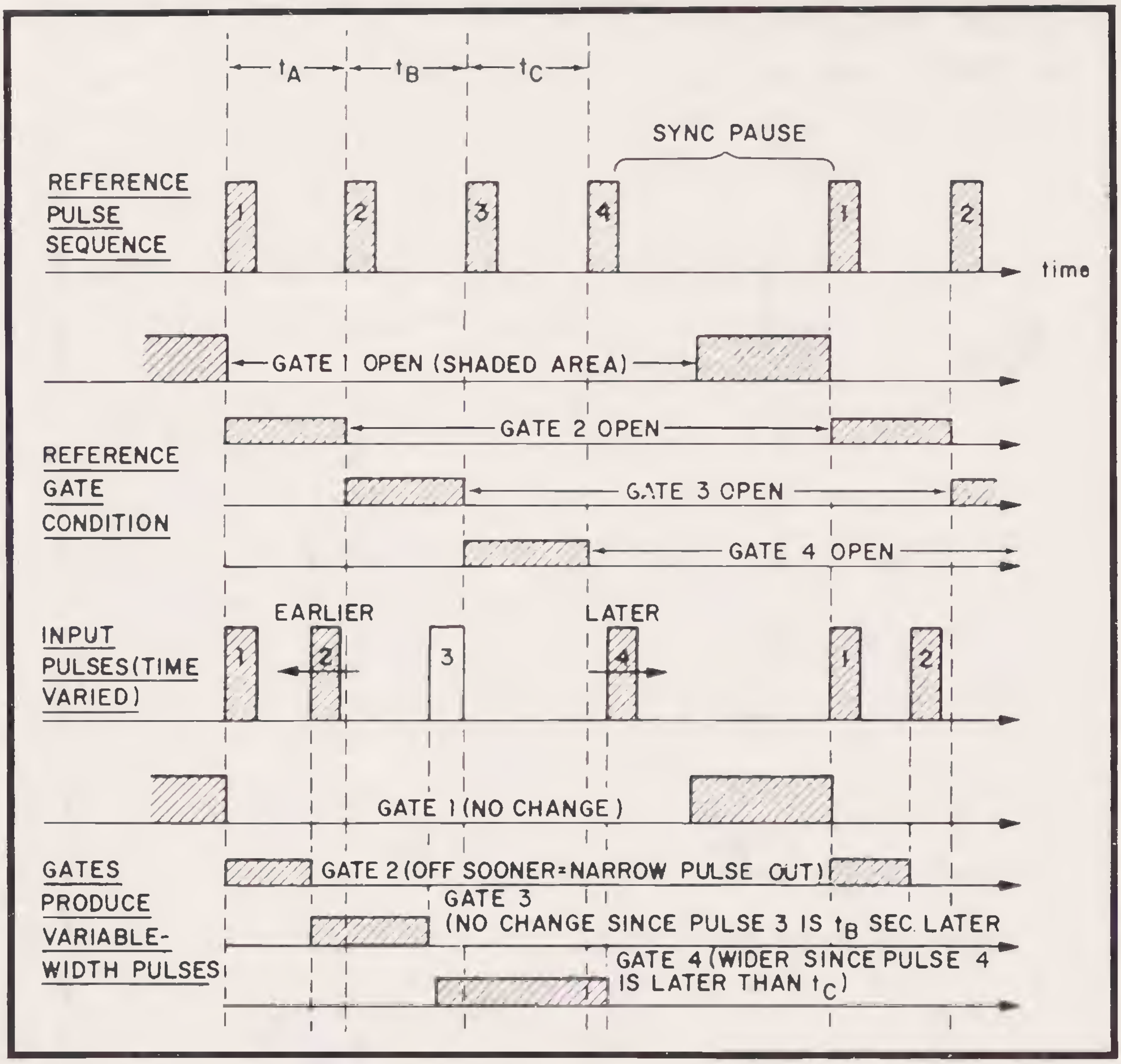


Fig. 1-42. Relationship between spacing of command pulses and width of pulse output from decoder gate circuit.

The coding circuit is fairly standard. A unijunction transistor Q1 begins the operation by producing pulses at some base rate. These pulses are then fed to one-shot multivibrators, Q2—Q3 and Q4—Q5, which have variable resistors in their base circuits to control the time constant. The outputs of the multivibrators are taken through diodes to a pulse amplifier-stretcher, Q6—Q7, which is again a one-shot multivibrator, and then through amplifier Q8 to the crystal stage of the transmitter. When a pulse is produced it causes a collector voltage to be applied to a transistor oscillator, and this in turn produces an rf pulse. When no pulse is produced from the coder during any time interval, the transmitter oscillator has no voltage applied to its collector and base and so there is no rf output produced. Figure 1-43 shows the coder circuit.

In order that the timing between the pulses be controlled, it is necessary to use a voltage regulator across the supply for this type pulser. The steering potentiometers for the model are labeled A through E on the diagram, and connected to a suitable stick or lever so that one can steer the model easily.

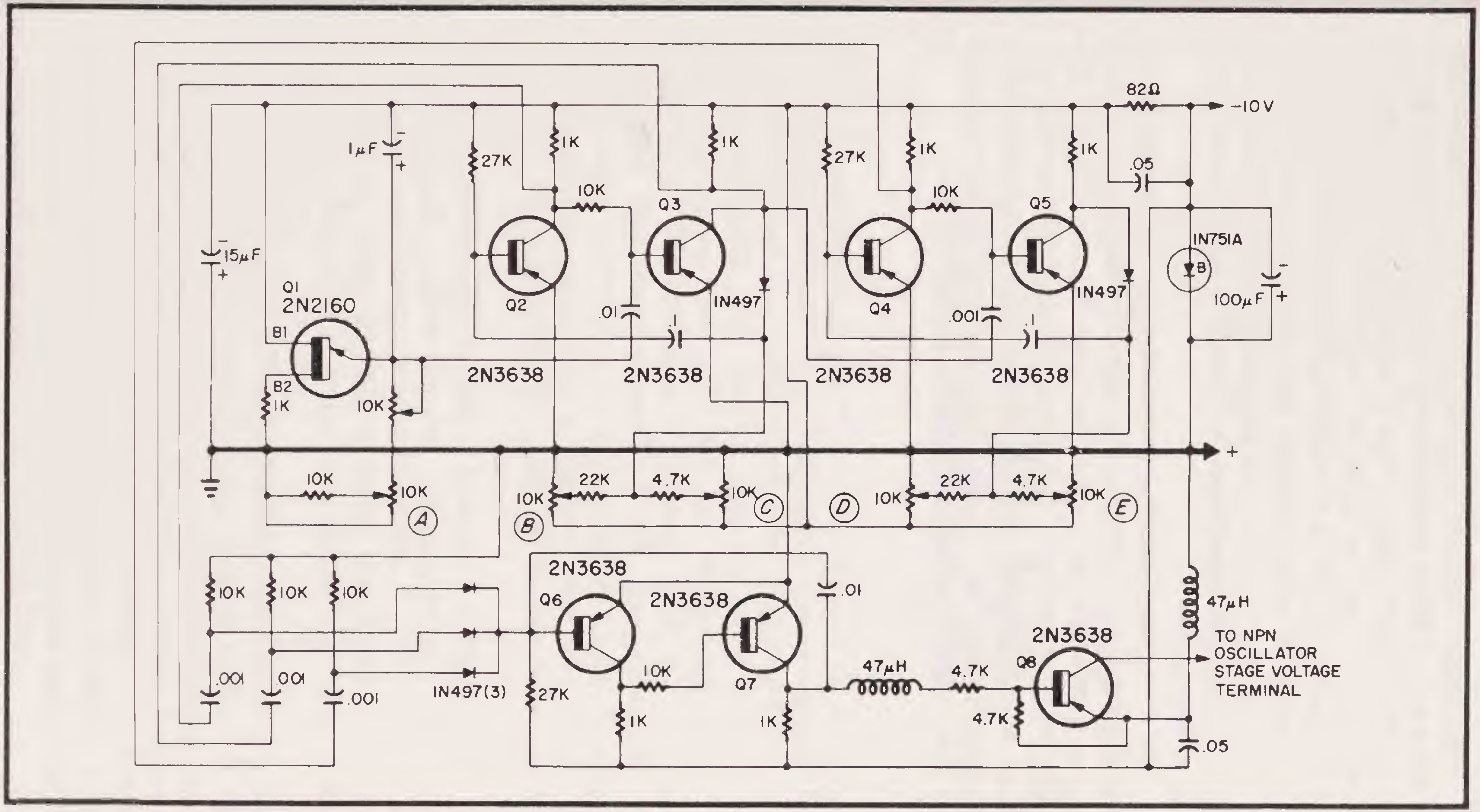


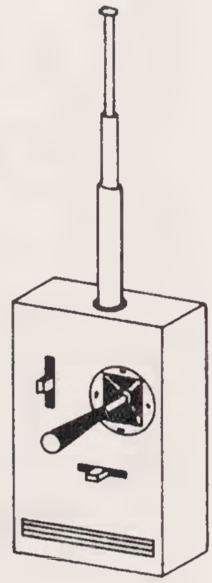
Fig. 1-43. The ground-based coder.

This system was one of the forerunners of our current and excellent type digital systems. Of course if you build it it can work for you if you get everything so that it operates correctly. Also the circuits are very interesting as they might be used in some other control applications. We have included it here primarily as an introduction to digital-control systems, and to intrigue you with its circuitry, if you, like ourselves, are fascinated by any kind of electronic circuitry which does something. So, if you want to experiment, have a go at this system.

But if you want firm and assured results, then we suggest a good digital kit so you won't have to search for the parts, or method of testing and adjusting, or proper layout. We next examine the fundamentals of three good digital systems and assure you there are others, but of these we have personal knowledge that they will be fun to put together and operate. There is enough to these systems that they warrant a separate chapter, so let's have at it.

2

Modern Digital Radio Control Systems



The modern digital radio-control system is made up of transistors and integrated circuitry all put together in a nice, neat package which has the proper levers or dials or knobs or steering wheels to make the actual control of our models a pleasure. Figure 2-1 shows one system made by Kraft which embodies the packaged form of the receiver and two servo units in one block. Notice how few components are required in the model, only the two items in front of the transmitters; on the left is the battery package. Of course only one transmitter is used, but this picture shows two which can be used. One is a single-stick and the second a two-stick arrangement for control.

To see what the various controls are for, examine Fig. 2-2, which depicts another physical arrangement of a radio-control transmitter with the various items labeled.

The use of the controls in handling a model airplane is the basis for the labeling. Of course for boats or cars the labels would be different.

If you purchase a radio-control system, there is a good possibility that it may come in a nice package as shown in Fig. 2-3. Again here, the receiver and two servos are packaged in the same "brick;" at top left, a spare servo; to the right of that, batteries; and down the left side, the charger for the batteries and cables. This, too, is a complete system. It has dual-level controls for rudder, elevator, throttle, and aileron control, or for other devices which you might want to use in your model.

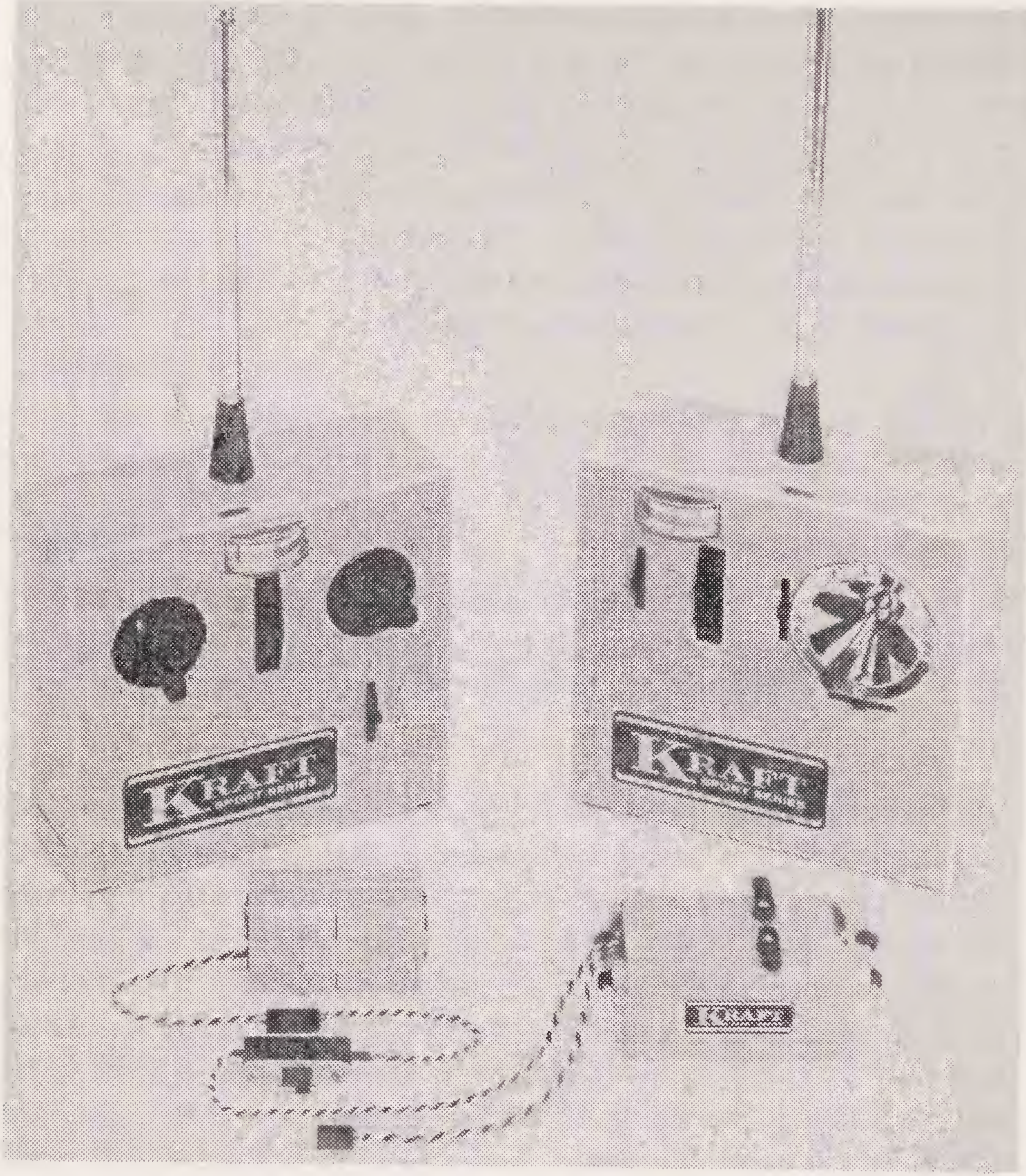


Fig. 2-1. Kraft KP 2/3B and KP 2/3S sport series.

We found much pleasure building the Heathkit shown in Fig. 2-4; opening the packages of parts was like unwrapping the presents under a Christmas tree.

And when you have worked at its construction as we describe in our TAB book *Flying Model Airplanes and Helicopters by Radio Control,* No. 825, you will have a system like that shown in Fig. 2-5. The servos are separated from the receiver so that you have some more flexibility in installation in case you want this.

Before we examine how they work, we want to spend a minute or two discussing the selection of an R/C system. We have a very simple rule to follow. We try to select a system from a manufacturer who has been in business a long time, who has a good record of operational success, and who has good relationships with their customers. The manufacturer should back up his product with factory service, and the factory should be located where you can maintain contact with it. Many manufacturers, such as those we have shown here, have service agencies located in convenient places around the United States so that it may be possible for you to visit them personally in case of trouble, or to get repairs after a bad flight or such.

Now we don't say that these manufacturers offer the cheapest systems. We don't believe in looking for that kind of a control system at all. As so many of our good friends and modelers from all over the world have told us, it is a wise rule to, "Buy the best you can afford." You won't regret that choice.

But if money is a prime consideration, and many times it is, then you might want to start with a simpler system, say a one-channel type, and try that for a while. They are available from Ace R/C, and

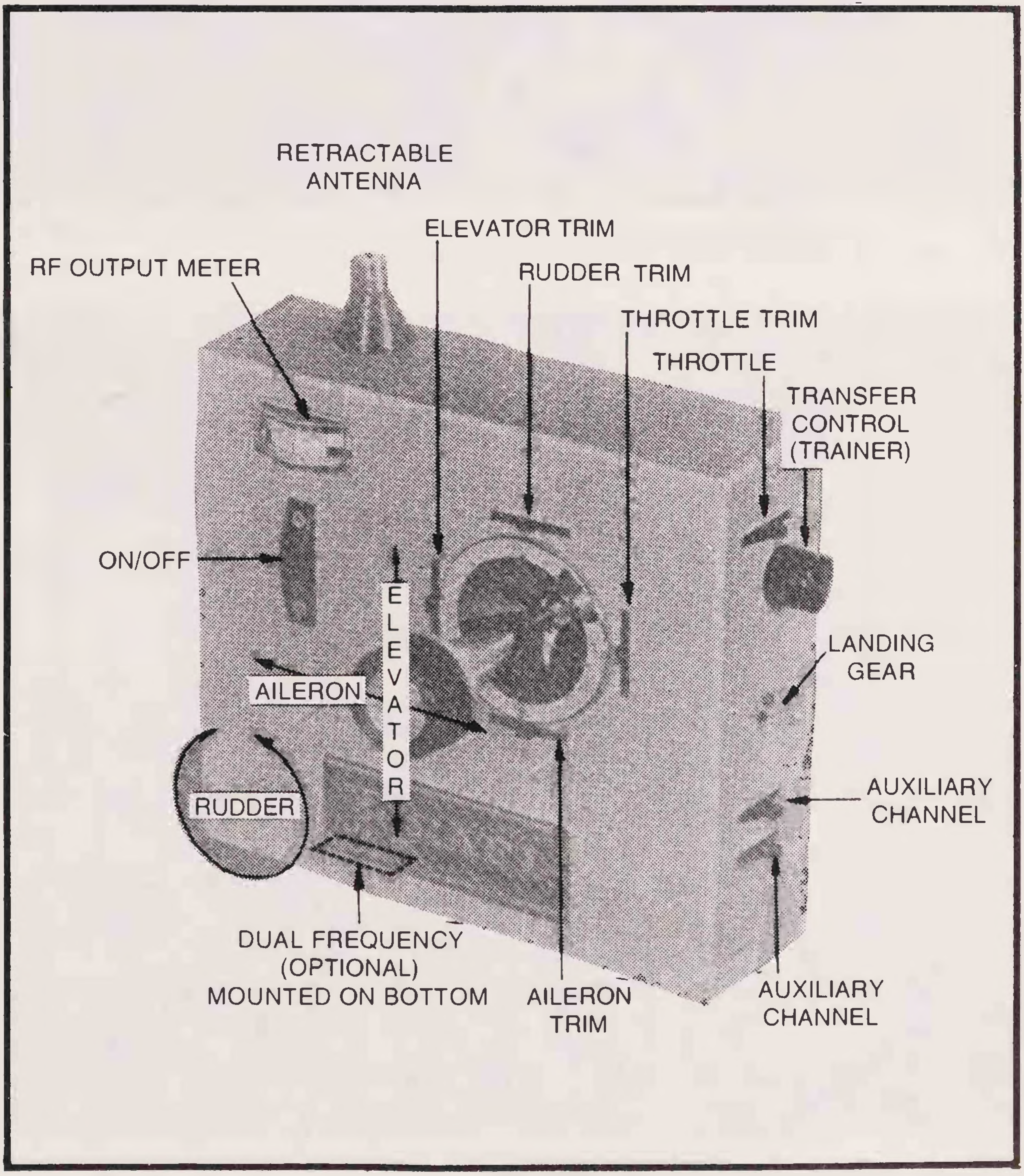


Fig. 2-2. KPT-7SX seven channel single stick transmitter.

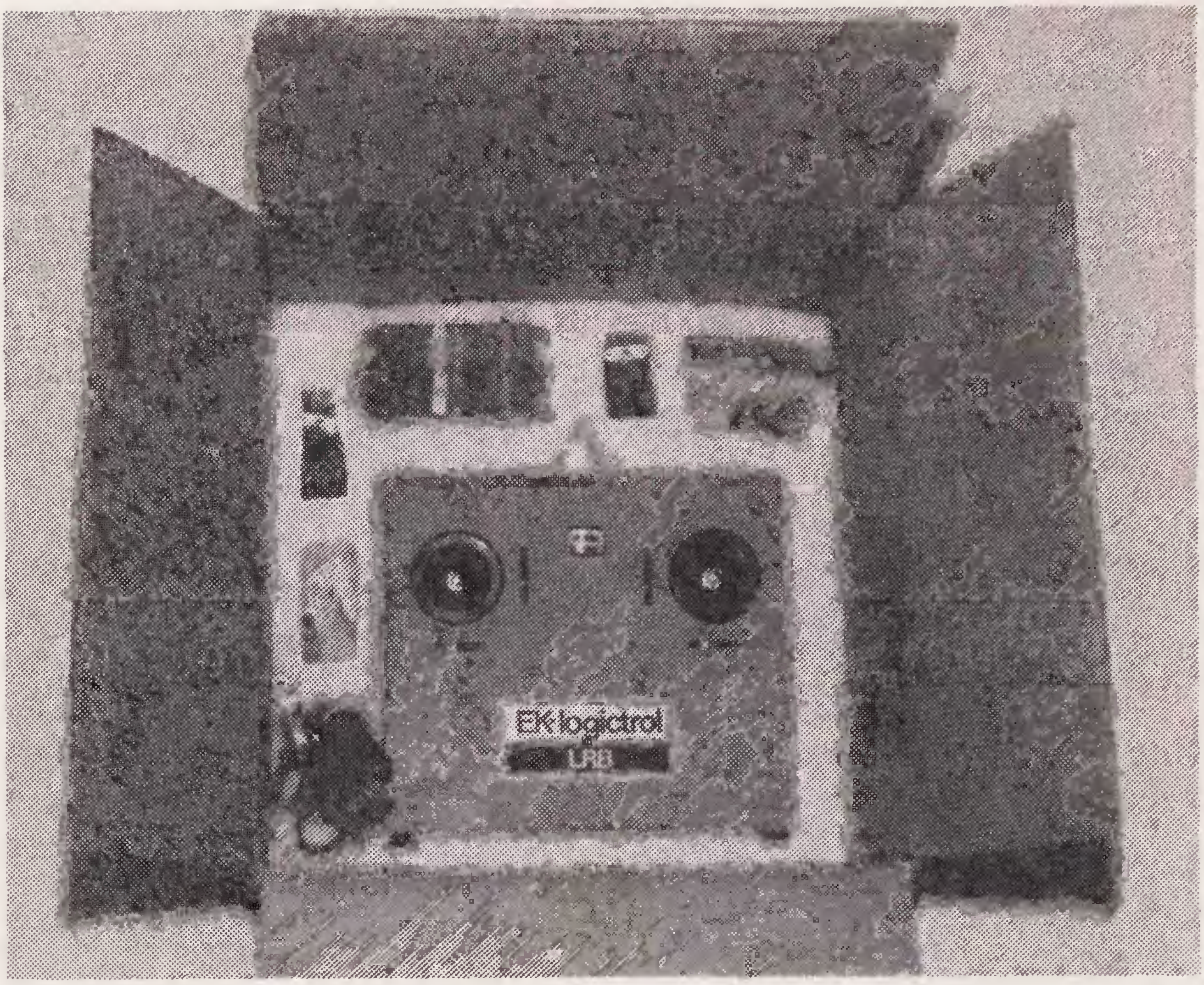


Fig. 2-3. The Logictrol Little Red Brick packaging.

Fig. 2-4. Heathkit transmitter kit package.

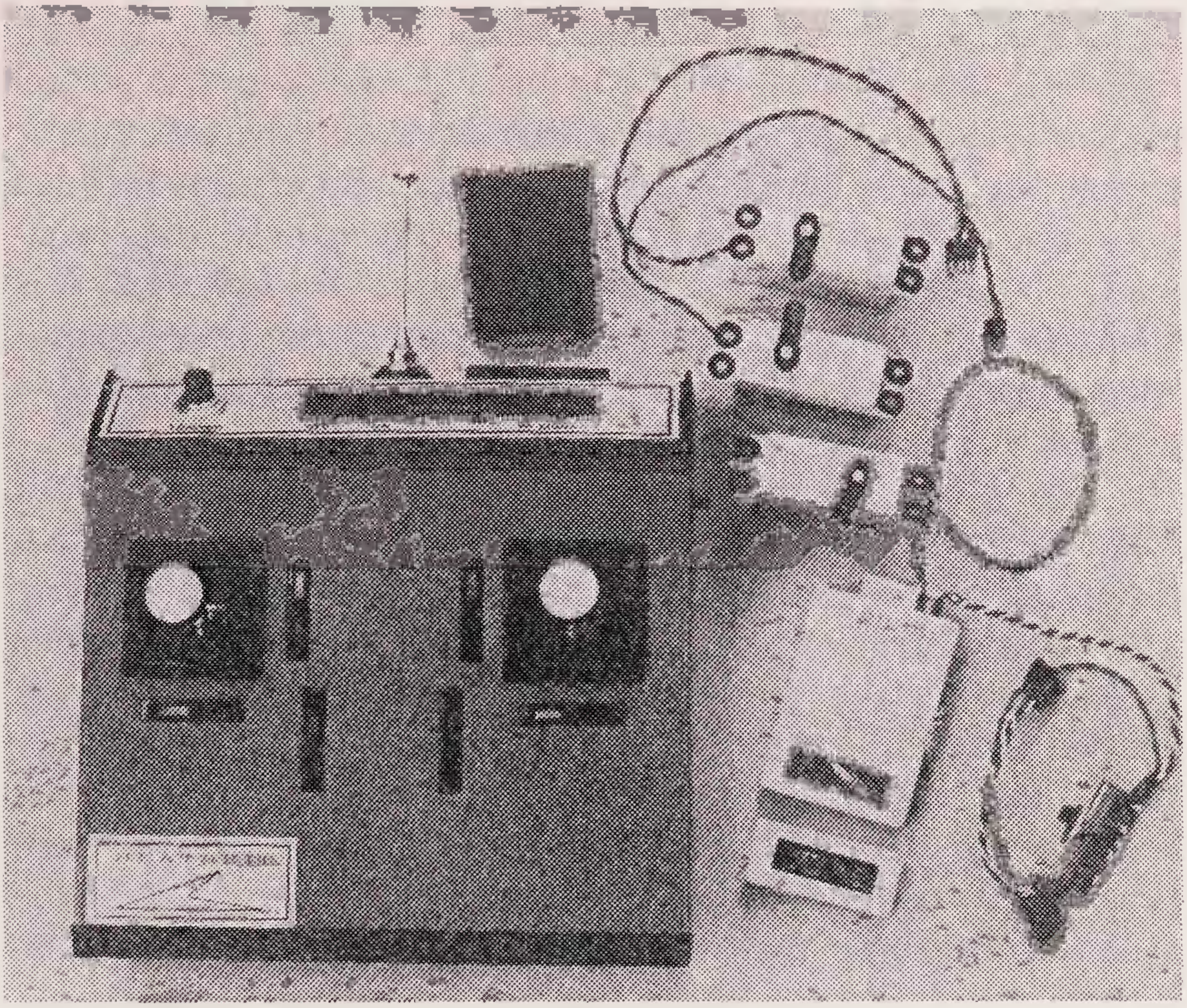


Fig. 2-5. The assembled Heathkit GD-1205 8-channel R/C system.

others. Or you might build up a system of your own from the circuits and discussions in our radio-control books. But ultimately, we believe that you will wind up with a modern digital system. So now we begin a close examination of these several types to see what makes them work. Ready?

THE KRAFT RADIO CONTROL SYSTEM

A block diagram of the transmitter is shown in Fig. 2-6. You want to remember that the code to be produced on the air will be a series of radio frequency pulse trains separated by a time interval called a sync pause. The pulse widths are varied to cause servo motion.

How It Operates

The transmitter (rf section) produces a crystal controlled rf carrier which is on continuously until it is pulsed off each time one of the encoder channels stops. An off pulse or time interval represented the beginning of an information- (control-) channel code. The time interval between each off pulse time is variable and dependent upon the control-stick position of that particular encoder channel. The time interval between the first encoder start pulse in one frame and that same pulse in the next frame (or pulse train) is fixed; therefore, the period labeled "sync pause," varies as each control element is moved. The sync pause itself carries no information and is merely a time delay to permit the receiver decoder to reset itself and get ready for the first pulse in the next incoming pulse train sequence. The transmitter being pulsed off means that essentially it is amplitude modulated and radiates a carrier all the time—except when a pulse is being transmitted. This is good because it tends to prevent interference from getting into the system.

One type encoder used successfully is shown in Fig. 2-8. A 72 MHz frequency transmitter section is shown in Fig. 2-9. Notice that the encoder consists of a series of half-shot multivibrators following a free-running multivibrator. The timing of the half shots is governed by the stick controls, and since the outputs of these half shots are coupled through a common line to the basic modulation multivibrator, these outputs govern the starting and reset time of this unit and so govern the transmitter off and on time. In the receiver there is a similar system, working in reverse and synchronized by the sync-pause time so that it gets the pulses and separates them through gate action and routes them to the various servos.

In construction of a Kraft kit it is interesting that the coding and decoding multivibrators are parts of integrated circuitry, which reduces the number of parts and makes the assembly easier.

The Receiver

First we should look at the block diagram shown in Fig. 2-10. We must also realize that in a large number of current digital systems the decoder is on the same printed circuit with the balance of the receiver, and they are not two separated units.

The diagram of the receiving portion of the system is shown in Fig. 2-11. In this system there was a possibility of two-channel operation by manually changing the crystal switch. This is good to give quick frequency changes in case of interference or when you find that there are lots of others flying on your frequency and you have to wait a long time to be able to get the air.

The circuit is straightforward, a superhet with three stages of i-f and an amplitude detector to pick off the pulses. In some systems the i-fs operate at 465 MHz, allowing the i-f transformers to be very small units, as shown in Fig. 2-12.

In the picture you see that the i-fs are adjustable, just as they are in any broadcast receiver. The antenna length is critical. Here it is a fixed length of rod, slightly rigid so you won't try to lengthen,

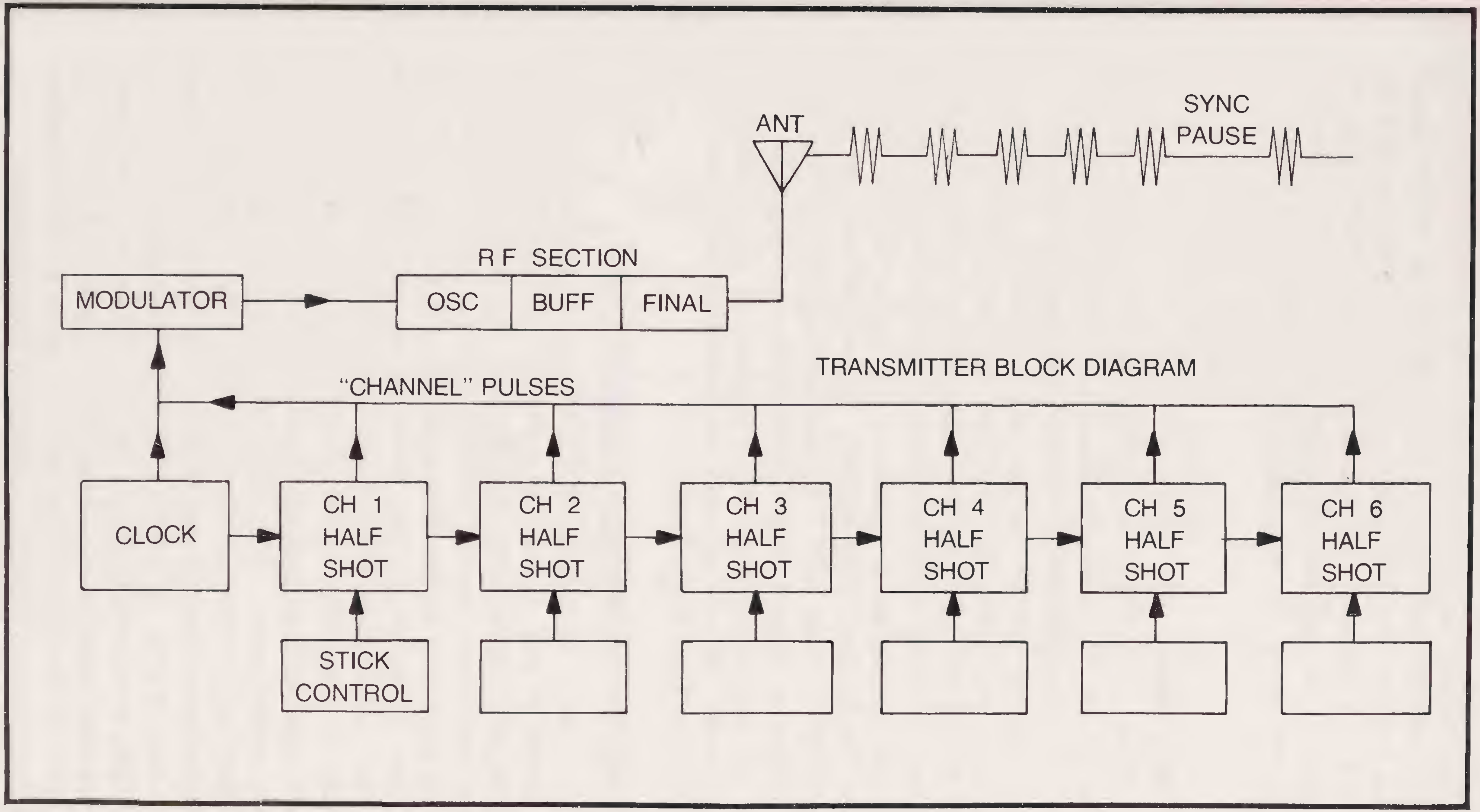


Fig. 2-6. A Kraft transmitter.

shorten, or bend it back on itself. There is no relay in this receiver; it uses a transistorized output which provides enough current change so that you can operate actuators, motors, or whatever with the receiver as it is shown. The actual Kraft receiver will have a different configuration and may use different physical parts, but for the diagram shown this is the layout indicative of this kind of control receiver.

The Servo System

Of course there is the channeling system, which is the decoder in the receiver. This routes the pulses to a servo, such as is shown in Fig. 2-13. This represents a standard arrangement, and, from the various circuits shown, you can follow through to see how the system works. Notice that the incoming pulse activates the reference system which then compares the reference-pulse timing with the incoming-pulse timing and width. From this it determines the direction and amount of rotation of the motor. When the motor moves the feedback potentiometer, fastened to its output gear, it causes the reference pulse to balance out the incoming pulse when the output motor gear shaft has moved the desired amount. Thus you have the proportional control required for our modern high-speed model airplanes and which we desire for all of our models no matter what type they may be.

THE HEATHKIT DIGITAL RADIO CONTROL SYSTEM

Of course all manufacturers are constantly updating their equipment to give you the best possible equipment. The Kraft system just examined was an earlier one, and changes have been made since it was originally developed and marketed. But now we choose to examine the Heathkit as an example of a later system to see what changes do take place and how the system might change as a result. Understand that basically the operation of any system has to remain the same because the principles of operation of a digital radio-control system just don't change. But to facilitate operation, to make control easier, and to take advantage of new technological breakthroughs—which usually results in smaller, lighter, and more efficient control systems—the manufacturers make model changes from year to year, or nearly so it seems. Sometimes it is just a packaging change and sometimes also a circuit improvement—kinda like systems of marketing new-model automobiles. In any event let's examine the Heathkit system, which we got as a kit, put together, and found most satisfactory results from the experience.

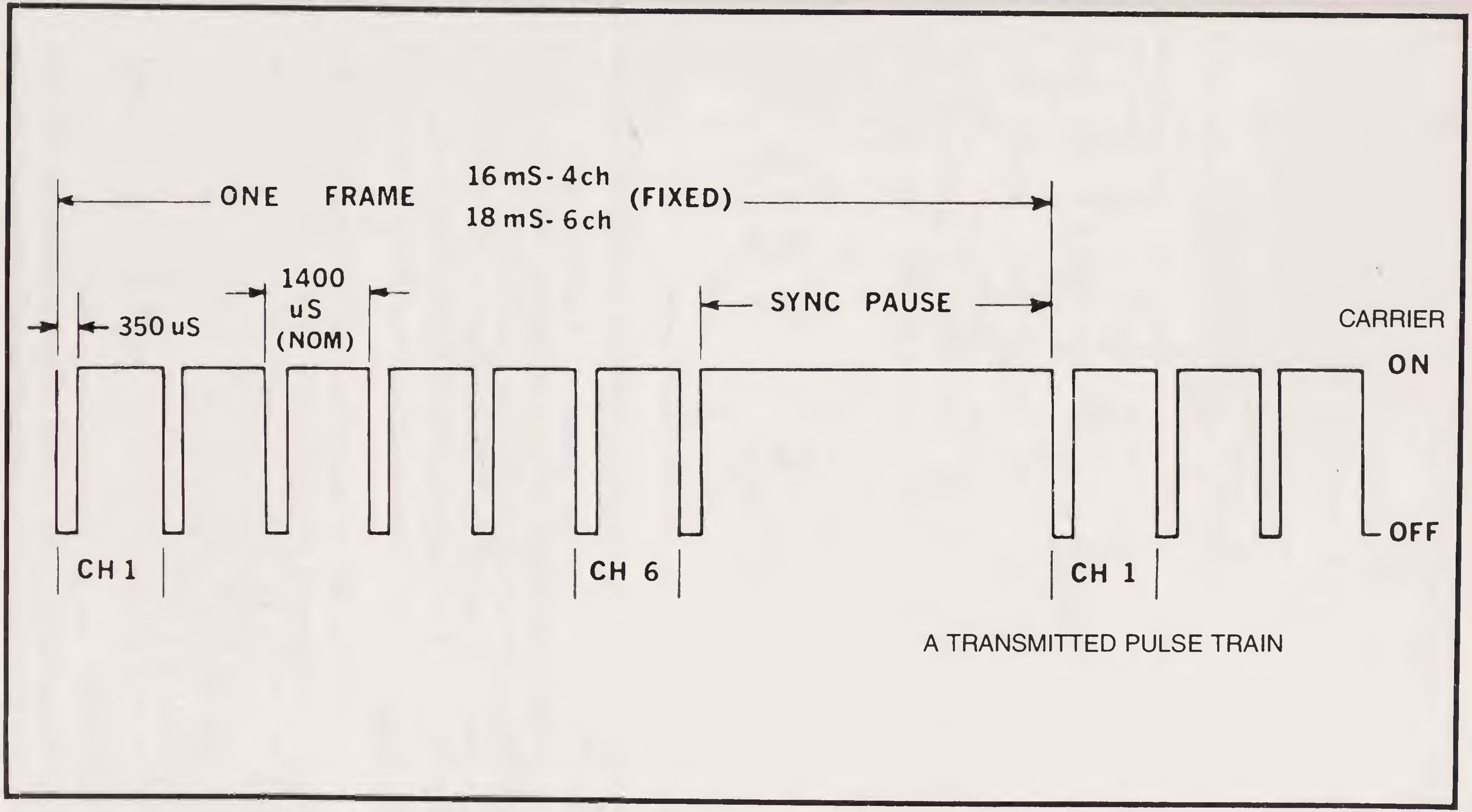
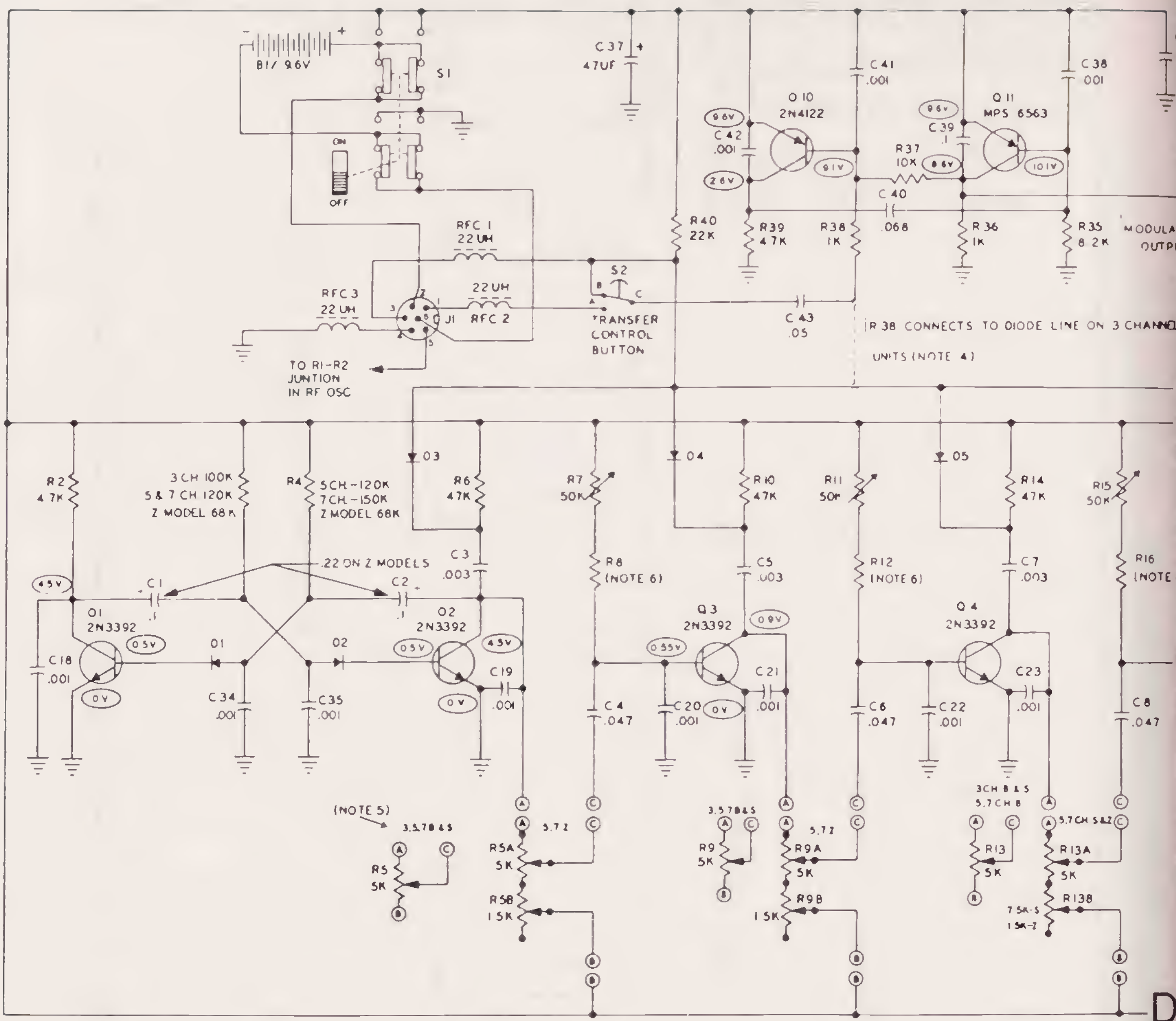


Fig. 2-7. One type Kraft pulse sequence. Note carrier on-off times.



The Code

Coding of the signals is like that previously discussed except that timing is different. Examine Fig. 2-14. Note that the carrier is on until pulsed off, as before. You can relate the r-f pulses to the diagram in block form and see that this is the case.

The System

The receiver, like the transmitter, has a plug-in module which will give instantaneous (almost) frequency changes to any of the R/C spot frequencies. In Fig. 2-5 you saw two r-f plug-in units (one inserted in the transmitter at top right and one below the receiver). The other units are the same sizes as these. This is nice because it means the bulk of your equipment is always good, and you can get on the frequency giving you the most control time at the flying field.

The Receiver

The receiver appears in block diagram form in Fig. 2-15. You will note that ceramic i-f filters are used. These are "something

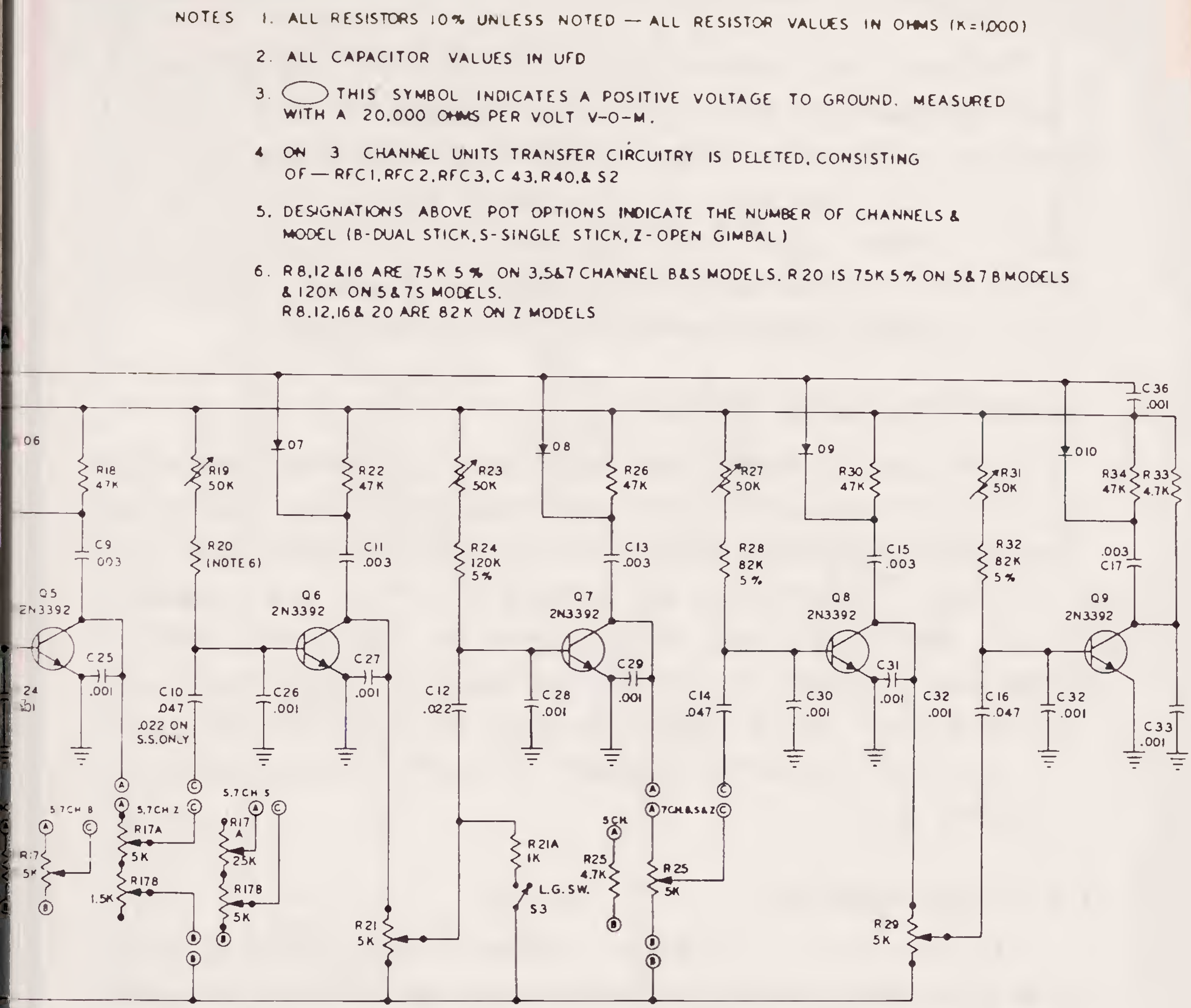


Fig. 2-8. One Kraft encoder system.

else." They are about ¼-inch square, and you do not tune them; this makes for a very small, compact and rugged receiver. Again, an integrated circuit makes up the pulse separation decoder to route the pulses to the servos. The r-f amplifier gives high gain, improves the selectivity, and minimizes interference. Note also the noise limiter block which is good to have in such a control system as this.

The Transmitter

The transmitter is shown in block form in Fig. 2-16. You will notice that, as before, control levers and switches and knobs are moved to change resistances which, in turn, change the timing of the monostable multivibrators and thus the width of the transmitted pulses. The free-running multivibrator is again the one which establishes the total pulse-train time. The modulator is a multivibrator pulsing the carrier off when a signal is to be sent. Note that the rf section is stated as a *module*. That is the small package at the top right of the transmitter in Fig. 2-5.

The Servo

Servos for this system may be subminiature or a larger size. It is well designed and relatively easy to construct in kit form if you have a magnifying glass handy. In block diagram form you can see in Fig. 2-17 that there are very few parts needed other than the integrated circuit which forms the main part of the package. The subminiature unit shown is strong, quick, responsive, and fits well into an airplane package as we shall show in later pages.

THE ACE R/C DIGITAL SYSTEM

In this system examination we will learn still more about how a digital system works and of some design concepts of how it gives you a fine performing system enabling you to do the things you want with your model. This system is also available as a kit or as a completed unit. Its construction procedures are more for the experienced electronics builder than are the instructions available with the Heathkit system. Of course you can purchase any of these systems (or later versions of them) assembled and ready to use if you desire that approach.

The Encoder Operation

The encoder is part of the transmitter, being that portion of the circuit generating and coding the command signals for transmission by the rf section. One such encoder is shown in Fig. 2-18. In this diagram only three operational channels are shown, but the system is capable of handling up to nine channels. We are interested here in how it actually codes the signals, but we would remember that this system is available as a kit from Ace R/C. So if you want to build one, find out about the kit.

This system uses a commutated encoder which employs only one set of timing circuitry for all channels. The control input to the timing circuit steps sequentially from one control potentiometer to the next until a complete frame of information is encoded. The information is contained in the pulse widths. This function of stepping is termed commutation.

The encoder consists of a free-running multivibrator which performs the timing function, a control-input buffer for this multivibrator, and two integrated circuits that commutate the control of the multivibrator time constant from one control input to another. The multivibrator switches state at a regular interval dependent upon the values of the related resistor and capacitors in its circuitry.

In the encoder the period of on time of the multivibrator may equal the off time, or they may be varied independently. In this case,

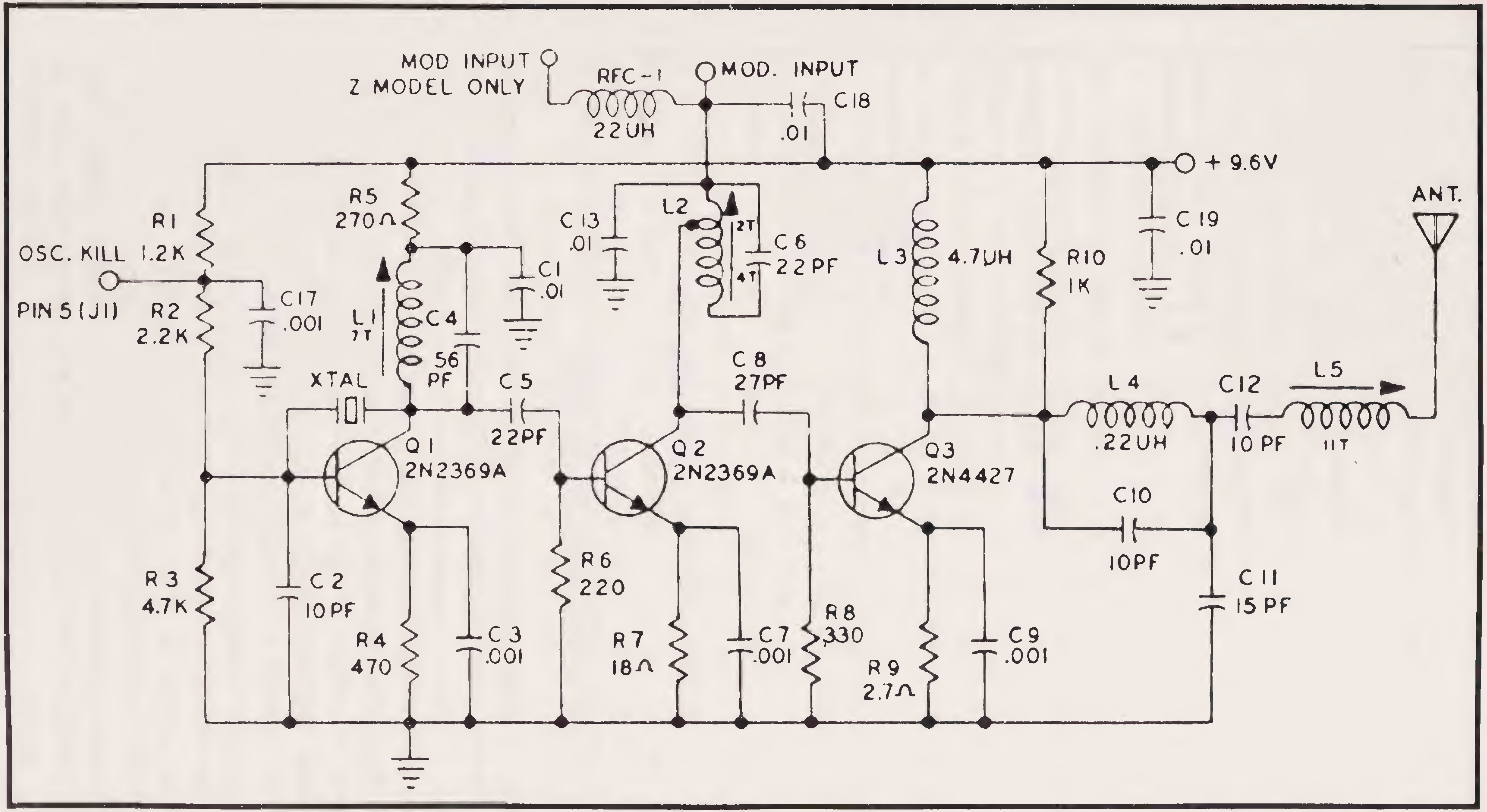


Fig. 2-9. A Transmitter Section (Kraft).

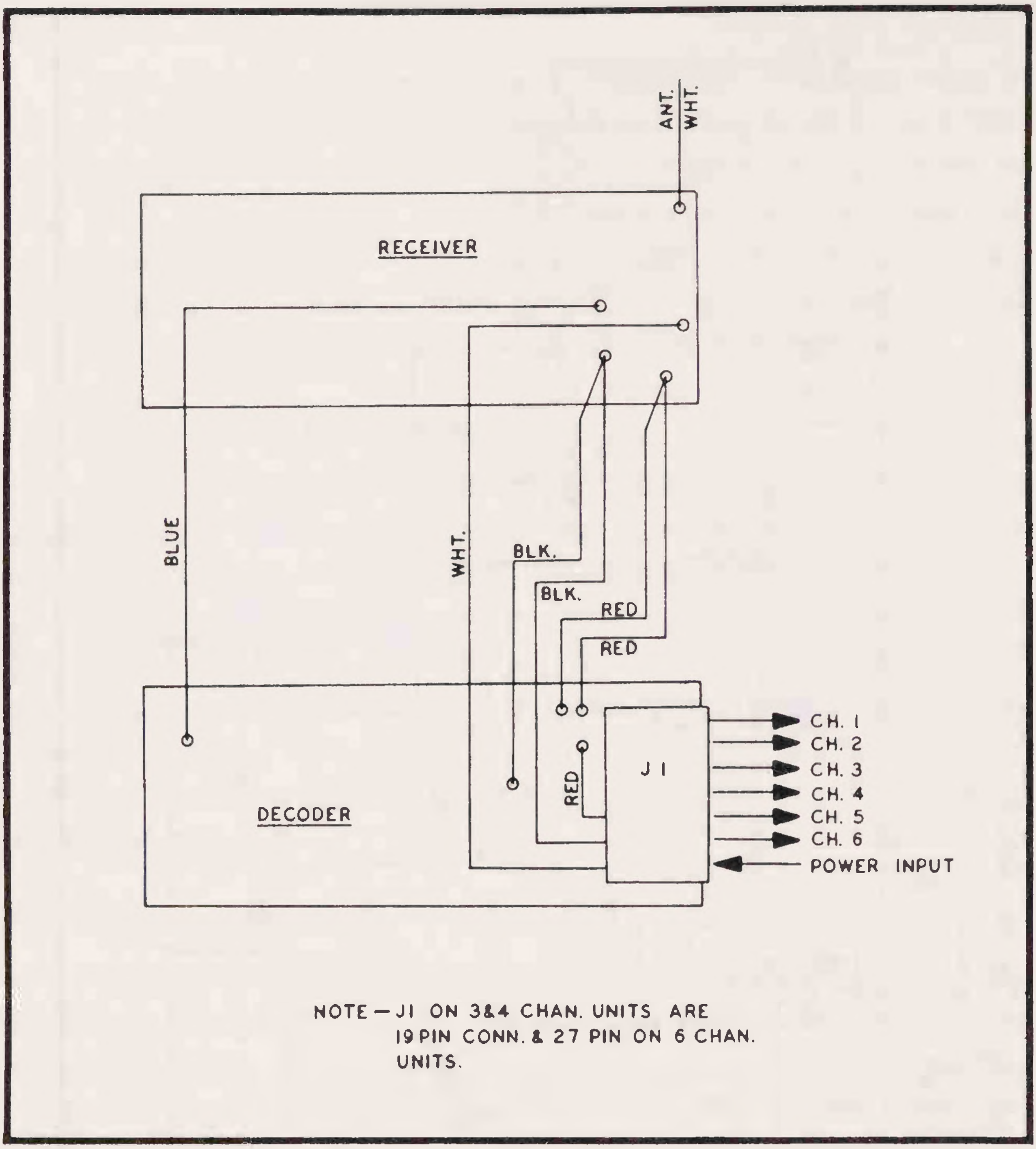


Fig. 2-10. Kraft receiver decoder interconnection.

where we assume the collector of Q2 to be high, biased to cutoff, the off time is set at 250 microseconds by the values of C2 and R5. This is the nominal (no command) width of the modulation pulse. The on time output of the multivibrator is variable.

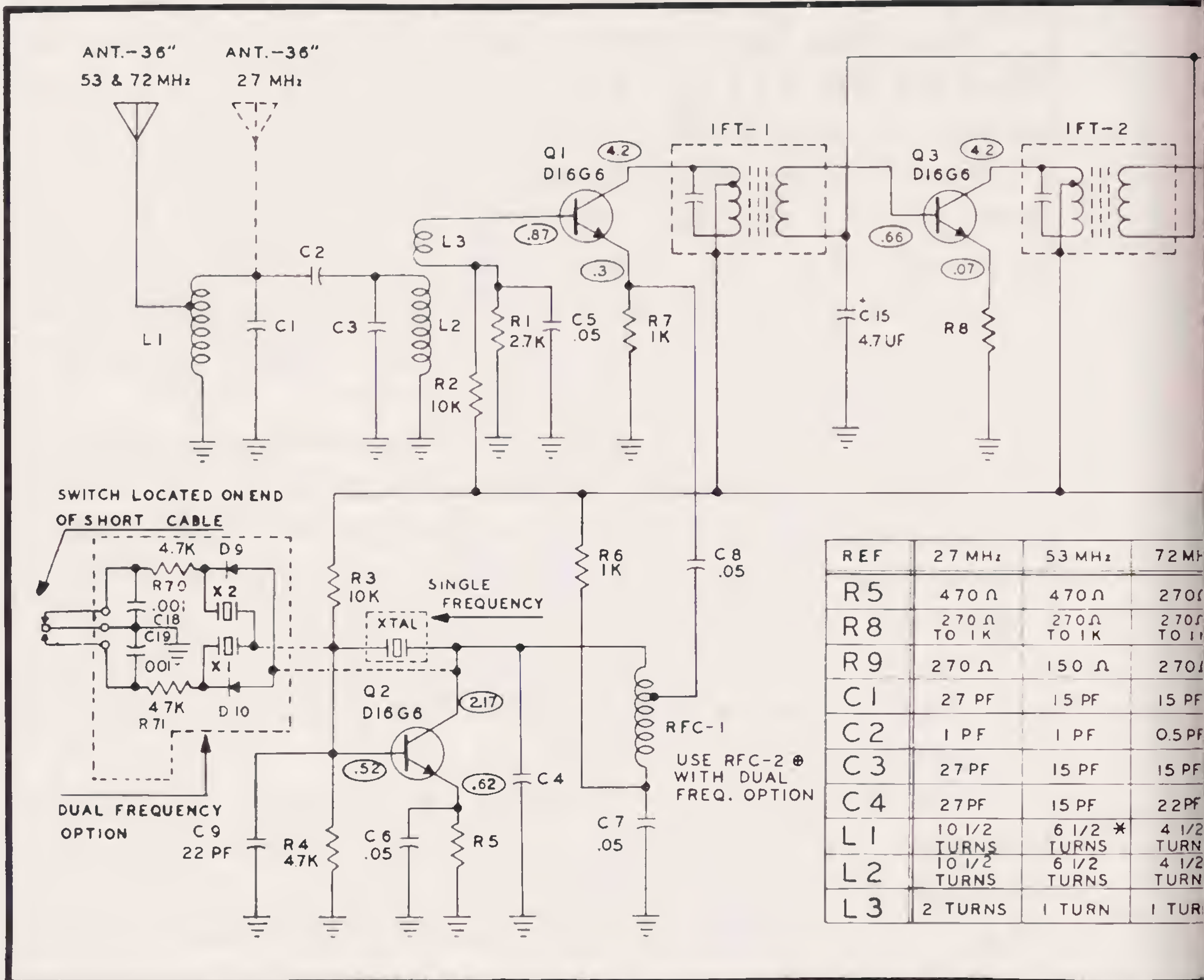
The on time is set by the value of C1 and R4 and by the voltage level at the emitter of Q1. Imagine for a moment that Q1 has been replaced by a fixed resistor of such a value that the multivibrator will run at an off time of 250 microseconds and that its on time will be set by this fixed resistor and also by R3 and R4. Assume there is no variation in the on time. The goal, then, is to make the on-time variable a time of about 1.5 milliseconds plus or minus 0.5 millisecond. That is, it may be shortened to 1.0 millisecond or it may be lengthened to 2.0 milliseconds. We want it variable continuously between these extremes, as this will specify rudder or elevator (etc.) position on, say, a model aircraft.

Now, if that fixed resistor is changed to a variable resistor, this will do just that; it will control the timing of the on pulse between the desired extremes. So we find that Q1 actually serves as a variable resistor to do this. As Q1 turns on—that is, its emitter becomes more positive, the on time increases; and as its emitter becomes less positive the on time decreases. Notice that the bias level for Q1 is controlled sequentially by each of the control potentiometers. These govern, then, the movement of the model's control and steering elements.

Since Q1 is an NPN transistor, it is biased off as the base goes more negative and less off (more on) as the base becomes positive. It is necessary to provide the bias required to produce the nominal (average) control-time period of 1.5 milliseconds (plus or minus 0.5 millisecond), and also it is necessary to provide the bias necessary to produce a synchronization pause of about 4,5 milliseconds between each frame of pulses. Integrated circuits SN7490 and SN74145 accomplish this.

The SN7490 is a decade counter that converts a decimal input into a binary output. It will take sequential clock pulses and produce its binary output (either a voltage or no voltage—a 1 or a 0) at its output at A, B, C, and D. When the A output goes high (1) on the first clock pulse and then low (0) on the second, it is the same as counting to 9, then making the last significant place 0 while the second becomes 1 to form 10. When A goes low it "carries" to the next significant place, just as was done going from 9 to 10 and the (B) output becomes high. It cannot go low again until A goes low once more. The same relationship is true for (B) versus (C) and for (C versus (D). Thus (A) changes stage with every count, (B) with every other count, (C) with every fourth count, and (D) with every eighth count.

The SN74145 is a binary-coded-decimal to decimal decoder/ driver. Its function is to accept the binary-coded-data characteristics of binary computation and convert it to 1-of-10 outputs. This integrated circuit has an outstanding characteristic. It is an open-collector TTL device, meaning that the drive transistors are normally used to drive display devices and also meaning that no internal collector load exists on any of the output transistors. In this case that means there is now provided the isolation needed to keep the control potentiometers separated from each other when the outputs (1 through 7, and 9) are high. It is this feature which permits the elimination of the blocking diodes needed when other counting devices, such as shift registers, are used.



REF	27 MHz	53 MHz	72 MH
R5	470 Ω	470 Ω	270Ω
R8	270 Ω TO 1K	270 Ω TO 1K	270Ω TO 1
R9	270 Ω	150 Ω	270Ω
C1	27 PF	15 PF	15 PF
C2	1 PF	1 PF	0.5 PF
C3	27 PF	15 PF	15 PF
C4	27 PF	15 PF	22 PF
L1	10 1/2 TURNS	6 1/2 * TURNS	4 1/2 TURN
L2	10 1/2 TURNS	6 1/2 TURNS	4 1/2 TURN
L3	2 TURNS	1 TURN	1 TUR

As the SN74145 steps through the sequence, the outputs go low, as shown in Fig. 2-19. When inputs A through D are low, all outputs are high. Thus Q1 is biased strongly on, and the free-running multivibrator will have the long 4.5 millisecond period required for synchronization with the receiver decoder. When the multivibrator reaches the end of the sync pause and goes off for 250 microseconds, a frame of information begins with the sending of a sync, or start, pulse. This sync pulse appears as a 250-microsecond pulse of 9-volt amplitude at the collector of Q3; it then goes to the modulator in the rf section via D2 and R8. It also goes to the clock input of the SN7490 at pin 14.

Those familiar with integrated circuits will be aware some counters do binary counting along with the decoding functions of the SN74145, all on one chip. However, these devices must count all the way to 10 before they can start over, unless an auxiliary clear circuit is used. The SN7490 has the feature of being able to clear itself, and in this Ace Commander system the feature is exploited. Notice that the D output (pin 11 of IC-1) is connected to the clear input, pin 3-4. As soon as the count reaches 8 (there must be one more pulse than there are channels) and (D) starts to go high, IC-1 is cleared, and all its outputs go low.

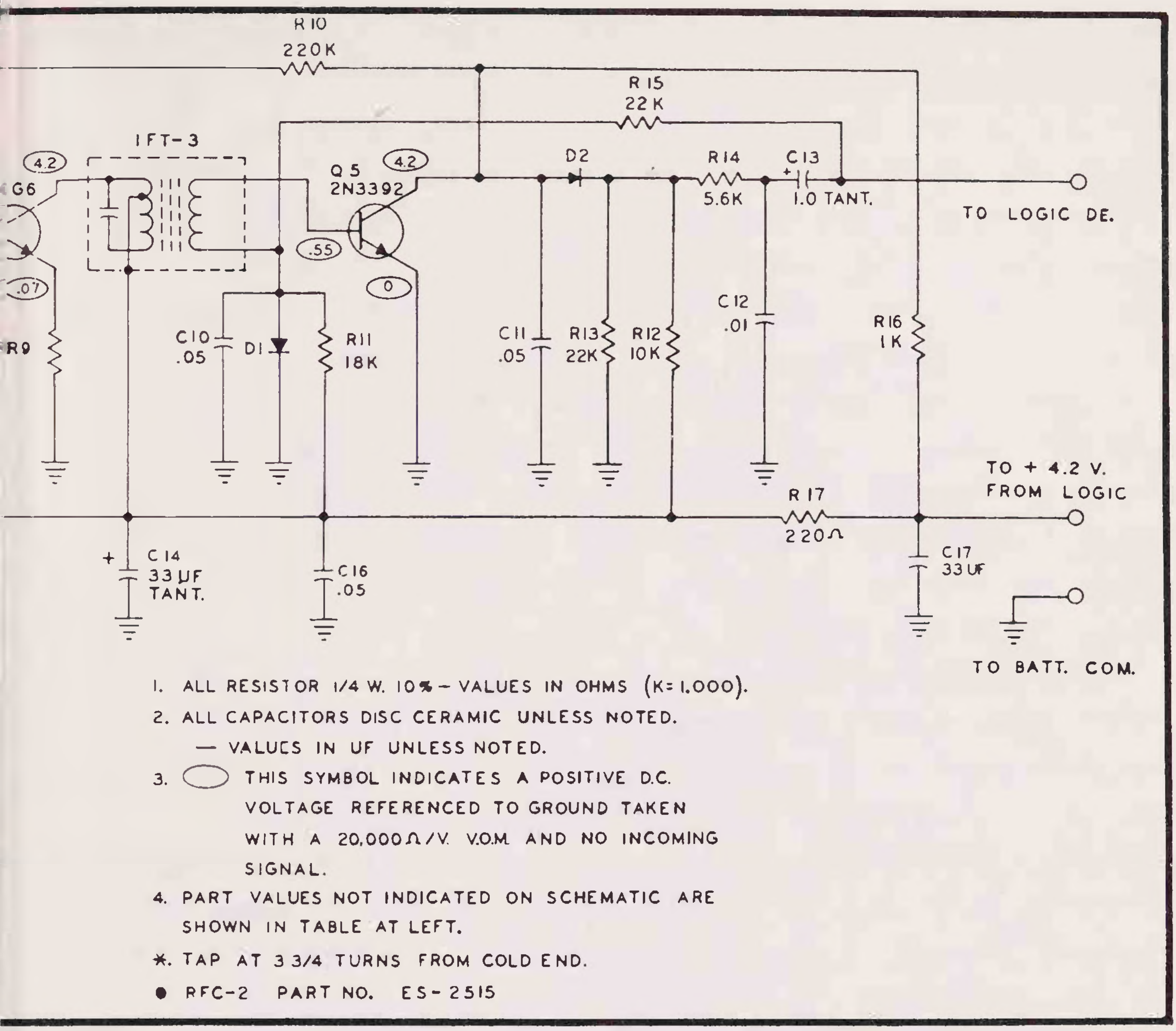


Fig. 2-11. The Digital R-9A/R-10B receiver less decoder.

As you examine Fig. 2-19 you see that in the code for IC-2 when all outputs are high, a new sync pause is started and a frame of information has been coded and sent to the rf-section modulator. By connecting the reset to (C) it is possible to stop the count at 4 and thus make a three-channel system. Or you could connect reset to (B) and get a one-channel system. We include in Fig. 2-20 the transmitter diagram of this system. Since it is similiar to others we have discussed we won't elaborate on its circuit operation, but leave that to your analysis.

The Receiver and Its Decoder Design

The decoder used in this receiver, which essentially separates the pulses transmitted and sends them to the various servos, is based on complementary metal oxide semiconductor (CMOS) integrated circuit, the best type to date as far as stability, noise rejection, and low-current drain are concerned.

This decoder is also designed to perform the squaring and pulse-stretching operations needed to give clock and synchronization pulses via an integrated circuit. And because it is a separate circuit form the receiving portion of the receiver it makes possible a very simple and straightforward receiver itself.

The Decoder appears along with the receiver in Fig. 2-21. Refer to the block diagram in the lower left corner. Hex inverter 74C04 consists of six transistors on a chip. Digital information operates between two levels: high and low voltages; so it is binary in nature. The inverter, of course, inverts the sign of the voltage output from that of its input.

The receiver output is a train of pulses (2 to 9 for 1- to 8-channel systems—remember one more pulse is needed here than the actual number of channels). The voltage levels of these pulses are from near 4.8 volts down to almost 0. The inverters in the 74C04 will switch at these levels, so the first block actually amplifies and inverts the incoming pulse train.

Now the train of pulses is sent to two different blocks. The one at the top (inverters 4 and 5) generates the set pulses, and the lower one (inverters 2 and 3) generates the clock pulses. The clock pulses have to be squared and shaped, which is also done. These clock pulses are also called shift pulses. The shaping required is a slight stretching, or lengthening, of the pulses, which is accomplished by feedback. The output from 2 is negative, but is reinverted so that it becomes positive at the output of this block; then the pulses are passed to the 8-bit shift register, 74C164.

Upon receipt of the first, or synchronizing, pulse, D3 and C26 act as a sample-and-hold, or pulse-stretcher circuit. Capacitor C26 discharges through inverter 4 and places it in a positive-going state. At this point the pulse is stretched across the entire pulse train. The output of inverter 4 is still slightly rounded and is of the wrong level; that is, it is positive going for set, so further stretching is provided by C28. The output from inverter 5 is quite square and negative going during the period when the pulse train is present.

The shift register is set by having the output of inverter 5 be 1 at the instant the first clock pulse is received. The set is immediately driven to ground at the first clock pulse and remains so until after the last pulse is received. In doing so, the first stage of the register, a flip-flop, is inhibited from shirting back to Q until the next frame of information is received.

The Register

The 8-bit register consists of eight R-S (as opposed to J-K) flip-flops. The requirement for the decoding function, which is routing of the pulses, is as follows:

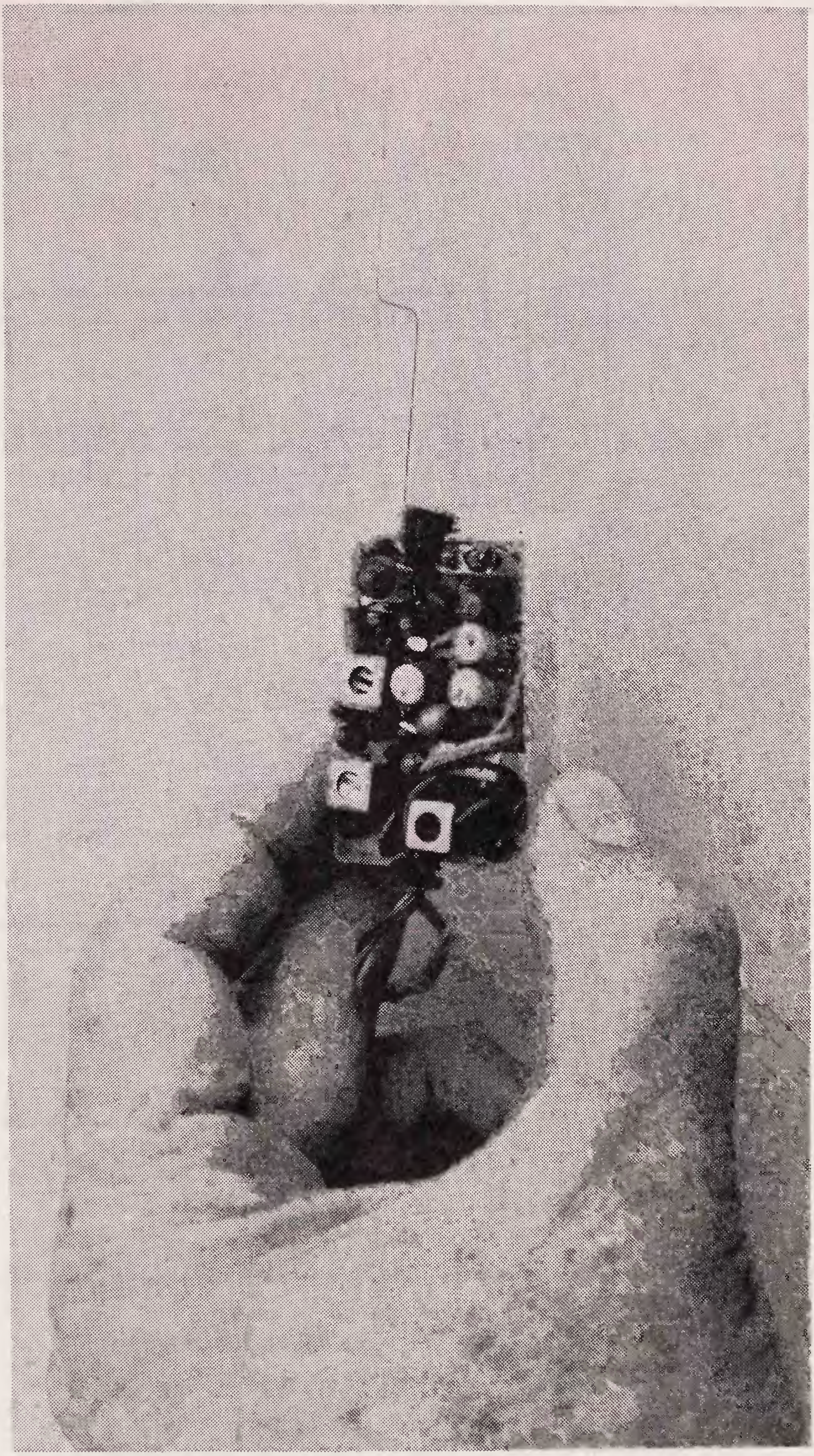
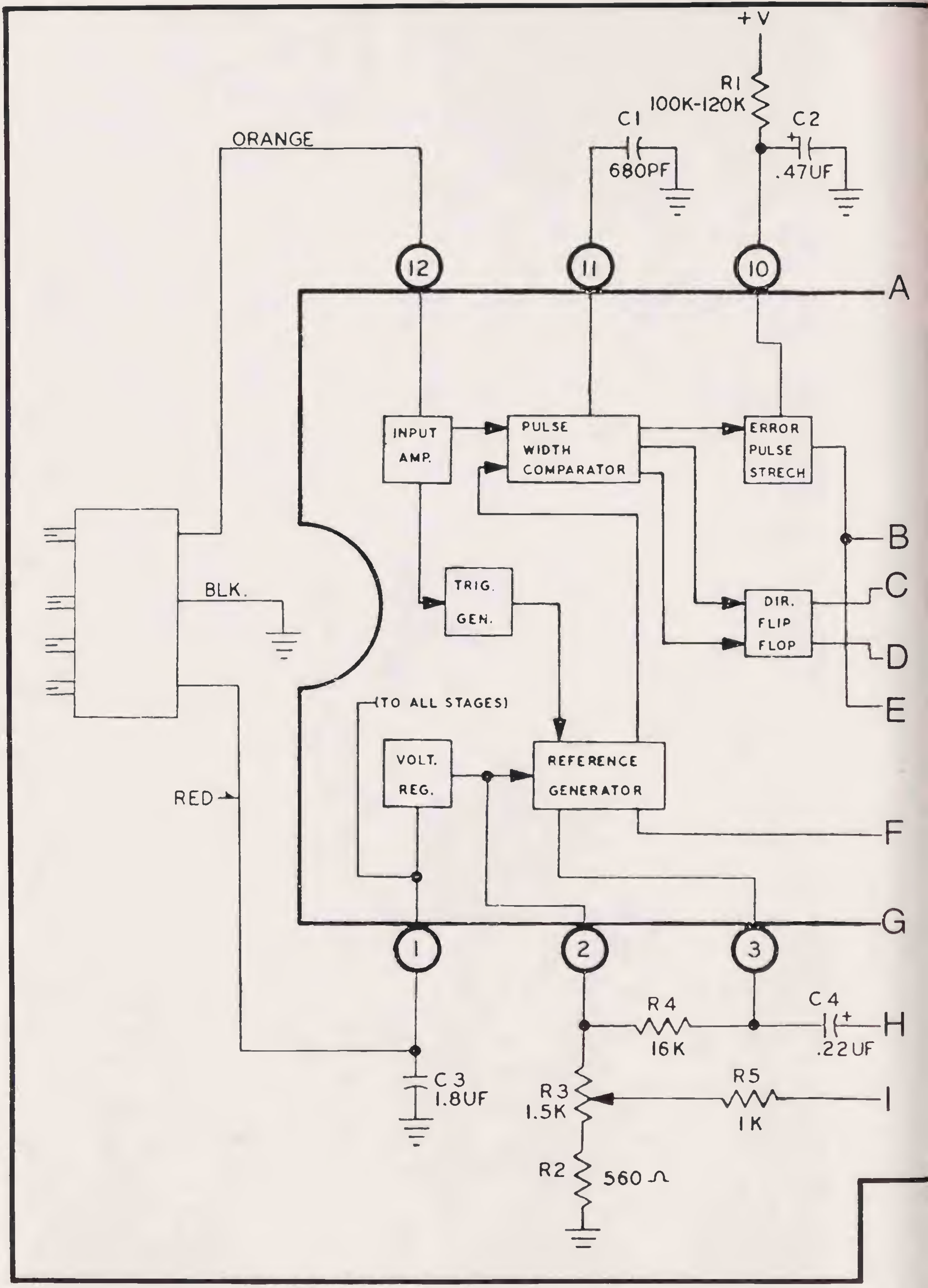


Fig. 2-12. A small R/C superhet (Ace R/C).



- No flip-flop will respond to a clock pulse; that is, Q becomes a 1 (positive) unless S is a 1 at the time the clock pulse is received.
- If the clear line is a 0 (negative), none of the registers will shift and any that are a 1 will be cleared or set to 0.

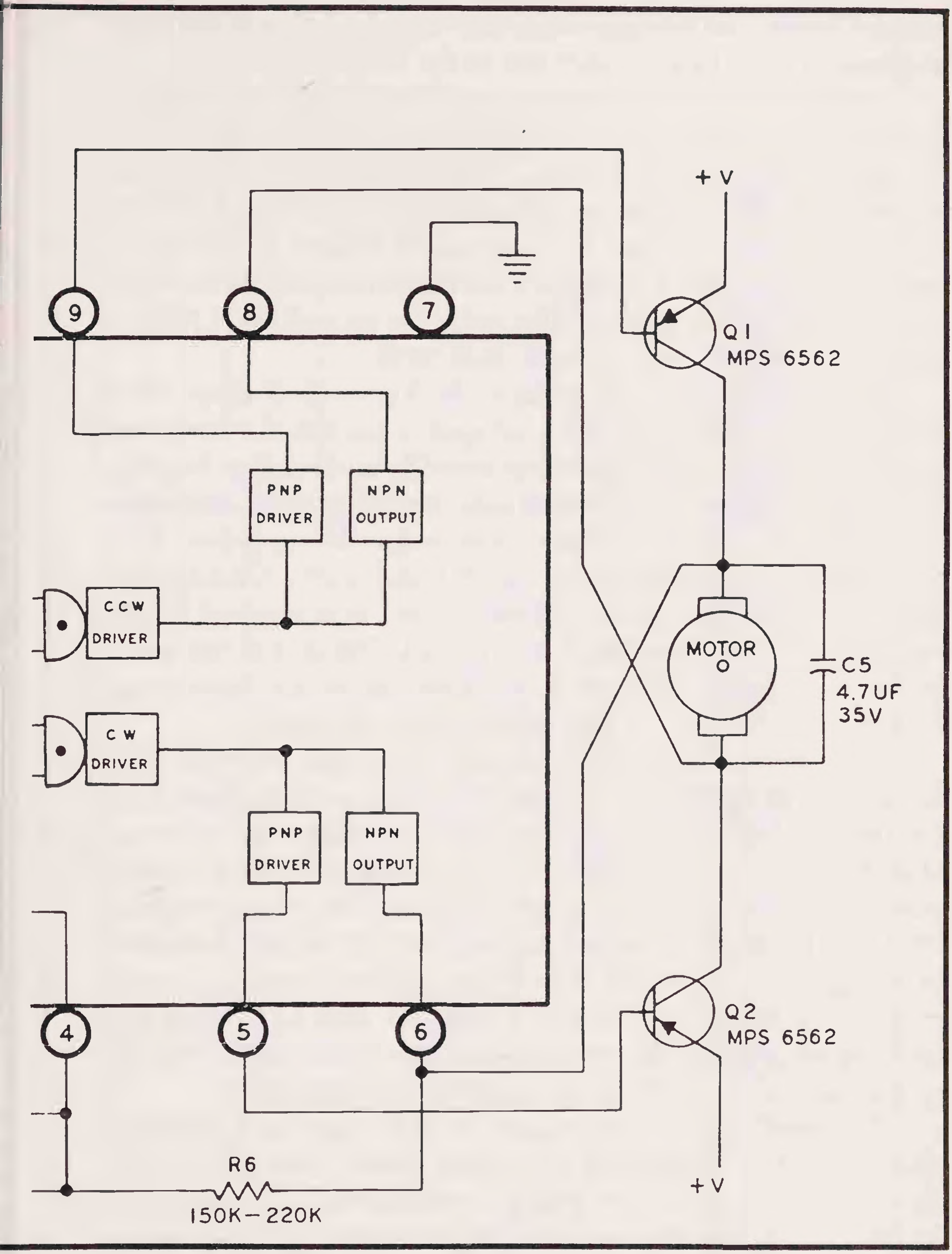


Fig. 2-13. A digital system servo system. (Kraft)

- Making SA or SB a 1 (positive) permits the first flip-flop to clock; that is, Q1 becomes a 1, upon receipt of the first clock pulse. (SA is set A, SB is set B).

The way the flip-flops work is as follows: It shifts its binary 1 (high voltage) back and forth between Q and not-Q each time a clock pulse is received. Whenever Q is positive (1), not-Q is negative (0), and vice versa. The two functions used for control are entered at the set input of FF-1 (the S input) and at the clock input.

When there is no information present during the synchronization pause, or set period, Q for FF-1 through FF-8 is 0. As soon as the first clock pulse is received, FF-1 shifts to Q and becomes positive, and as stated before, not-Q becomes negative. FF-1 cannot shift to Q unless it sees a 1 or a positive level at SA/SB (pins 1 and 2), which it does at the instant the first clock pulse is received. The Q for FF-1 remains positive until the second clock pulse is received, at which time it reverts back to 0.

If S for FF-1 were to remain at the 1 level at all times, FF-1 would simply shift back and forth between Q and not-Q every time a clock pulse was received, and there would be no decoding. Thus the set pulse was driven to 0 an instant after the first pulse was received, as mentioned a moment earlier. Now under this condition, FF-1 cannot shift again as long as the output from inverter 5 is negative; that is, it cannot shift until after all pulses have been received and the output of inverter 5 returns to the 1 level. This is why the pause between frames is called the synchronization, or set pause, since FF-1 is set to accept the first pulse during this pause.

Now, remembering what has been discussed, note that FF-2 cannot shift to Q unless its S sees a 1. It sees a 1 only when Q for FF-1 is a 1, which is during the first control pulse time. So, as soon as Q for FF-1 is a 1, FF-2 is set and free to shift to Q when the second pulse of the control group is present. This second pulse also returns FF-1 to 0. FF-2 shifts to Q until the third pulse is received to return it to not-Q, and so on, for the number of channels chosen, up to the maximum of this system, which is eight. As soon as C26 and C28 have discharged after the last pulse, the output of inverter 5 returns to a 1, and FF-1 is reset to be ready for the next frame.

The length of the control pulses are determined by the length of time (1.5 ± 0.5 milliseconds for control motion,) *between the clock pulses*. The sync pause is nominally 4 milliseconds and so the entire frame is 4 ± 1.5 milliseconds per channel nominally. This makes a frame rate about 65 per second for the 8-channel equipment.

Now we have a good idea of how the coding and decoding is accomplished in a modern digital radio control system. The use of integrated circuitry makes the oeprations, which used to be very complicated circuitwise, very straightforward and the circuitry very simple and compact. Of course if you have troubles you must have the proper test equipment (often expensive) to *see* what is happening, just as you do in servicing television sets. A very good oscilloscope is almost mandatory.

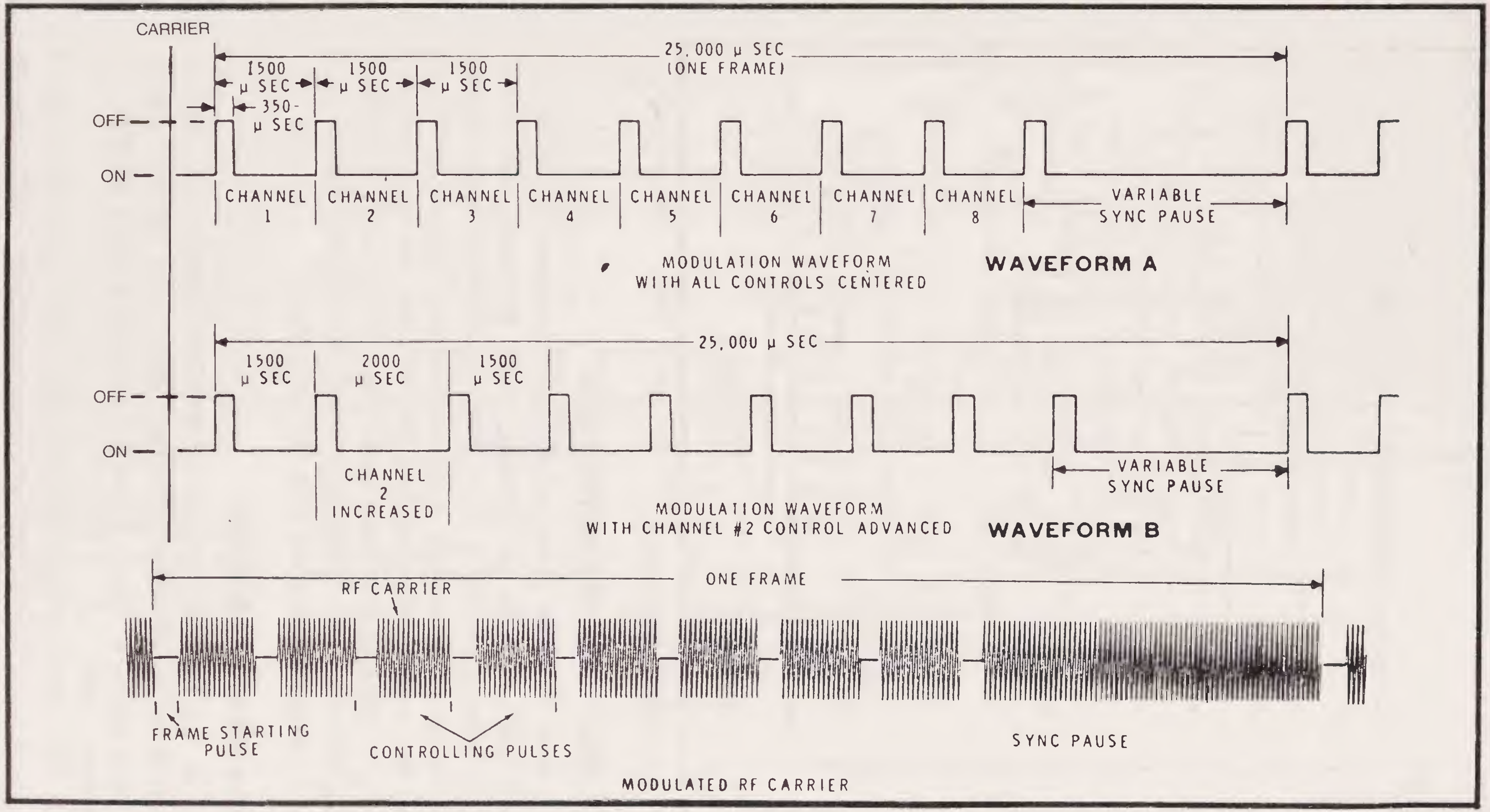


Fig. 2-14. Heathkit code for R/C coding system.

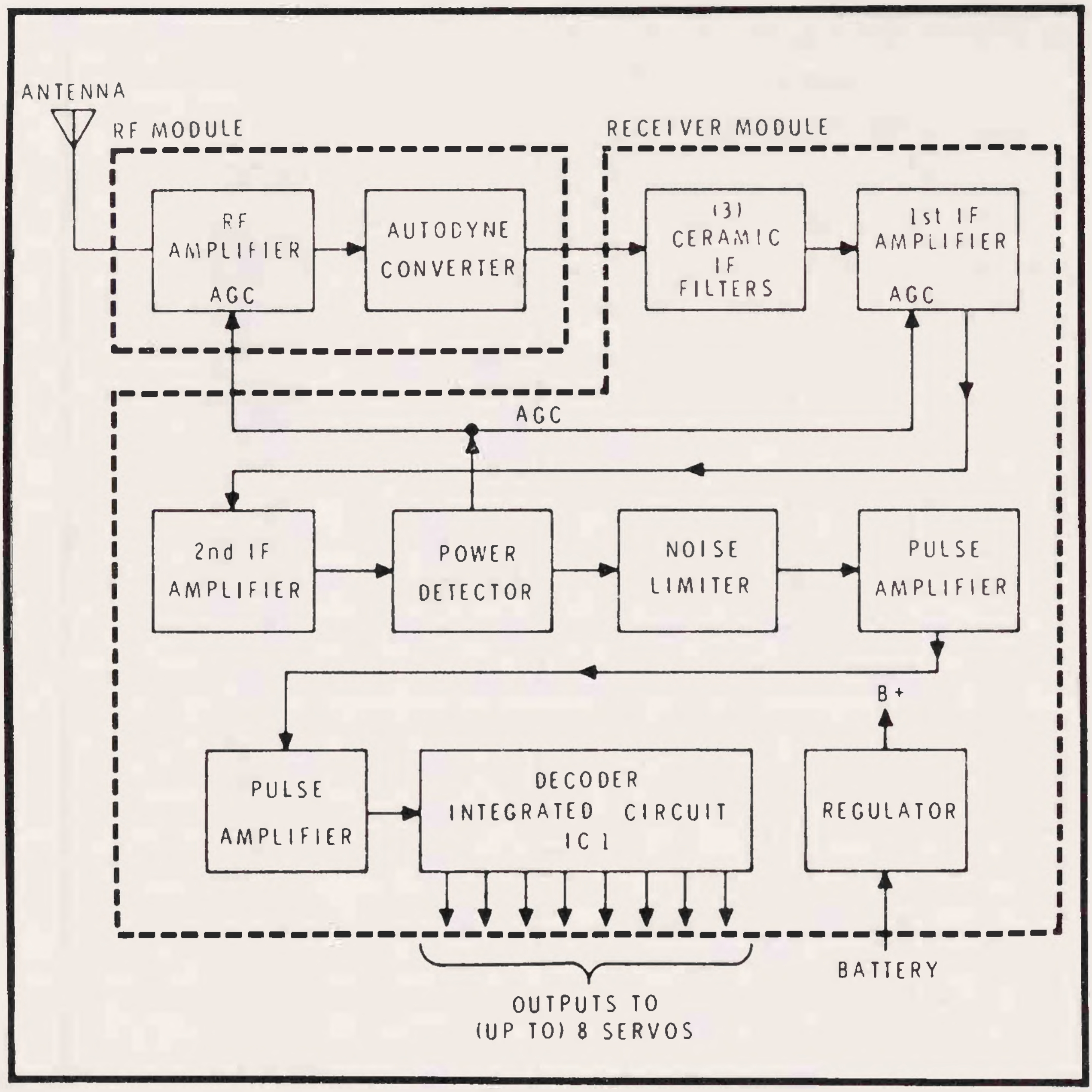


Fig. 2-15. Heathkit R/C receiver.

THE BINARY CODE AS A CONTROL CODE

In the systems discussed we have seen how the variation of pulse width or timing has given us control operations. We wish to mention that the binary system, that is the presence-omission type of code can also be used for control operations. This may become an important code for future radio-control systems, for models, as well as for commercial vehicles and devices. Of course it will require a computer coder and a computer decoder, but then, nowadays, we all have a computer of some type, do we not?

Binary Pulse Code Systems

In a pulse-code system the bits of a word are included or omitted to form particular commands. By omitting various combinations of pulses in, say, a 10-bit word, many possible subwords or patterns result.

This type of system is used by such remote-controlled vehicles as the Surveyor moon craft and other devices for which maximum

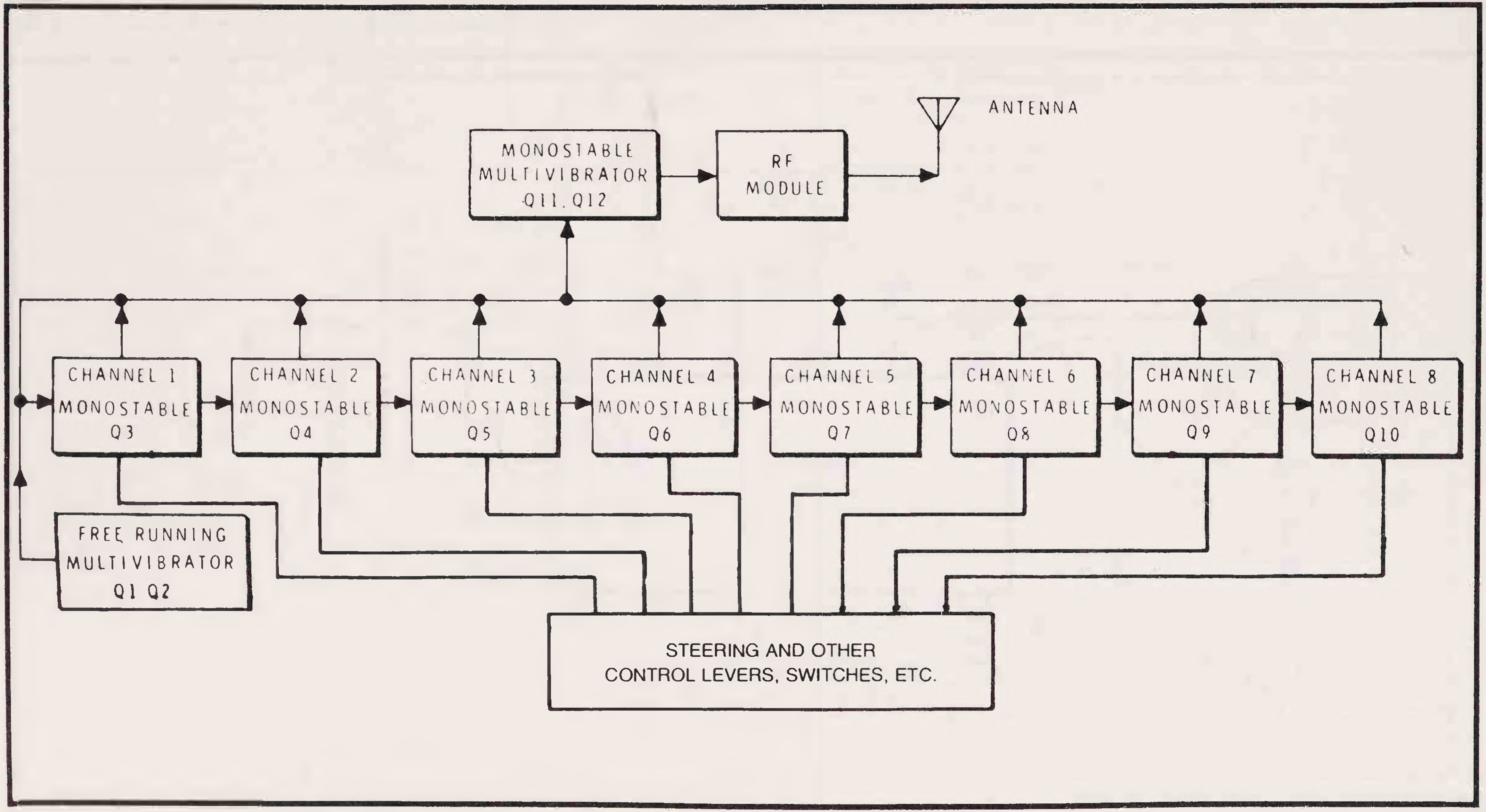


Fig. 2-16. Heathkit R/C transmitter.

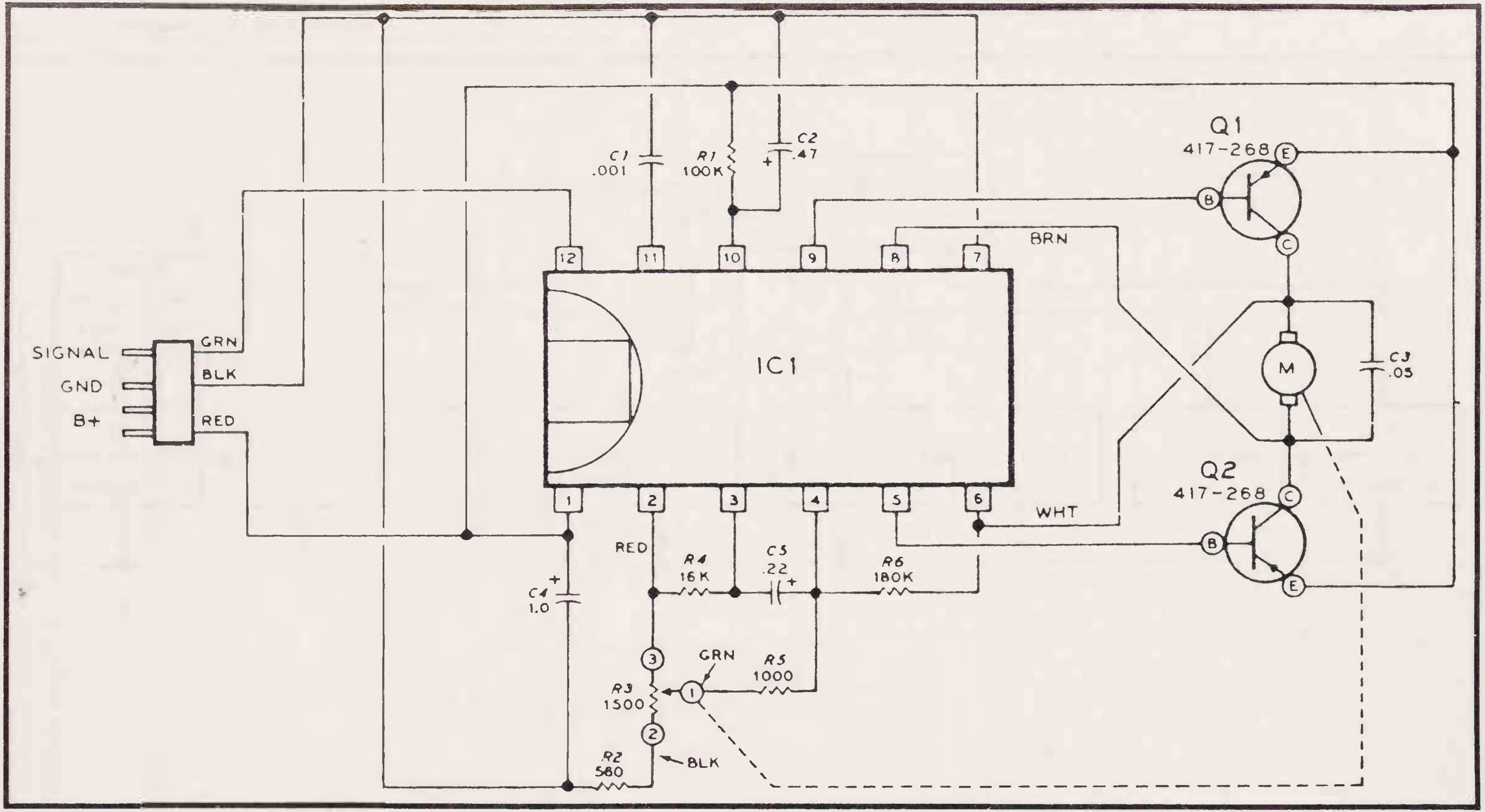


Fig. 2-17. The Heathkit GPA-1205-5 servo block diagram.

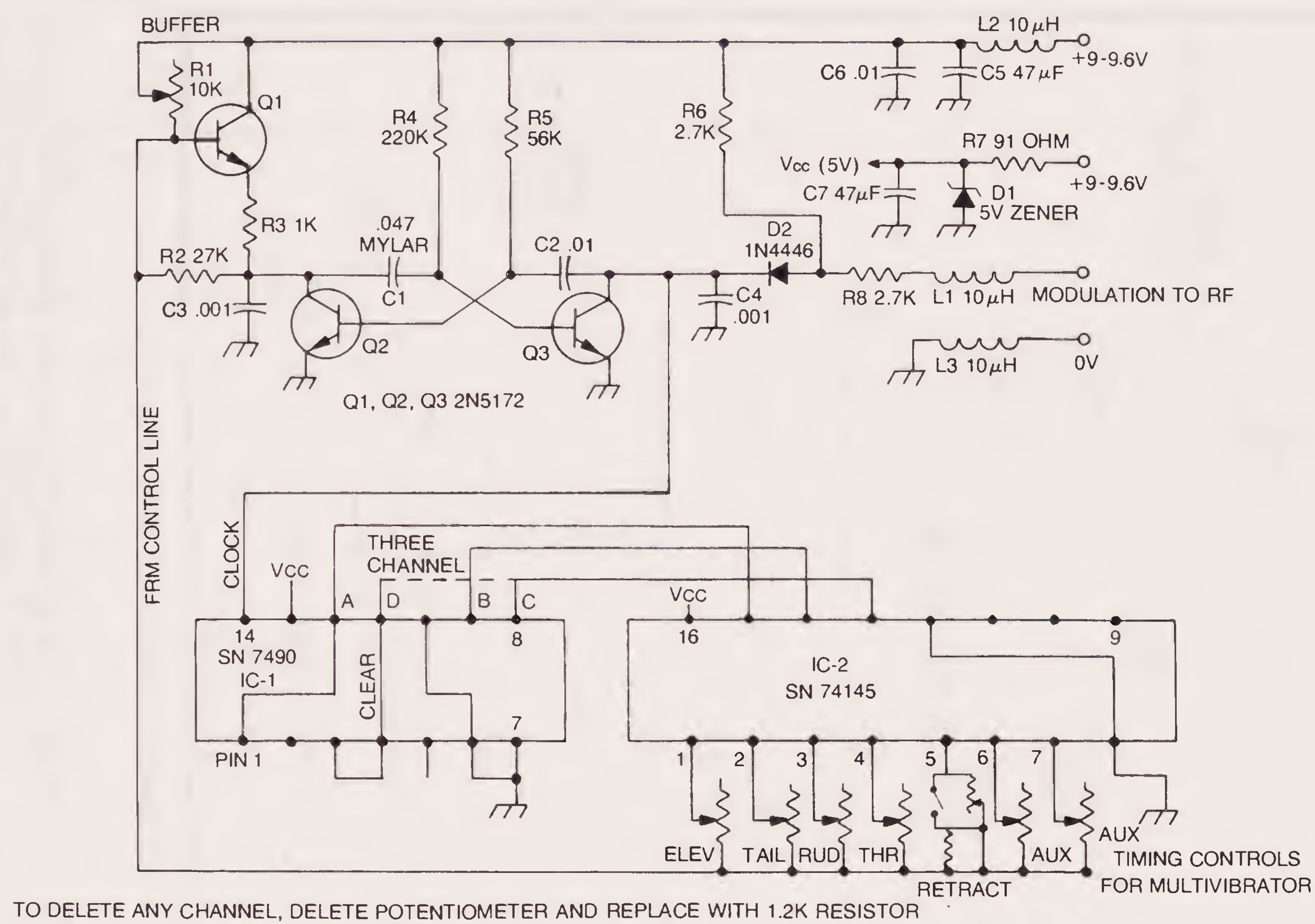


Fig. 2-18. Ace R/C digital commander encoder.

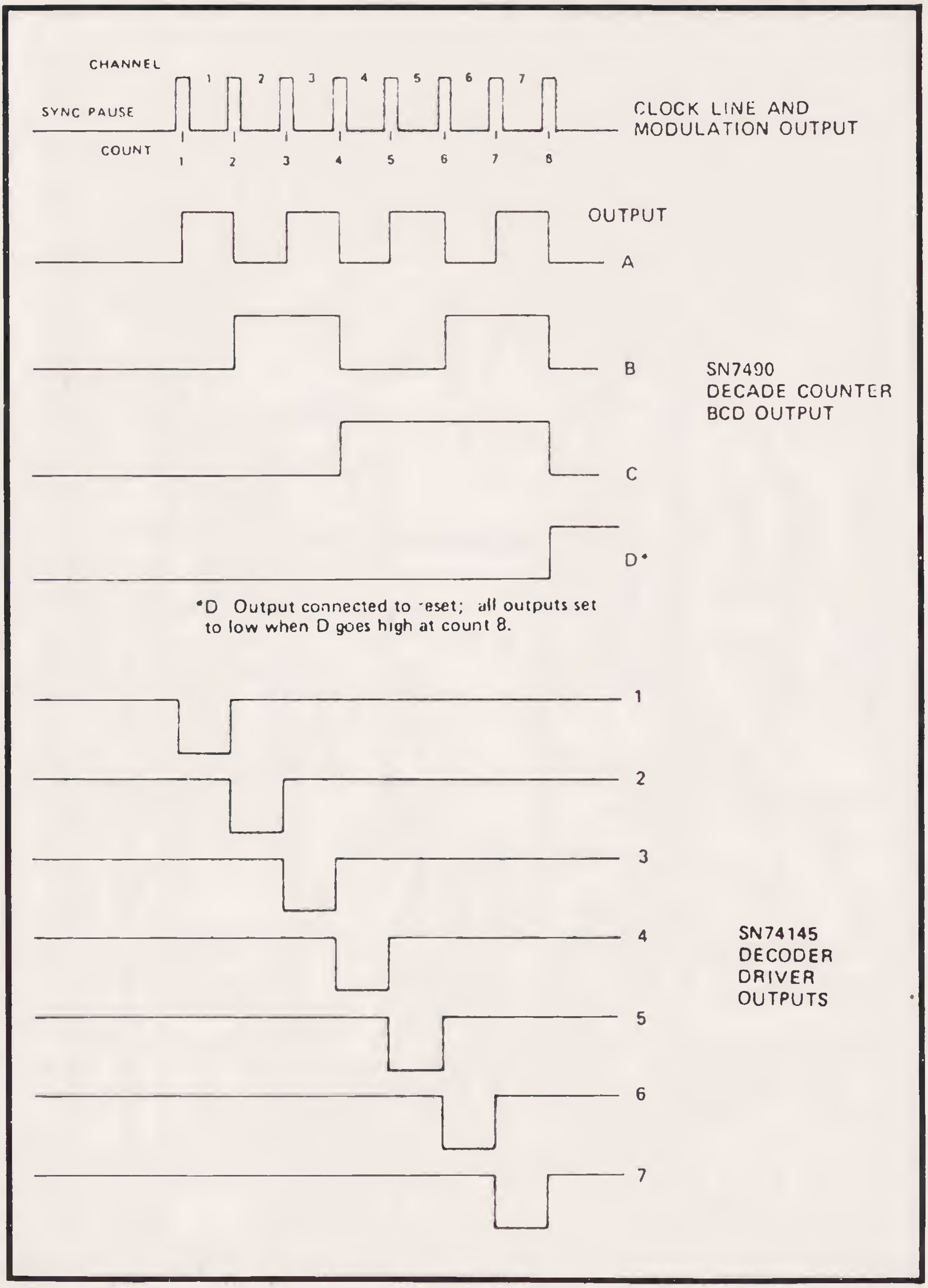
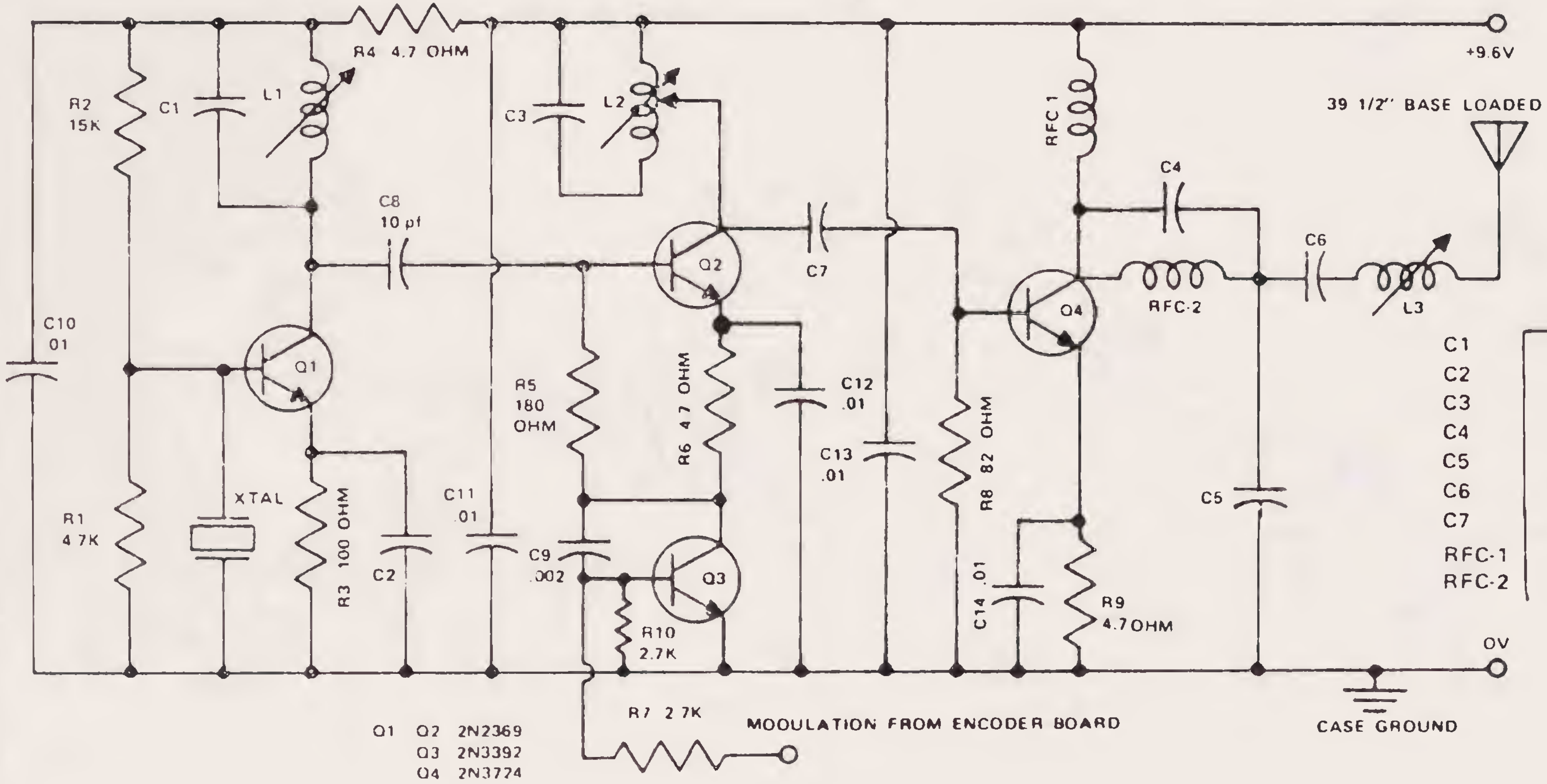


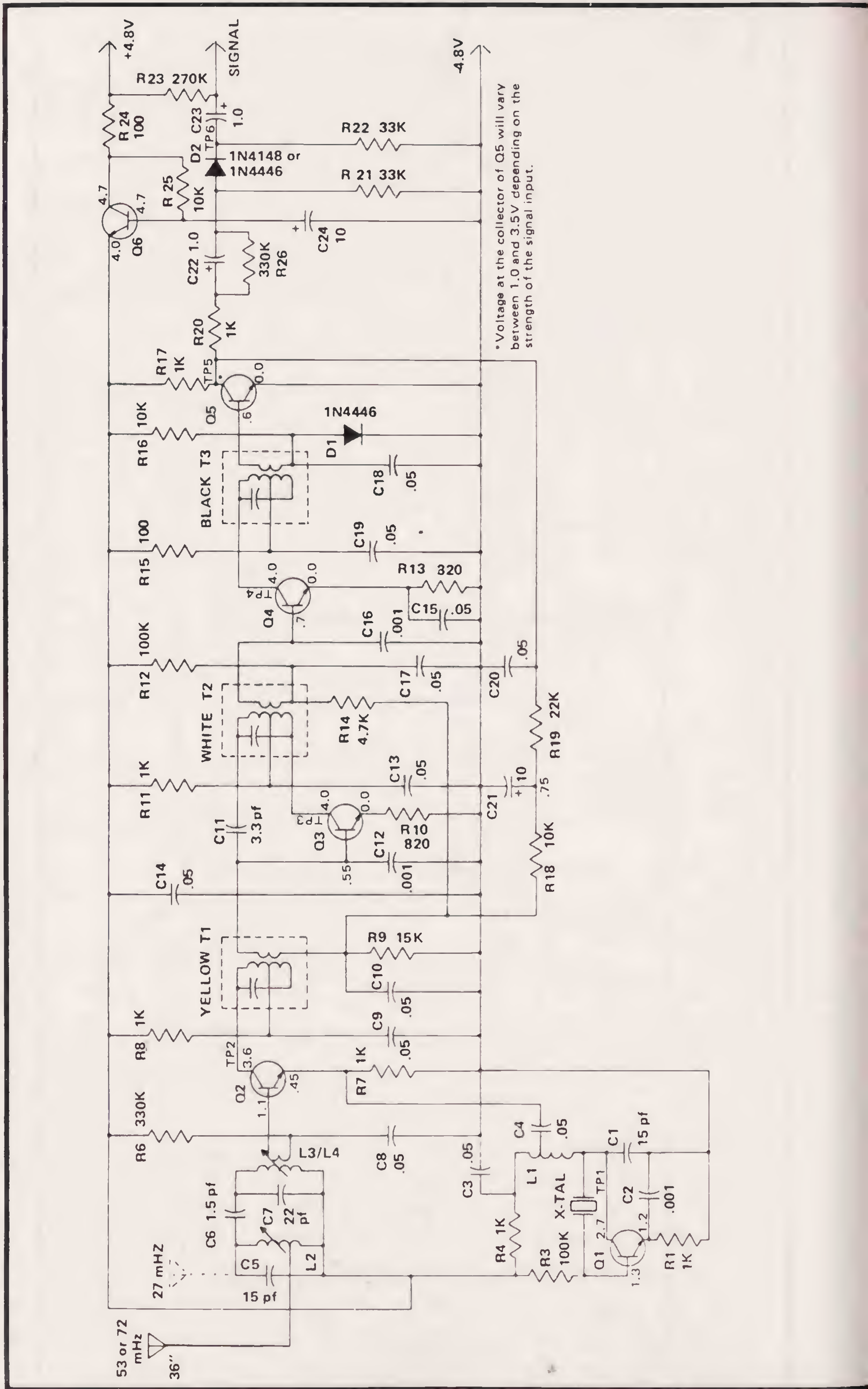
Fig. 2-19. Pulse level outputs of encoder.

reliability is required. The circuitry is a form of the multivibrator decoder we just discussed, in which gates are opened upon coincidence of pulses. Note, however, that the output will be a discrete group of commands, not proportional. Proportional control here is accomplished by making each command cause a very small movement. That is, one command may call for a 1° movement, a second for a 2° movement, and so on. Reliability is higher with this type of system becasue of the present—not-present idea. A receiver need

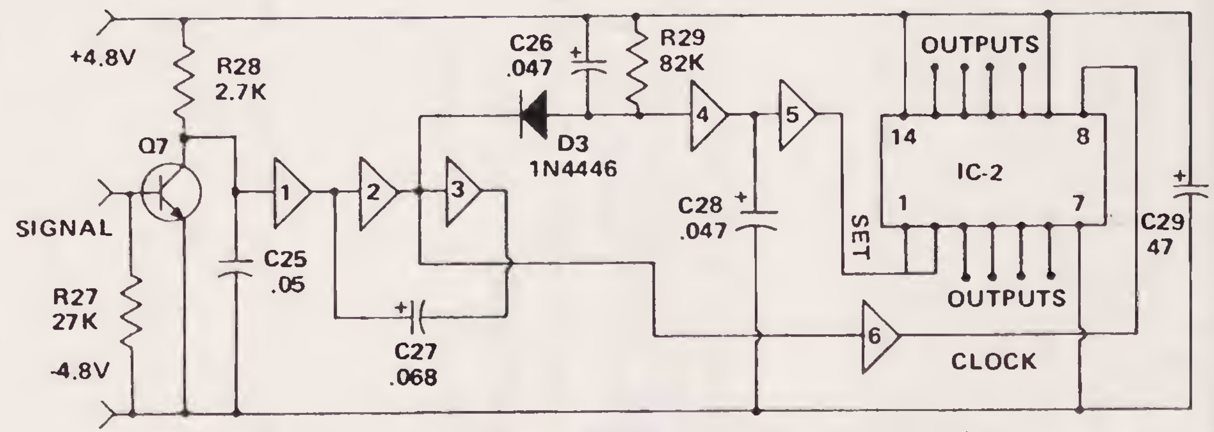


	27 MHZ	53 MHZ	72 MHZ
C1	33 pf	15 pf	3.9 pf
C2	62 pf	33 pf	33 pf
C3	33 pf	20 pf	25 pf
C4	47 pf	10 pf	6.8 pf
C5	33 pf	20 pf	15 pf
C6	10 pf	10 pf	3 pf
C7	62 pf	62 pf	25 pf
RFC-1	22 uH	4.7 uH	4.7 uH
RFC-2	.15 uH	.22 uH	.22 uH

Fig. 2-20. Ace Digital Commander transmitter circuit.


+4.8V
SIGNAL
-4.8V
*Voltage at the collector of Q5 will vary between 1.0 and 3.5V depending on the strength of the signal input.
R23 270K
R 24 100
C23 1.0
TP6
D2 1N4148 or 1N4446
R22 33K
R 21 33K
R 25 10K
Q6
C24 10
C22 1.0
330K R26
R20 1K
R17 1K
TP5
Q5
1N4446
D1
R16 10K
BLACK T3
C18 .05
R15 100
C19 .05
R13 320
C15 .05
Q4
TP4
C16 .001
R12 100K
C17 .05
C20 .05
WHITE T2
R14 4.7K
R19 22K
R11 1K
C13 .05
C21 10
Q3
TP3
R10 820
C11 3.3 pf
C12 .001
R18 10K
C14 .05
YELLOW T1
R9 15K
C10 .05
R8 1K
C9 .05
TP2
Q2
R7 1K
R6 330K
C8 .05
L3/L4
C4 .05
C3 .05
L1
C1 15 pf
C6 1.5 pf
C7 22 pf
X-TAL
TP1
C2 .001
R4 1K
R3 100K
Q1
R1 1K
27 mHZ
C5 15 pf
L2
53 or 72 mHz
36"

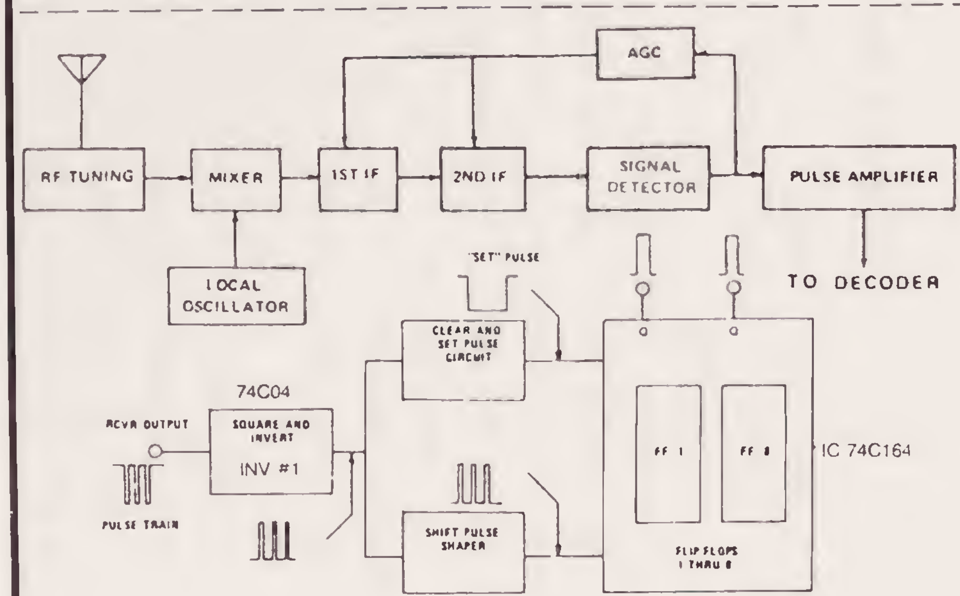
Voltages taken with incoming signal present.



INVERTERS 1-6 = IC-1, 74C04 SHIFT REGISTER = IC-2, 74C164

NOTES:

1. ALL CAPACITORS MF UNLESS OTHERWISE NOTED
2. Q1 2N/PN3646
3. Q2, Q3, Q4 2N/PN3563
4. Q5-2N2925; Q6-2N5088; Q7-2N4124 or 2N4400
5. L1 TAPPED RF CHOKE
6. SCHEMATIC INDICATES VALUES FOR 72 MHZ. CHECK LEGEND FOR 27 AND 53 MHZ CHANGES.



VALUES REQUIRED FOR FREQUENCY BANDS:

FREQ.	C1	R1	R3
53/72 MHz	15 pf	1K	100K
27 MHz	47 pf	470 OHM	47K

Coils L2 and L3/4 are wound differently for each frequency band. These coils, plus the crystal, plus the components indicated to the left must be changed if the frequency band is changed.

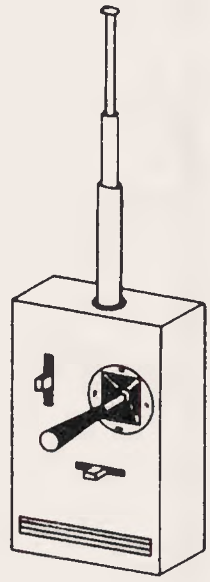
Fig. 2-21. Ace Digital Commander receiver and decoder.

not detect fine changes; it needs only to decide whether a command is there or not. In spacecraft, the equipment itself may be subjected to influences that could cause changes in pulse spacing or width—but normally a pulse will not be spuriously created. This alone, even if a pulse may sometimes be lost, helps to increase the reliability. Of course commands are repeated constantly. As of this writing, no model systems I have been able to discover use this method.

SUMMARY

We have had a good examination of codes and systems in this chapter and have spent much time on the digital systems currently in use and which will be in use for years to come. When you go to the flying field near you the next time, look over the digital transmitters that are impounded and realize how they work and what they can do in giving you the finest radio control ever over your models.

3
Radio Control Circuits



This chapter is devoted to various types of electronic circuits vital to radio-control systems. There are many variations of the same kind of circuit. These are included because some circuits often work better than others, although both may do exactly the same job. If one circuit doesn't perform as you think it should, it is always nice to have an alternate circuit to try. That's the reason we have provided at least one of each circuit commonly used in radio control and communications.

TRANSISTOR OSCILLATOR CIRCUITS

Oscillators are used in transmitters to generate carrier frequencies and control signals. They are used in superheterodyne receivers to improve selectivity and sensitivity. They are used as filters in decoders. Let's examine the circuits of Fig. 3-1.

With the new frequencies in the 70-MHz range, it is good to know that one can purchase an oscillator that's ready to use.

The circuit at (c) meets the FCC requirements for stability and tolerance. All circuits of Fig. 3-1 have feedback of some type; Fig. 3-1a uses a tapped coil, Fig. 3-1b is a variation of a tri-tet oscillator, and Fig. 3-1c uses both the idea of a tri-tet and a tapped coil. Figure 3-2 shows a typical oscillator.

Now examine the circuits of Fig. 3-3a and b. They have the crystal directly between collector and base and are a form of *Pierce* oscillator. This type is commonly found as the local oscillator in receivers of the superheterodyne variety. Circuit (c) is suitable for

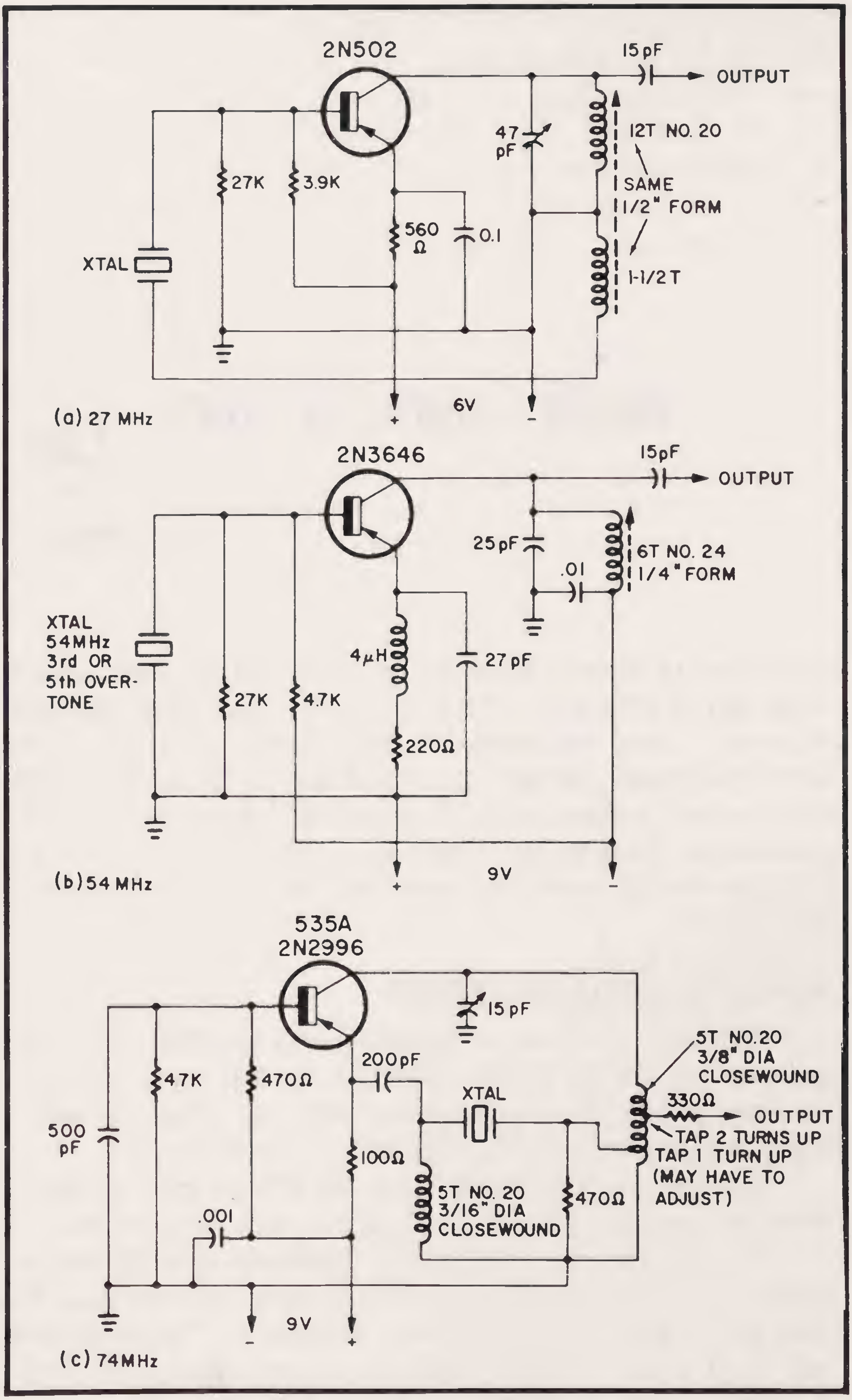


Fig. 3-1. Transistorized oscillators for 27.54 and 74 MHz.

one of the new higher frequencies and uses a Peterson Radio Co. Z-9 fifth-overtone crystal.

The circuits of Fig. 3-4 are still further variations.

In Fig. 3-4a a tapped coil is used again, but the crystal is connected to the emitter instead of the base. Circuit 3-4b, again a form of Pierce oscillator, has a link-coil output instead of the capacitor in other circuits. The 54-MHz oscillator of Fig. 3-4c is a tri-tet circuit with a link output, designed to work from a 12-volt source.

In Fig. 3-5, two further-out versions of crystal circuits are shown. Each might be used as test equipment, although the tunnel-diode circuit, courtesy GE, is suitable for receivers. If we connect the output of a tone oscillator to the circuit of Fig. 3-5b we can test reed-type or filter decoders. We might also use this oscillator as a low-power, short-range transmitter for radio-control experiments around the house.

Before examining the next section of circuits, a word of caution to all builders of radio-control equipment. The FCC does have regulations governing the construction of radio-control transmitters, especially the frequency tolerances and radiation of spurious signals. You can order Volume VI of the Rules and Regulations, which contains Part 95, applicable to model radio control in the 27-MHz Citizens band and the 70-MHz R/C band. Send $1.25 to the Government Printing Office, Washington, D.C. 20402, and request publication FCV-6. Part 15, which deals with low-power communication devices (such as CB and radio-control units with DC power inputs to the final stage of 100 mW or less), is available in Volume II,

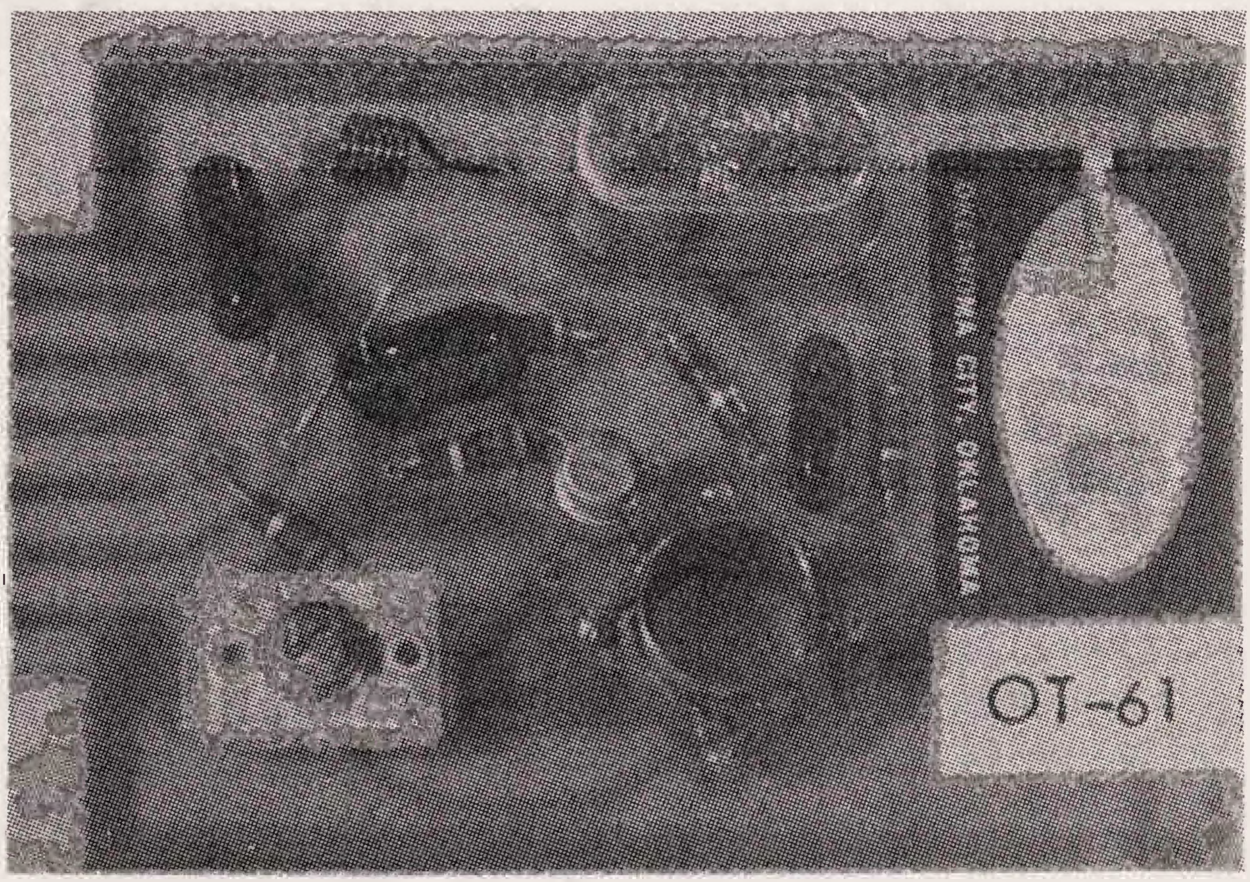


Fig. 3-2. A 74-MHz crystal oscillator, model OT-61, by International Crystal Co., Oklahoma City, Okla.

which you can order from the GPO for $2 (ask for publication FCV-2). Also be careful with metal push rods when using the 70-to-74-MHz band. These can resonate if their lengths are correct. Best to use hard balsa push rods in model-aircraft installations.

SUPERREGENERATIVE DETECTOR CIRCUITS

The superregenerative circuit has been responsible, more than any other, for the tremendous growth of radio control. It detects a modulated signal and tends to reject noise and interference, it is small, light and easy to build and adjust, and it has tremendous gain. It does radiate at the frequency it's tuned to, however, and so you must be careful when using one around other receivers on the same frequencies, because there may be interaction between them.

The circuits shown in Fig. 3-6 are suitable for 27 MHz (a) and 70-to-74 MHz (b).

The circuits of Fig. 3-7 are for even higher frequencies. The amateur 2-meter band (144 to 148 MHz) is within the range of the circuit in Fig. 3-7a.

The final group of superregenerative detector circuits is shown in Fig. 3-8 and 3-9.

In circuit 3-8a, the feedback control is a 1- to 8-pF capacitor. In (b) the circuit is a modified Colpitts using a split capacitance across the tank. The circuit in (c) uses a tapped coil and so falls into the Hartley circuit family.

All these circuits are currently in use in radio control. Some may work better than others in your particular application. There are enough here so that at least one should fulfill your requirements.

THE AUDIO-SUPERHET RECEIVER

It is interesting that the thinking of some years back produced an *audio* superheterodyne. This circuit developed a good many years ago, is based on the fact that if a signal of, say, 27 Mhz is received by a circuit which has an oscillator producing 27.001 or 26.999 MHz, the result is a 1-kHz *audio* best which can be amplified in a regular audio amplifier. The advantage of this circuit would be that no audio circuits are required in the *transmitter*, but the receiver would operate to all intents and purposes just as though the transmitter were a tone-transmitting type. Note the difference between this and the conventional superhet, in which the incoming rf signal is beat with another (locally generated) rf signal, producing an intermediate frequency (i-f) still in the *radio*-frequency range.

In the circuit shown, from the *DC–RC Newsletter*, the output of the local oscillator is fed to a balanced mixer. The mixer

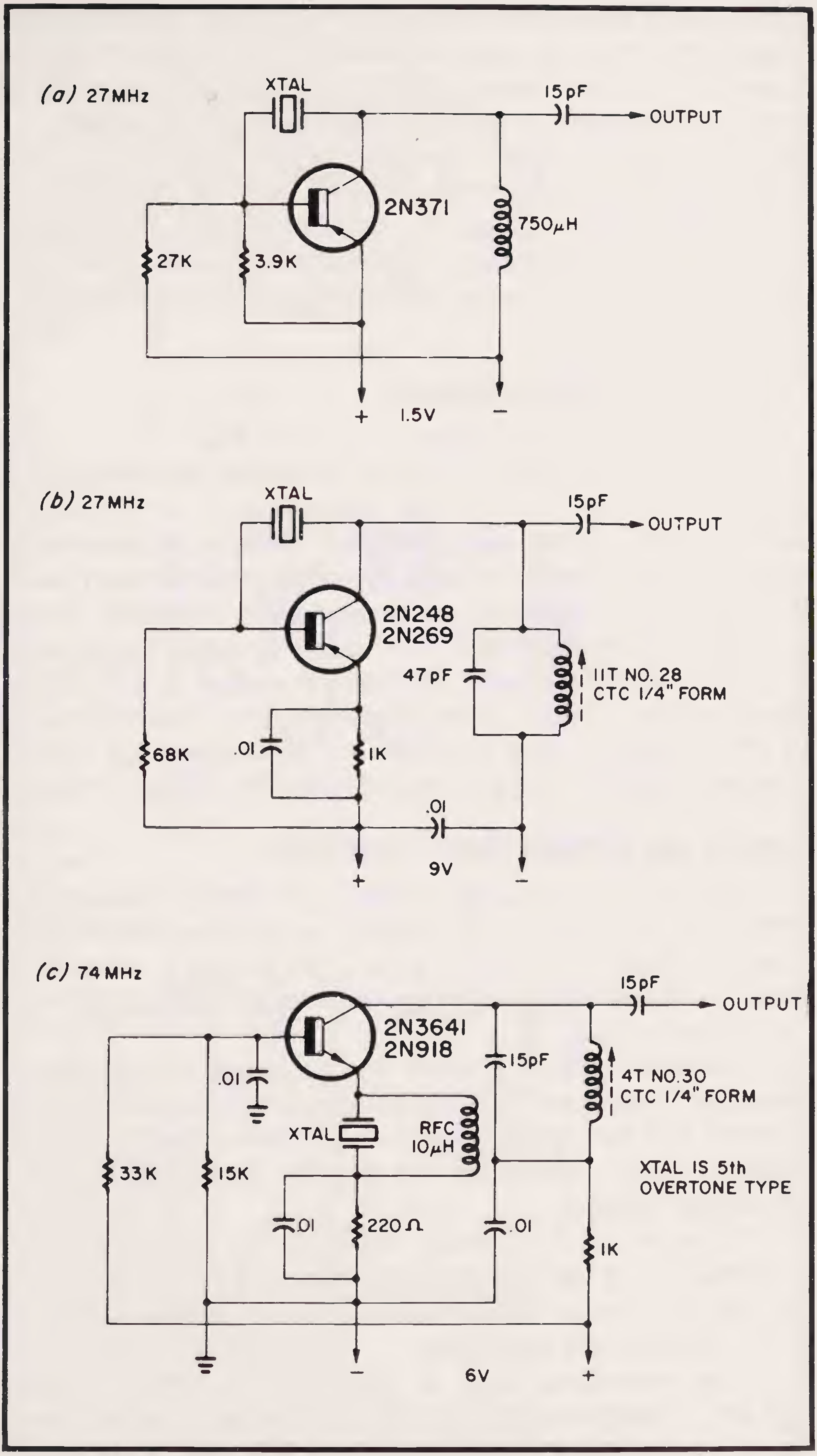


Fig. 3-3. Pierce-type crystal circuits.

using a bifilar-wound coil, cancels out the rf. Notice that there is an electrostatic shield between the primary and secondary of the antenna coil. Also notice that one might use a harmonic of the crystal as the beating frequency so that the crystal would not be operating on the same frequency as the transmitted signal. Since it is virtually impossible to grind two crystals to *exactly* the same frequency, one might just order two crystals for, say, 27.255 Mhz. There would probably be 500- to 1,000-Hz difference between them, but they would still be within tolerance. One would be used in the transmitter, and one in the receiver.

THE SUPERHETERODYNE RECEIVER

The basic superhet receiver is shown in Fig. 3-10.

In this receiver, the i-f stages are neutralized with small 10-pF capacitors connected between one end of each i-f transformer and the input of the corresponding transistor. The i-f is 465 kHz and the transformers are readily available. A transistor-substitution manual will find you other transistors than those listed. The circuit is conventional and straightforward. It is a superhet circuit that requires no neutralization, because of the type of transistors it uses. Notice that a Clevite crystal filter is incorporated to increase the selectivity of the circuit and prevent interference. This receiver, Fig. 3-11, is suitable for receiving very-high-speed pulses for the digital coding.

MODULATION METHODS WITH TRANSISTORS

Methods for modulating transistors are similar to those used with vacuum tubes, but often simpler. There is the equivalent of the plate modulator, grid modulator, etc. The circuits to follow have been selected to illustrate, as much as possible, each type of modulator in use.

Figure 3-12 shows a simple modulator that uses a filament transformer connected so that its primary or high-impedance side is in series with the voltage supply to a transmitter final-amplifier or oscillator section. The secondary is in the emitter circuit of the modulating transistor.

In the circuit of Fig. 3-12b, transistor Q1 modulates Q2 by controlling the voltage supplied to the base of Q2 via the 18- (or 20-) μF capacitor. This is a form of base modulation. Applied to tubes, it would be called grid modulation.

Two conventional forms of modulation are modified-*Heising* and plate (collector) modulation. In both, the collector (or plate) current is modulated. Figure 3-13 shows how this is done with transistors.

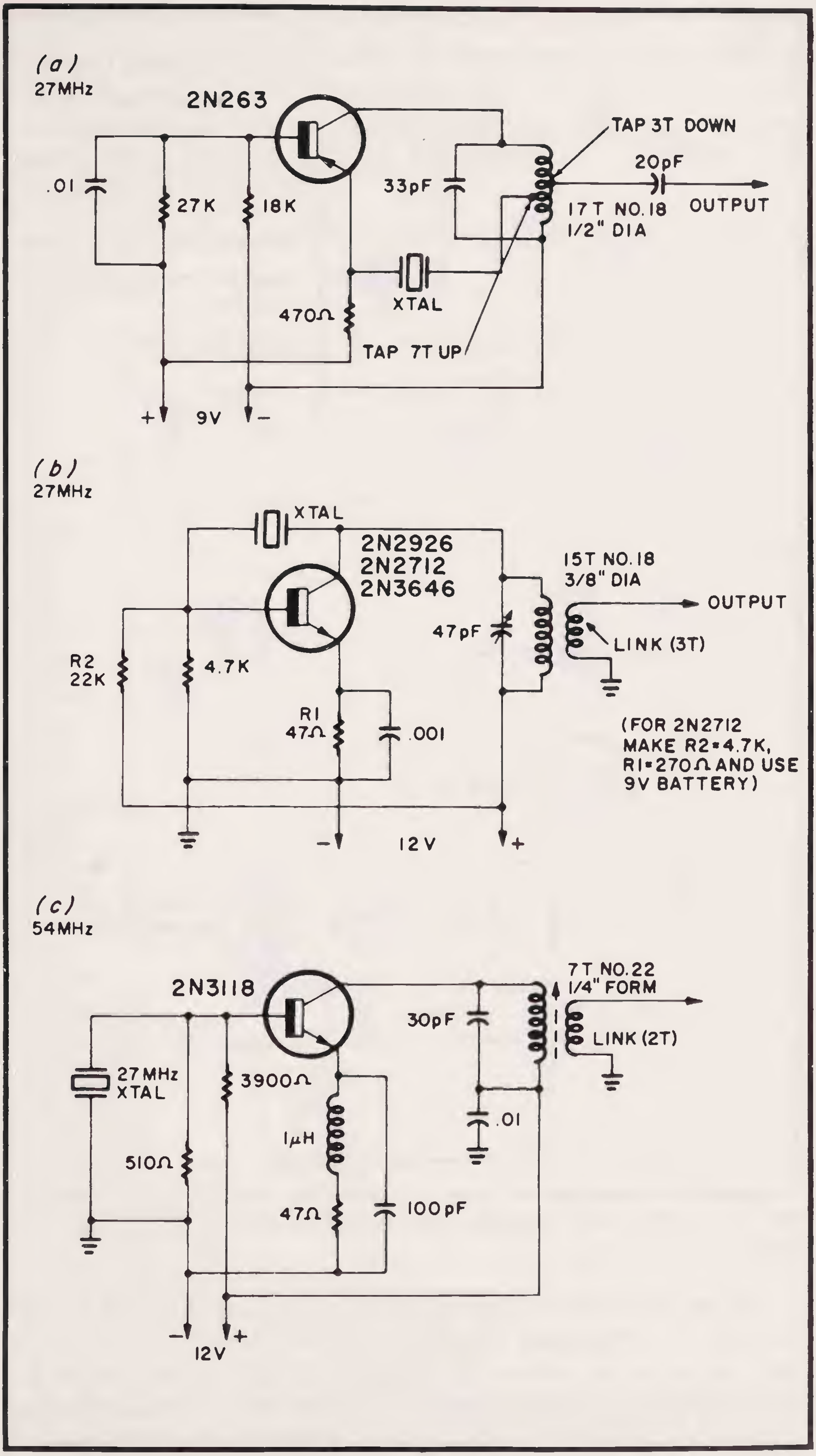


Fig. 3-4. 27- and 54-MHz crystal circuits.

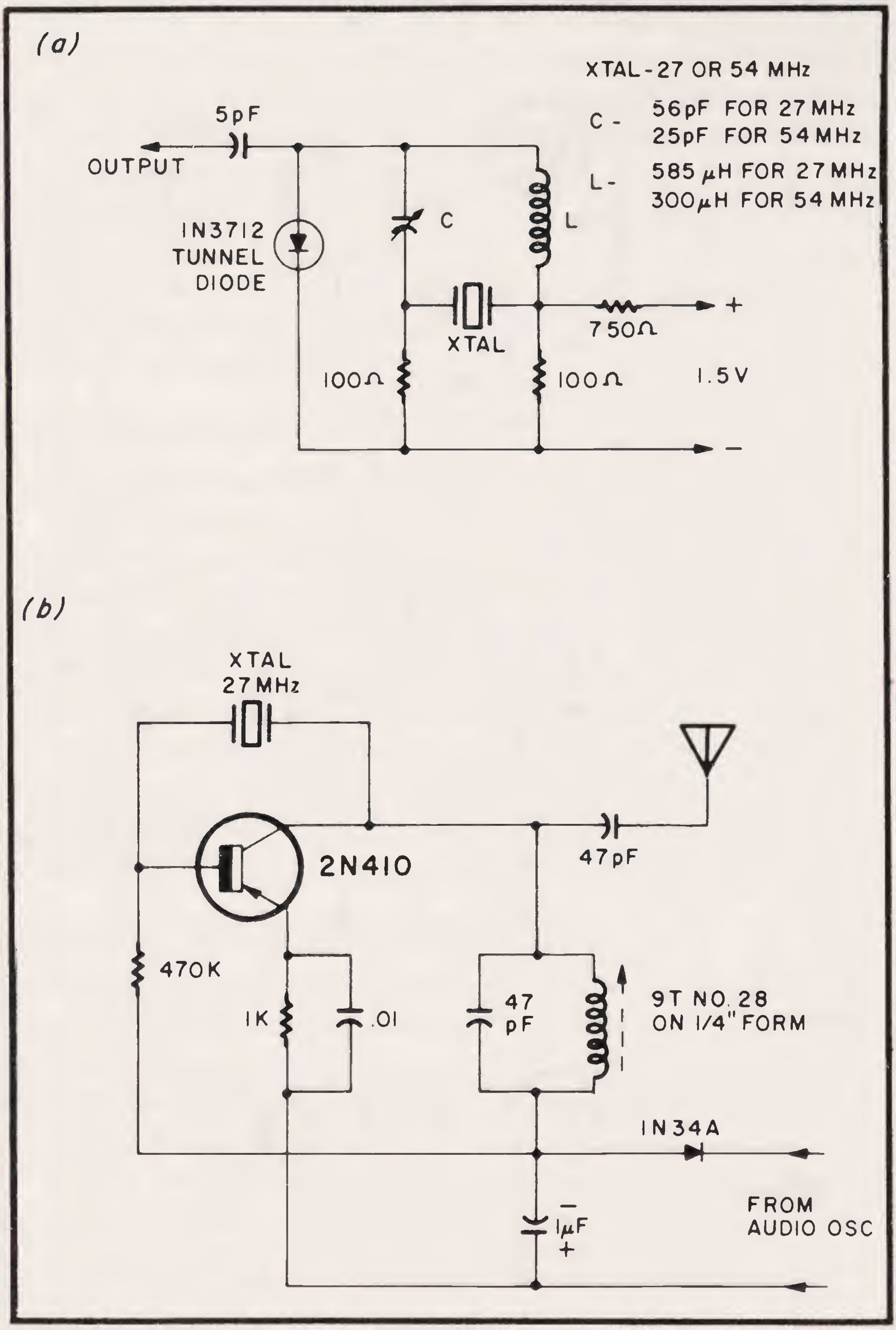


Fig. 3-5. A tunnel-diode oscillator and a tone-powered modulated oscillator for testing.

In (a), the collector current to the final rf stage is simply passed through the modulating transistor. This current is varied by the audio signal via the gain of the modulating transistor—a simple and effective method of modulation. It's a bit different from tube-Heising modulation, in which the tubes are effectively in parallel for the DC supply, not in series as the transistors are here.

In 3-13b we find a more conventional modulator, with a transformer. This transformer must be large enough to handle the currents in its primary and secondary, and its impedance ratio must match the modulator transistor to the final stage. Typical impedance values are shown in Fig. 3-13b. To calculate the modulation impedance of final, use:

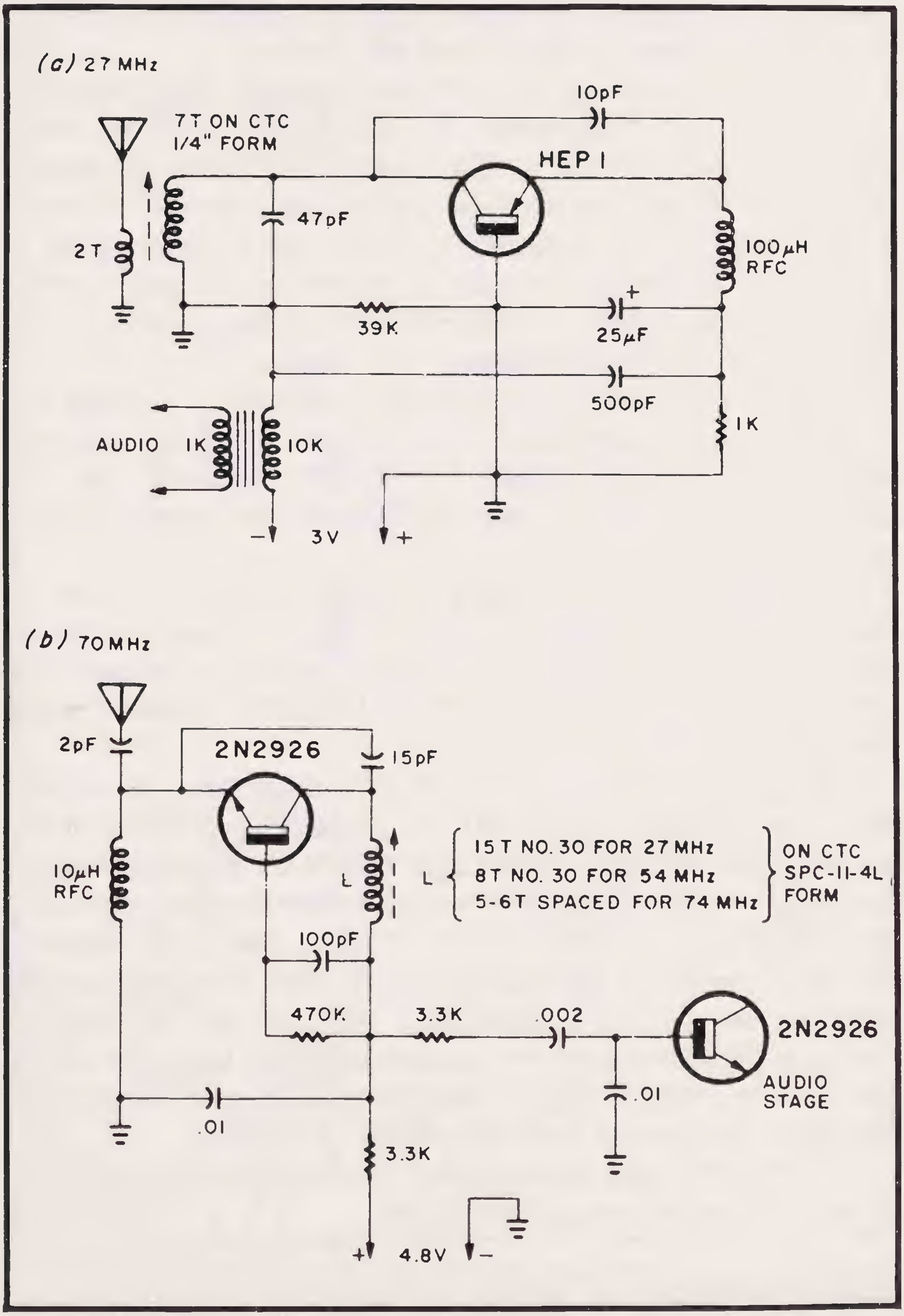


Fig. 3-6. Two types of superregenerative detectors. The circuit at (a) is designed to work into an audio transformer while that at (b) will feed a resistance—capacitance-coupled audio stage.

$$\text{Final impedance} = \frac{Cv}{Ca}$$
$$\text{Collector volts} = Cv$$
$$\text{Collector amperes} = Ca$$

The impedance of the modulator transistor can be estimated in a similar way, or obtained from transistor tables. The Fig. 3-13b circuit shows an untuned final stage, which is not as efficient as a tuned stage, but useful in test gear for short-range transmission, or to isolate the crystal oscillator from the antenna.

In Fig. 3-14a we see a modulated oscillator stage using the transformer-coupled modulator. The main requirement for a modulated oscillator is that the oscillator maintain its required frequency tolerance during modulation. Note that the impedance of the transformer primary is somewhat higher than in the previous circuit.

In part (b) of the figure we see a modulator preceded by an audio amplifier. Each of these circuits would be suitable for voice communication as well as radio-control tone signals.

Figure 3-15 shows two methods of modulation suitable for transmitting high-speed pulses. The outputs of pulsers are connected directly to these modulator transistors, which are turned off and on by the incoming pulses and interrupt the radio-frequency signal, producing rf pulses.

Of course these modulators, too, can be adapted for tone or voice signals. Note that in Fig. 3-15 the modulated signal is applied to the base, like grid modulation in tubes. In both of these cases the modulating transistor is simply connected between the base of the rf stage and ground.

The antenna network of Fig. 3-15b is interesting—an old reliable antenna-tuning circuit called a "pi" (because its schematic drawing resembles the Greek letter π) network. It allows tuning (almost) any length of antenna wire for maximum transmission efficiency. Normally, you adjust the antenna-side tuning capacitor for maximum reading on a meter in the collector circuit, then the transistor-side capacitor for minimum, continuing until you get the highest *minimum* (dip) when you tune the capacitor on the transistor side of the coil. No further tuning is necessary unless you change your antenna (or sometimes your transmitting frequency).

So much for types of modulators. You should be able to find one to suit your needs among those shown.

AUDIO AMPLIFIERS

Many audio-amplifier circuits have been published, so we won't dwell on them here. I do want to include the basic circuits shown in Fig. 3-16.

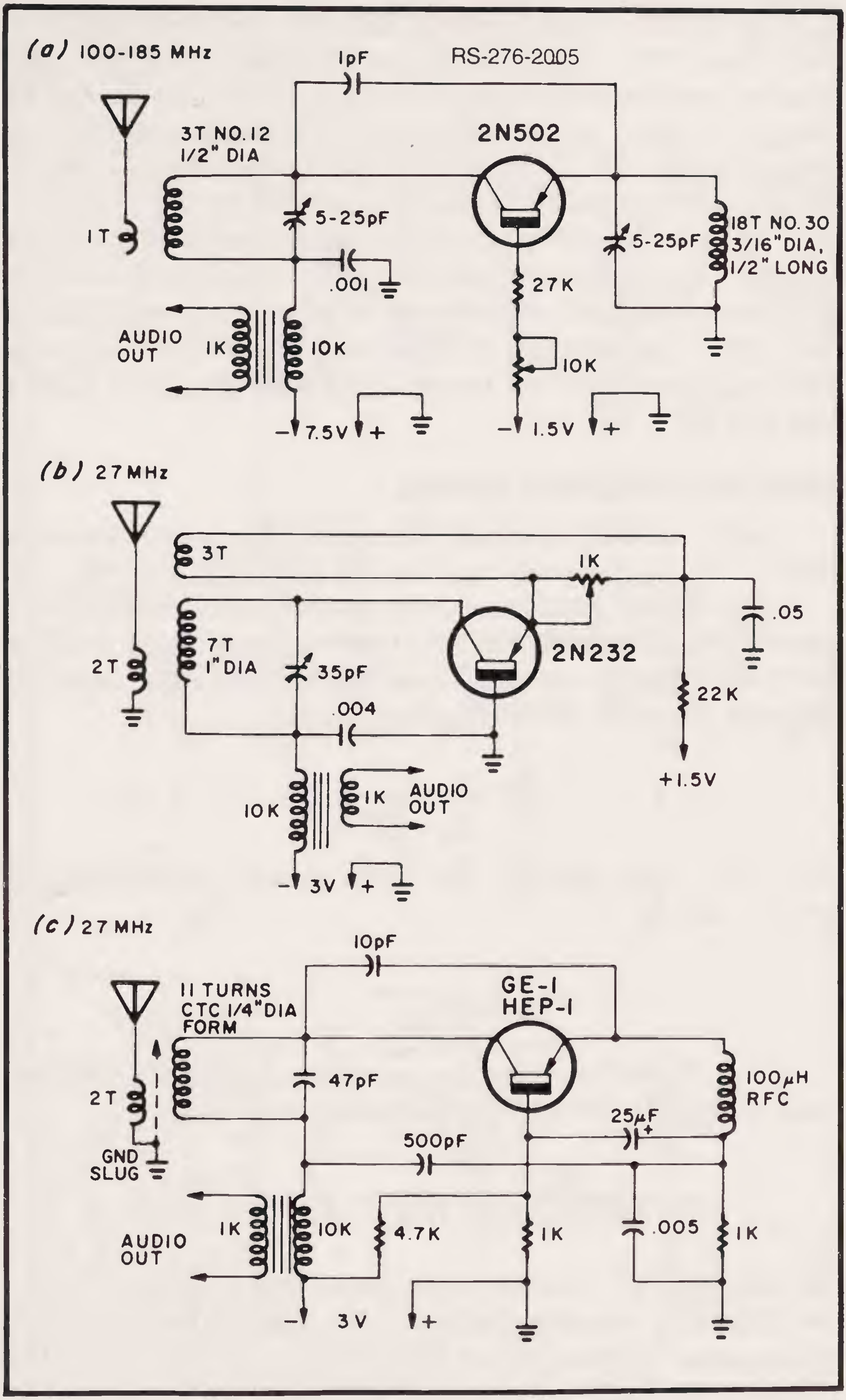


Fig. 3-7. Superregenerative detector for 100 to 180 MHz (a). The circuit at (b) has a conventional tickler type of feedback and is commonly used in Citizens-band equipment for voice detection. The 1K pot adjusts the amount of superregeneration. The circuit in (c) is a good performer, but ground the slug of the tuning coil. This circuit needs a supply of only 3 volts.

The first is a straightforward high-gain, low-power audio circuit, the second a direct-coupled current amplifier of a type much used with servomotors (the servomotor is connected in place of the relay). Normally, in this application, this circuit is paired with another to cause the motor to run in the opposite direction. Watch for this type of circuit in the schematics in this book.

The final circuit is a direct-coupled feedback-stabilized amplifier. The feedback improves frequency response and reduces the effect of transistor and temperature variations on performance. The output is shown going to a relay stage, but one might connect this also to a modulator in a transmitter or to further stages of audio amplification.

SOME TONE GENERATING CIRCUITS

Often, we want a circuit that will produce a tone for radio control. Two such circuits are shown in Figs. 3-17 and 3-18.

Both circuits produce tones to operate single-channel, reed-multichannel or audio-discriminator type equipment. In Fig. 3-17 the controlling elements are L1, C1 and the frequency-control potentiometer. The tone can be calculated from:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

or, if you know the capacitor value and frequency and want to find the correct value of L:

$$L \text{ (henrys)} = \frac{1}{39.5 f^2 C.}$$

As an illustration, assume a capacitor of $.05\mu F$ and assume we want a tone of 1,000 Hz. The inductance we need is:

$$\frac{1}{(39.5)\,(1000)^2\,(.05 \times 10^{-6})} = \frac{1}{19.7} = .051 \text{ H.}$$

An inductance of .05 henrys, adjustable ±10% would give the correct frequency. The potentiometer in Fig. 3-17 also has some effect on frequency. One would key this oscillator with a switch in the minus-voltage lead.

The circuit of Fig. 3-18 uses a colpitts oscillator, which means that the feedback is obtained from a "split" capacitor. This is a fine oscillator. The only requirement is that the ratio of C1 to C2 must be 2:1 or even a little larger. With the values shown, the circuit oscil-

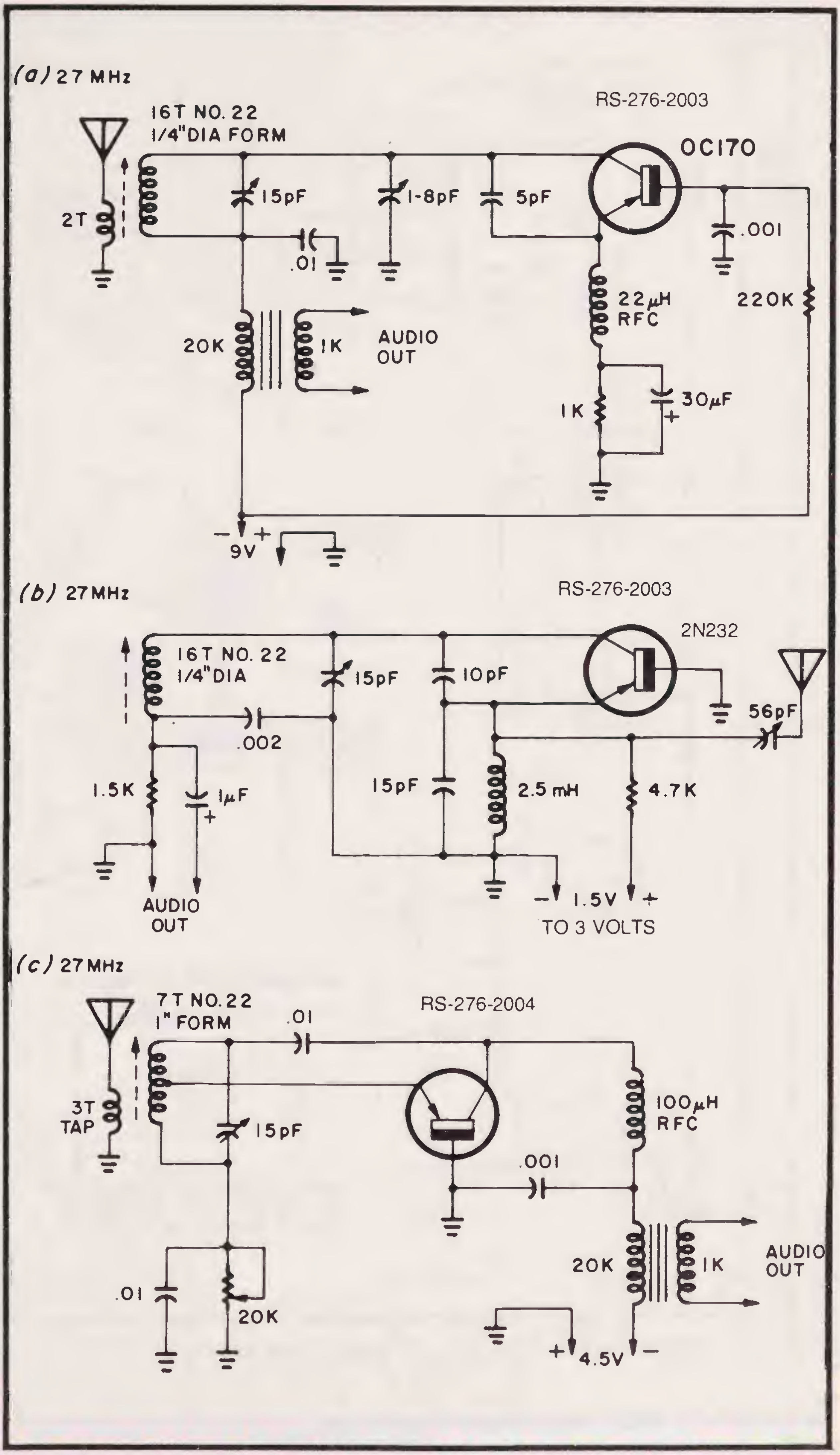


Fig. 3-8. Miscellaneous Superregenerative detector circuits using silicon transistors.

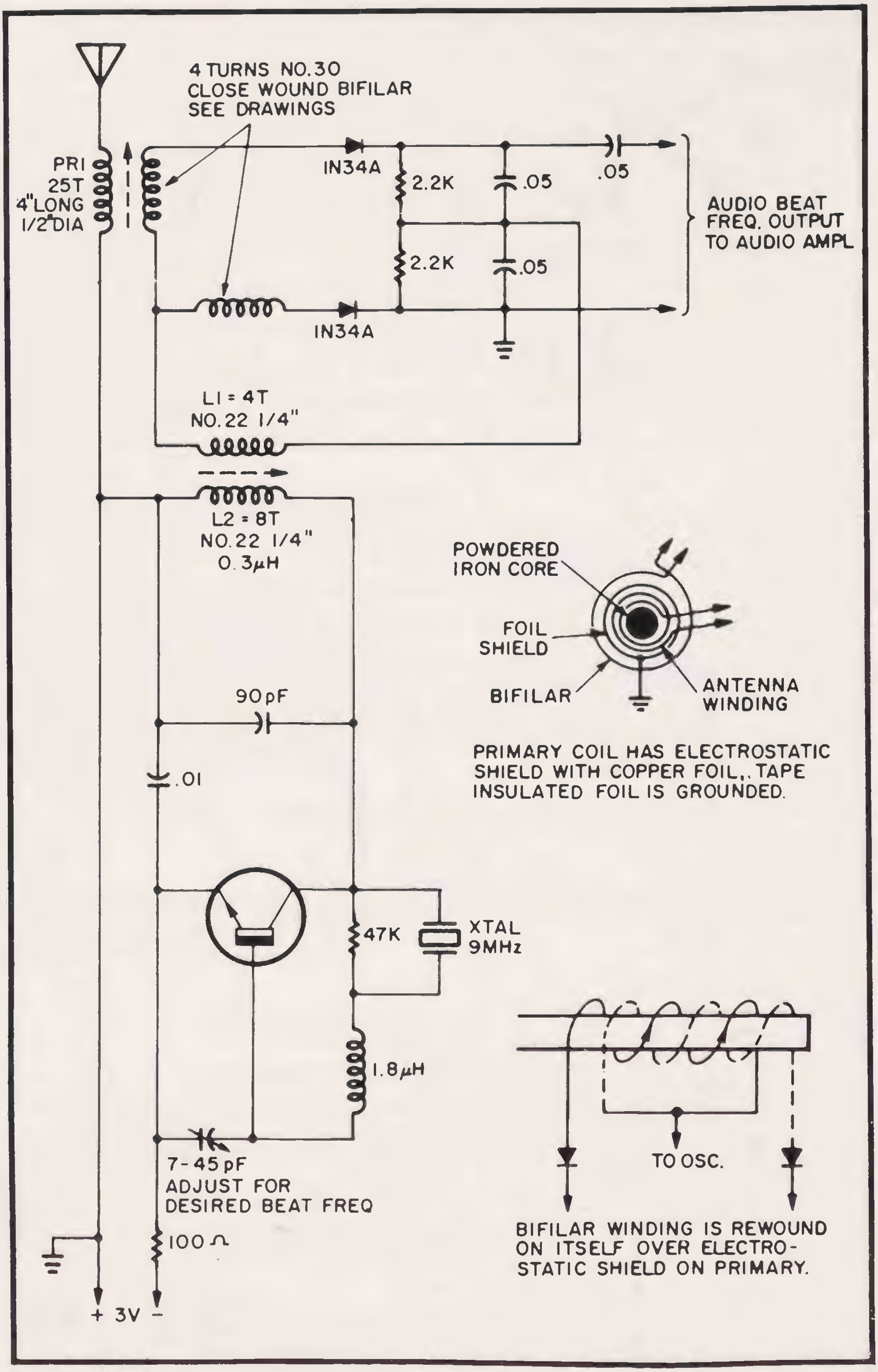


Fig. 3-9. The balanced mixer of an audio superheterodyne.

lates quite readily with common inductances over the audio range. The value of inductance for 1,000 Hz is about 0.15 henry, but you can buy slug-tunable inductances and thus obtain different frequencies. Several inductances could be used and switched into the circuit to

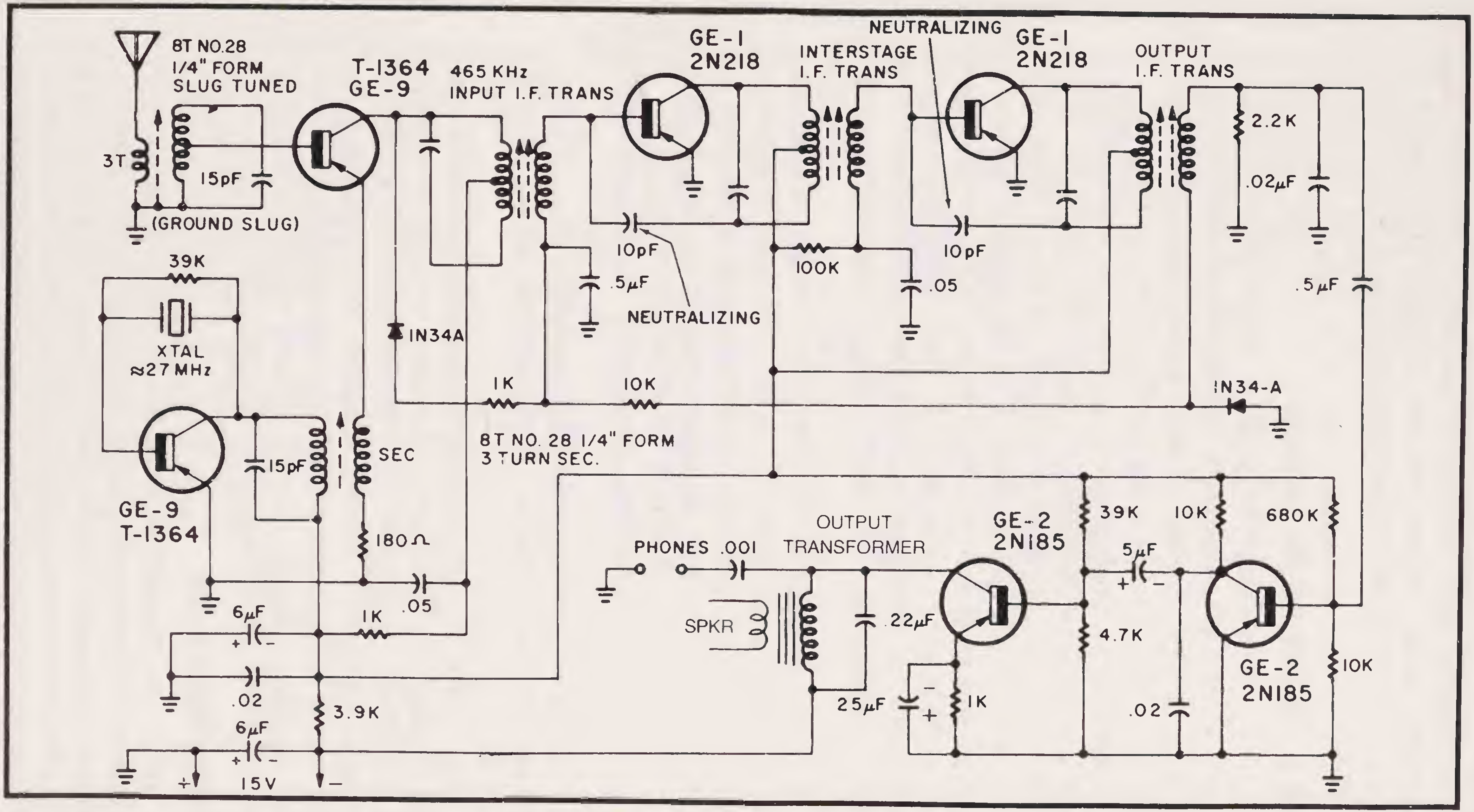


Fig. 3-10. Superheterodyne receiver with neutralized i-f stages.

produce different tones. Note that if you apply the resonance formula to this circuit, you must take the total value of C1 and C2 in *Series* as C in the formula. This is the product of C1 and C2 divided by the sum.

SOME ELECTRONIC PULSER CIRCUITS

In radio-controlling model airplanes, one of the most popular systems was the pulse-rate-width system. I've shown you some mechanical pulsers that can be used in this system. There are electronic circuits that will do the job (Fig. 3-19), too.

These pulsers produce pulses at about 2 to 10 per second, which is suitable for mechanical decoders. The first circuit (Fig. 3-19a), which uses transformer feedback, produces a variation in pulse *rate* only. You might use this for a system designed around the rate-type mechanical decoder. (See Chapter 1.) The second circuit (Fig. 3-19b) produces a change in rate with a switch. The switch could be replaced by making the 2,000-ohm trimmer resistor variable for a variable rate. Width is adjustable with the WIDTH potentiometer.

Although relays are shown in these two circuits, we can use rate-width pulsers with transistors to cut the transmitter off and on directly as explained previously under modulators. In this case, an output would be taken from the multivibrator of, say, Fig. 3-19b at point X and connected directly to the modulator inputs.

A more complicated pulser, but one of the best, is shown in Fig. 3-20.

This pulser provides a tone output directly to the transmitter modulator. No relay is required. A variation of this pulser is shown in Fig. 3-21.

Note that the output transistor can be connected to a 400-ohm relay, or directly to the transmitter oscillator to supply the modulating voltage for transmission of the radio-control code. When connecting to a transmitter oscillator, consider these terminals in the same way as the terminals of a battery. The transmitter oscillator would require no connection to a battery, since it receives its operating power through this modulator.

A MOTOR-NOISE FILTER

Here is an important circuit: A filter to help eliminate interference caused by sparking electric motors in radio-controlled models. This filter, designed by Ted Strader, is perhaps one of the best and can be used on servomotors or driving motors. Note that you have a connection to the motor frame. If you buy an electric motor you will

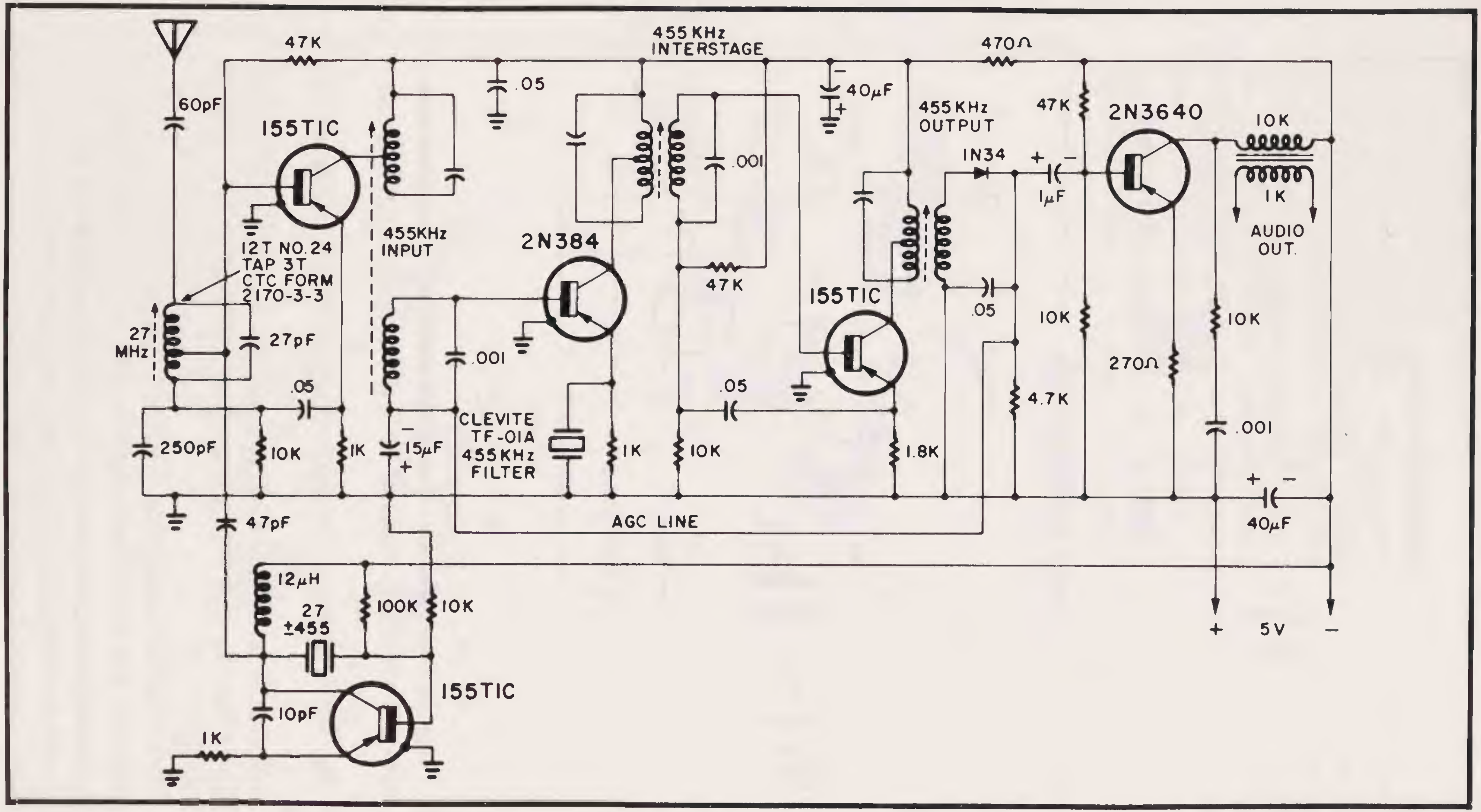


Fig. 3-11. This superhet doesn't require neutralizing the i-fs.

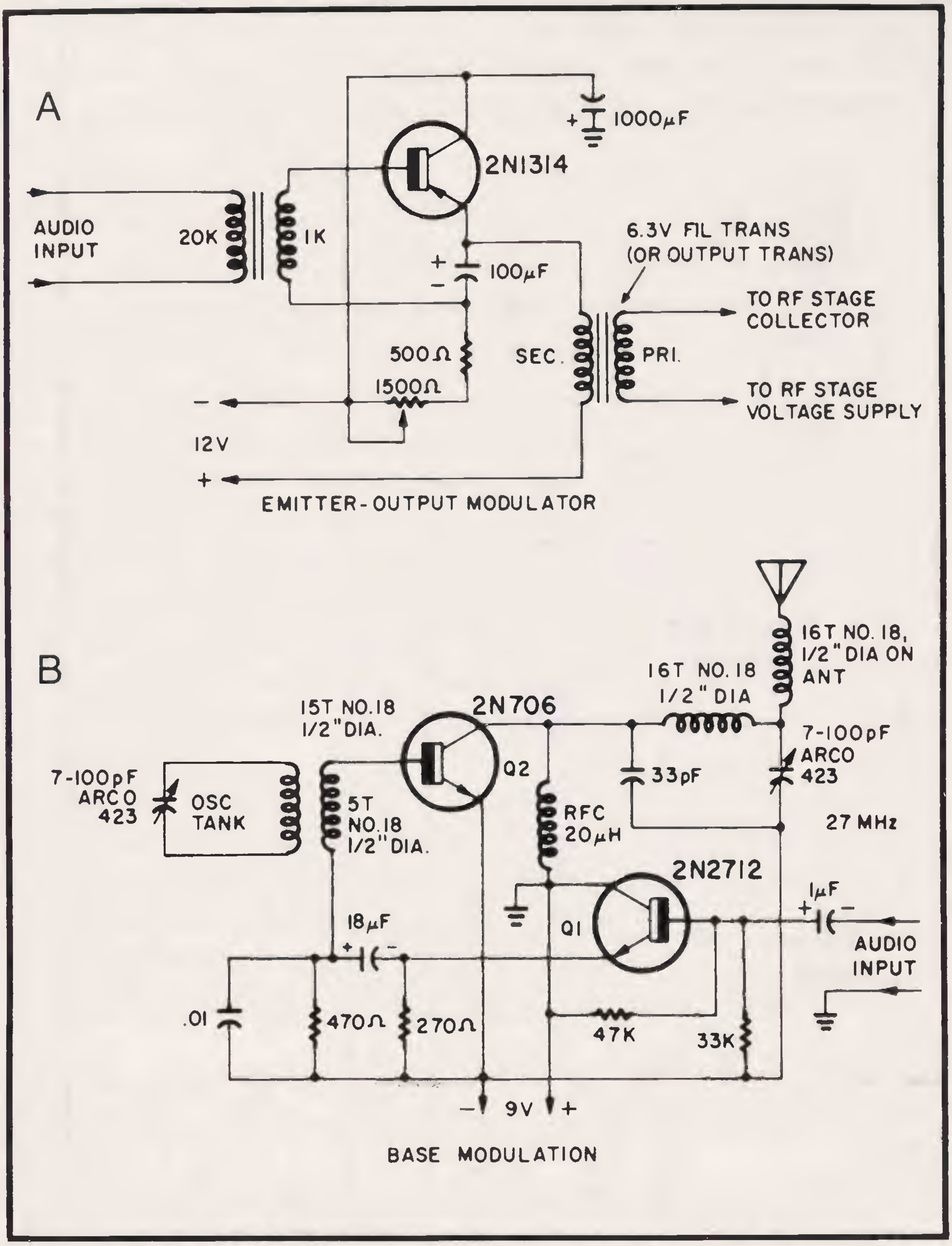


Fig. 3-12. An emitter-output modulator (a) and a base-modulation circuit (b).

want one that is enclosed completely by a metal case. Examine Fig. 3-22.

Of course in commercial servos, the manufacturer usually supplies a filter designed for this product. Normally, such a filter is sufficient.

It is easy to determine if a motor in a system is causing interference. Just make the motor run with the control receiver on, and no transmitter signal on the air. If there is radiation from the motor, the receiver will now pick it up and cause the motor to "jitter" or turn off and on by a kind of noise feedback.

SOME CONVERTER CIRCUITS

In the construction section I'll illustrate how to build a very simple radio-control system using a standard broadcast portable receiver. An expansion of this idea is to design an input (frequency converter) circuit for such a receiver so that you can receive signals in the Citizens band on those frequencies allocated for radio control. This will allow you to use a standard radio-control transmitter and increase the range of operation to your model without reworking the whole receiving system. The circuits of Fig. 3-23 are of this type. They pick up the radio-control signal and convert it to a lower frequency so that your normal broadcast receiver can be used.

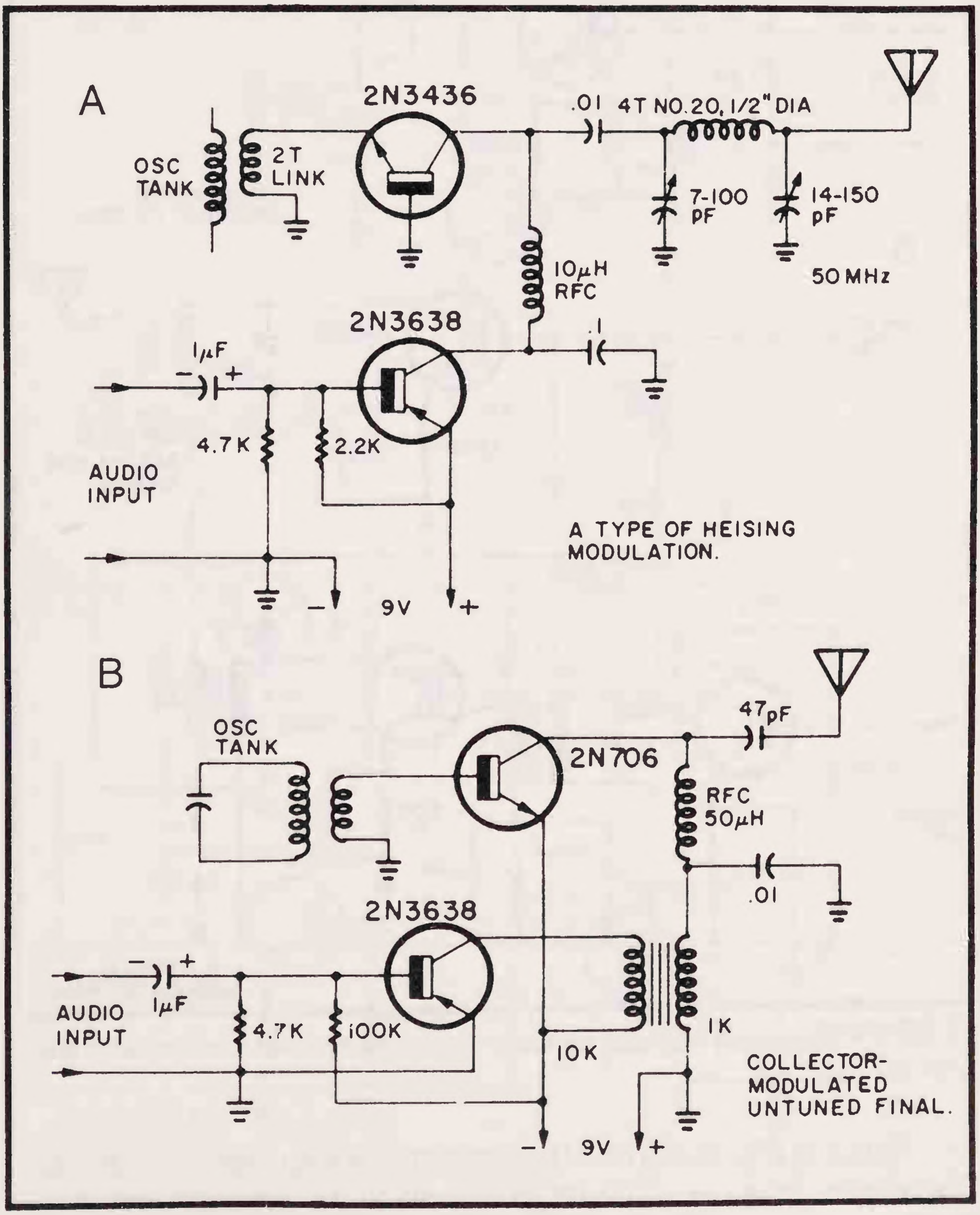


Fig. 3-13. Examples of modified-Heising (a) and transformer-coupled (b) modulators.

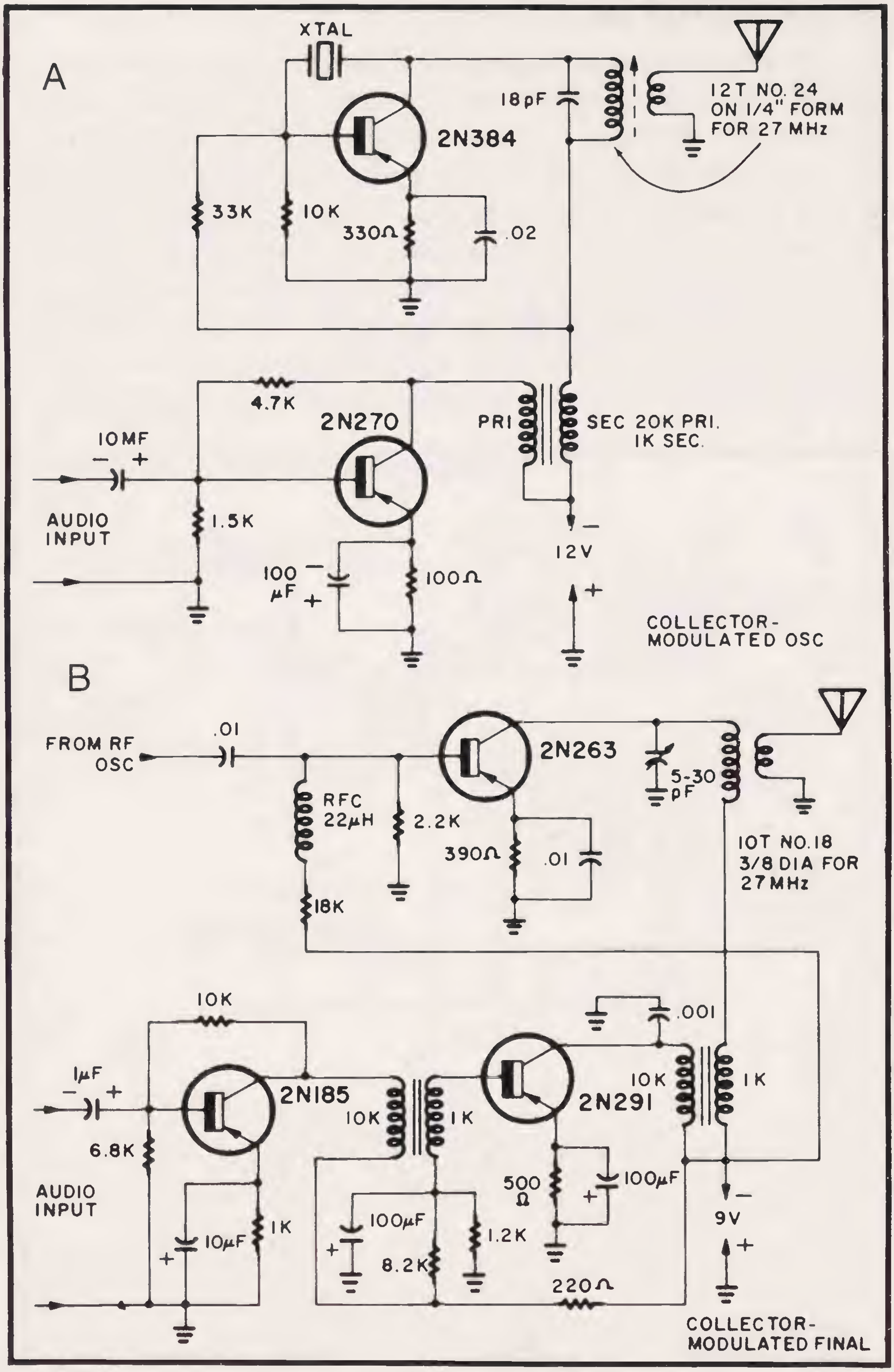


Fig. 3-14. A modulated oscillator (a) and a two-stage modulator with a tuned final stage (b).

Notice in Fig. 3-23a that the converter is not crystal-controlled. The output of the circuit would go directly to the antenna terminal of the broadcast set. Or you might wind a two- or three-turn loop around the broadcast antenna coil (the long ferrite core in the set usually identifies this coil in the portable) and connect from this coil to the output of the converter circuit. Figure 3-23a has an output designed to feed such a loop. Figure 3-23b and c are designed to feed directly to the antenna connection of the portable. Don't forget to make a common ground connection between the converter and the receiver. Figure 3-24 again has a loop connection that may be used

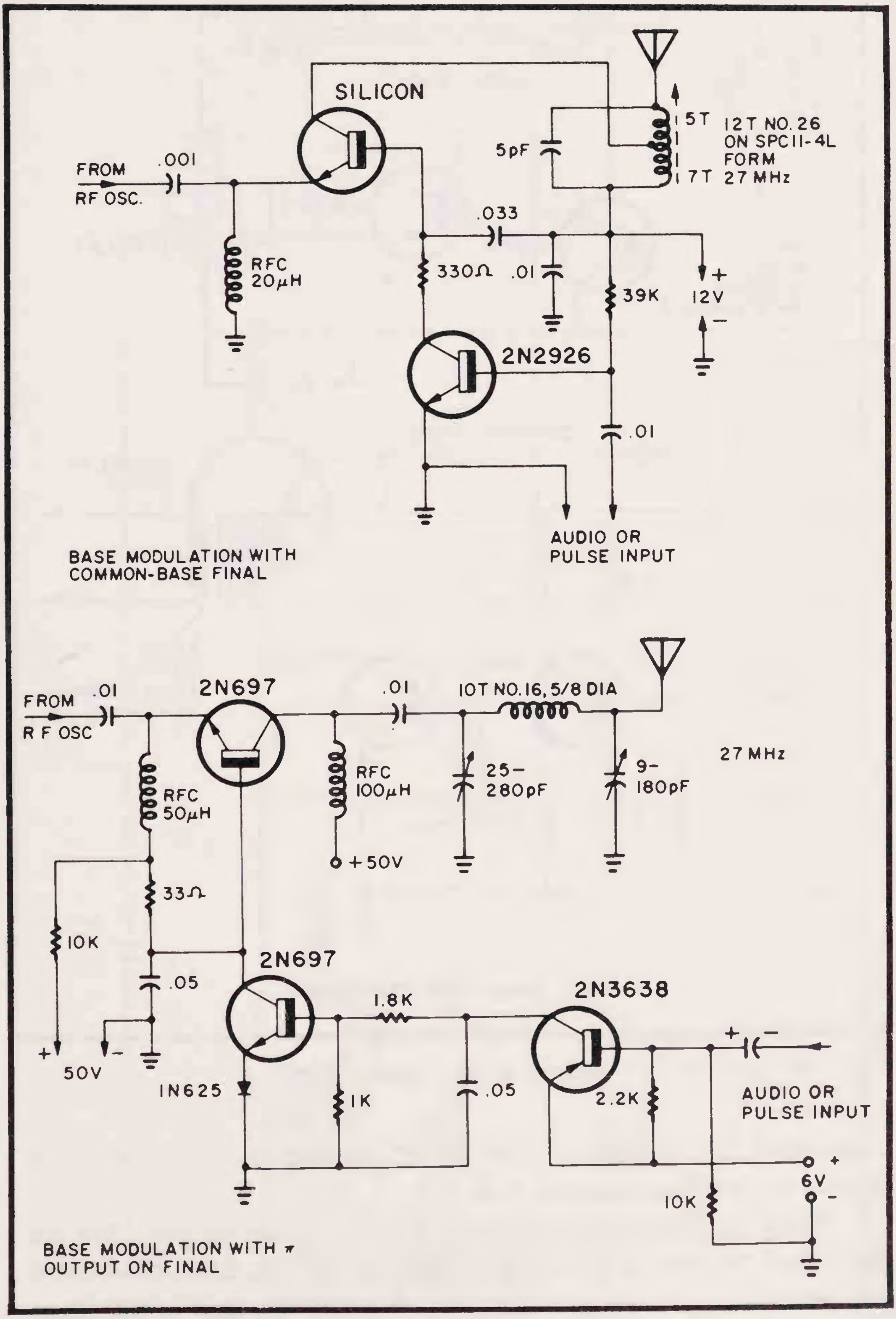


Fig. 3-15. Modulators suitable for high-speed pulses.

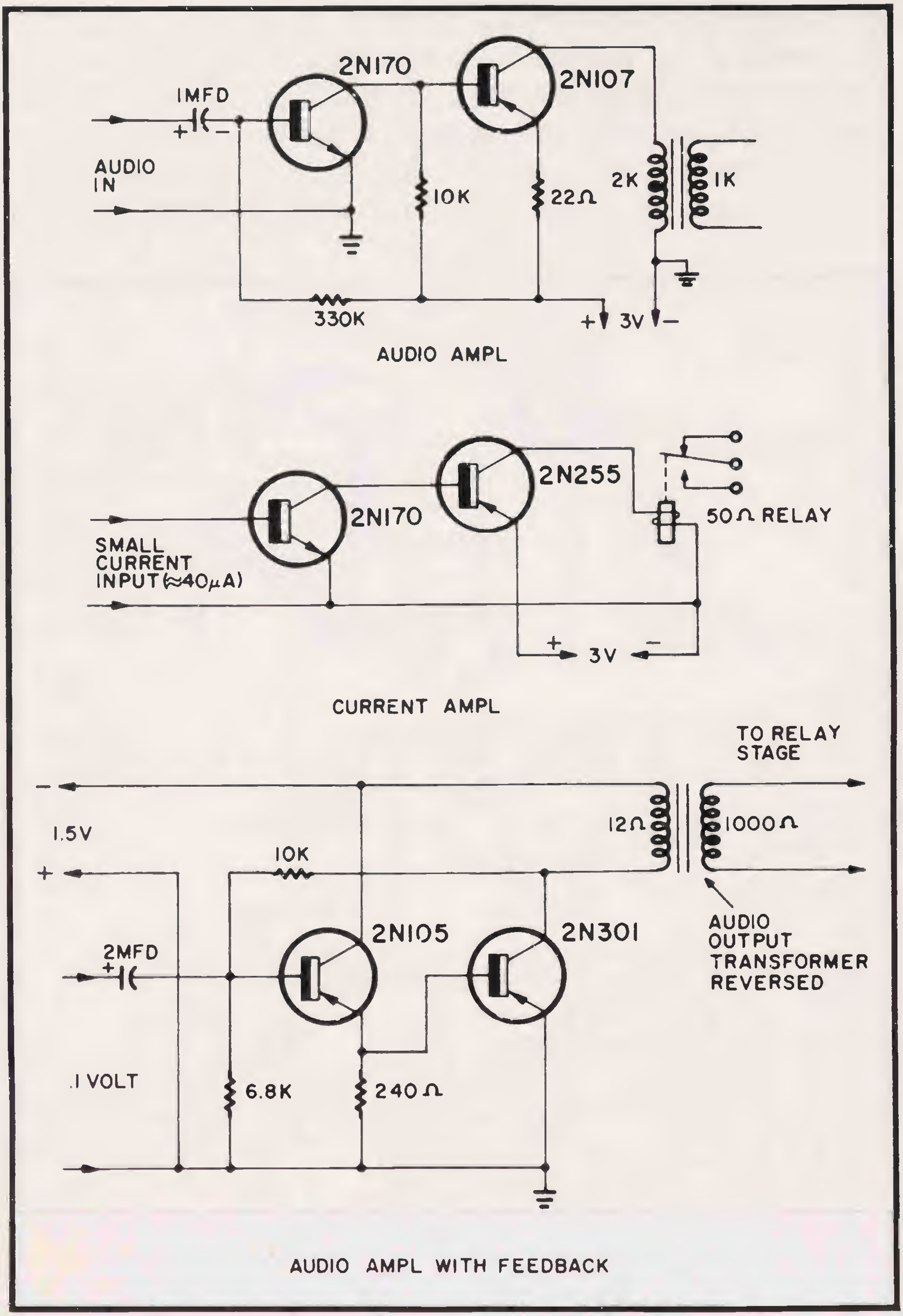


Fig. 3-16. Three audio amplifiers used in radio control.

with either the antenna connection or the loop winding around the broadcast receiver antenna coil.

With the crystal-controlled converters you simply tune the broadcast receiver until you hear the signal from the radio-control transmitter and then adjust the converter antenna coil for maximum signal. Crystals would be selected so that the *difference* between the

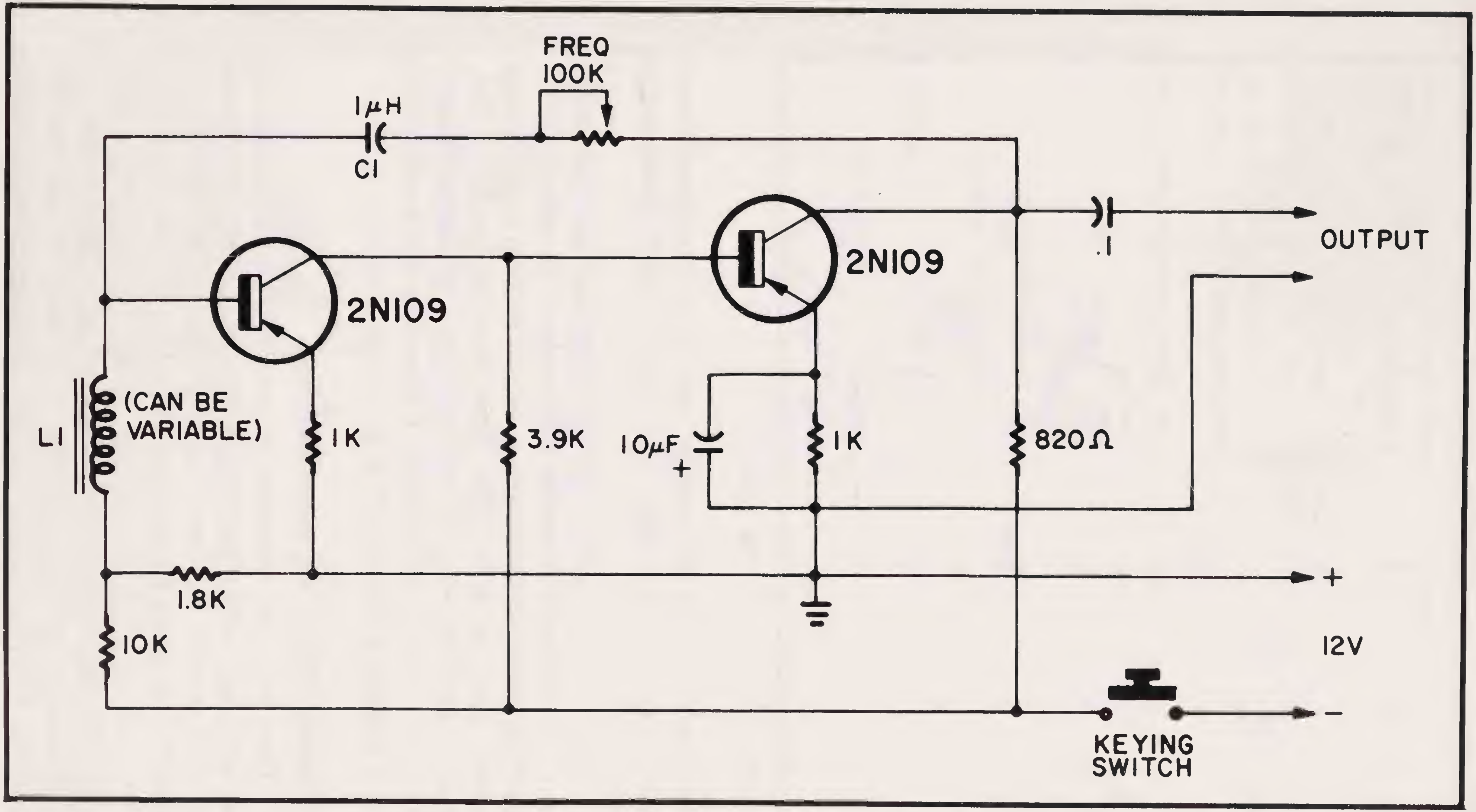


Fig. 3-17. Two-transistor tone oscillator. 2N109 = RADIO SHACK 276-2003

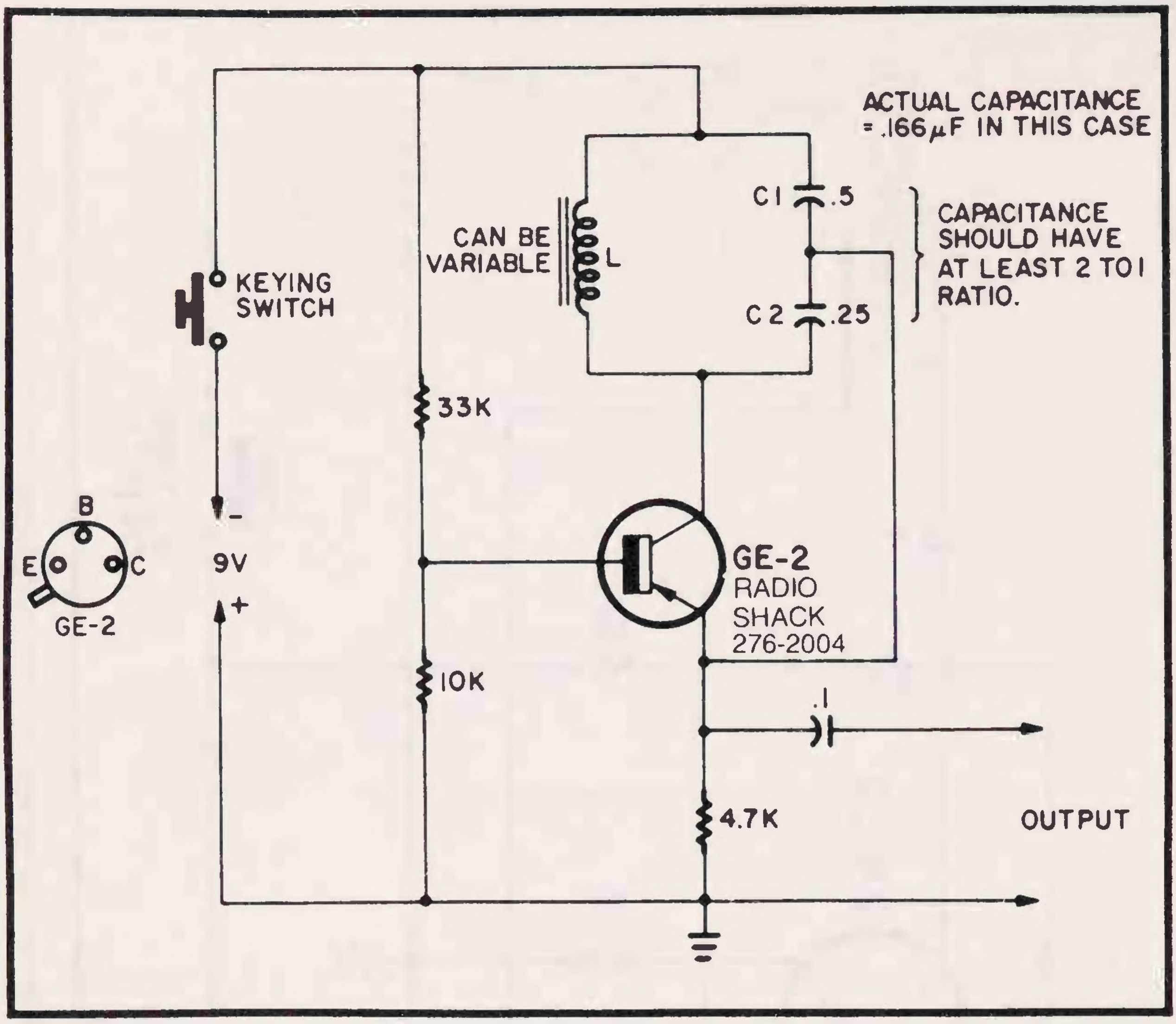


Fig. 3-18. Single-transistor tone oscillator.

crystal frequency and the frequency you want to receive is somewhere between 600 and 1,500 kHz, so that the converter output is in the broadcast band.

There is no reason why these converters cannot be used on the higher radio-control frequencies, if the antenna coils are selected to receive signals at these frequencies (50 and 70 Mhz) and the crystal is selected to provide an output near these frequencies so that, again, the *difference* between the incoming and crystal frequencies is a frequency in the broadcast band. You may want to use one of the crystal oscillators shown previously.

TRANSISTOR AND ICs APPLICABLE TO R/C

There have been many new circuits developed during the past few years which are applicable to radio control and to other types of controlled devices. We want to examine some of these and present schematics of others for your use and information. Integrated circuitry, with its small size and low voltage requirements, makes possible the realization of circuits that years ago would have taken up too much space and have required such large power supplies that heat alone would have been intolerable. And the number of components which would have had to been soldered together piece by piece also was prohibitive.

There is much that can be done with integrated circuitry and transistors in combination. Of course some additional components, such as resistors and capacitors, are still required, but their numbers are vastly reduced. We invite your experimentation and research into other circuits than these which we will show you, for as a wise man once said "Nothing ventured, nothing gained."

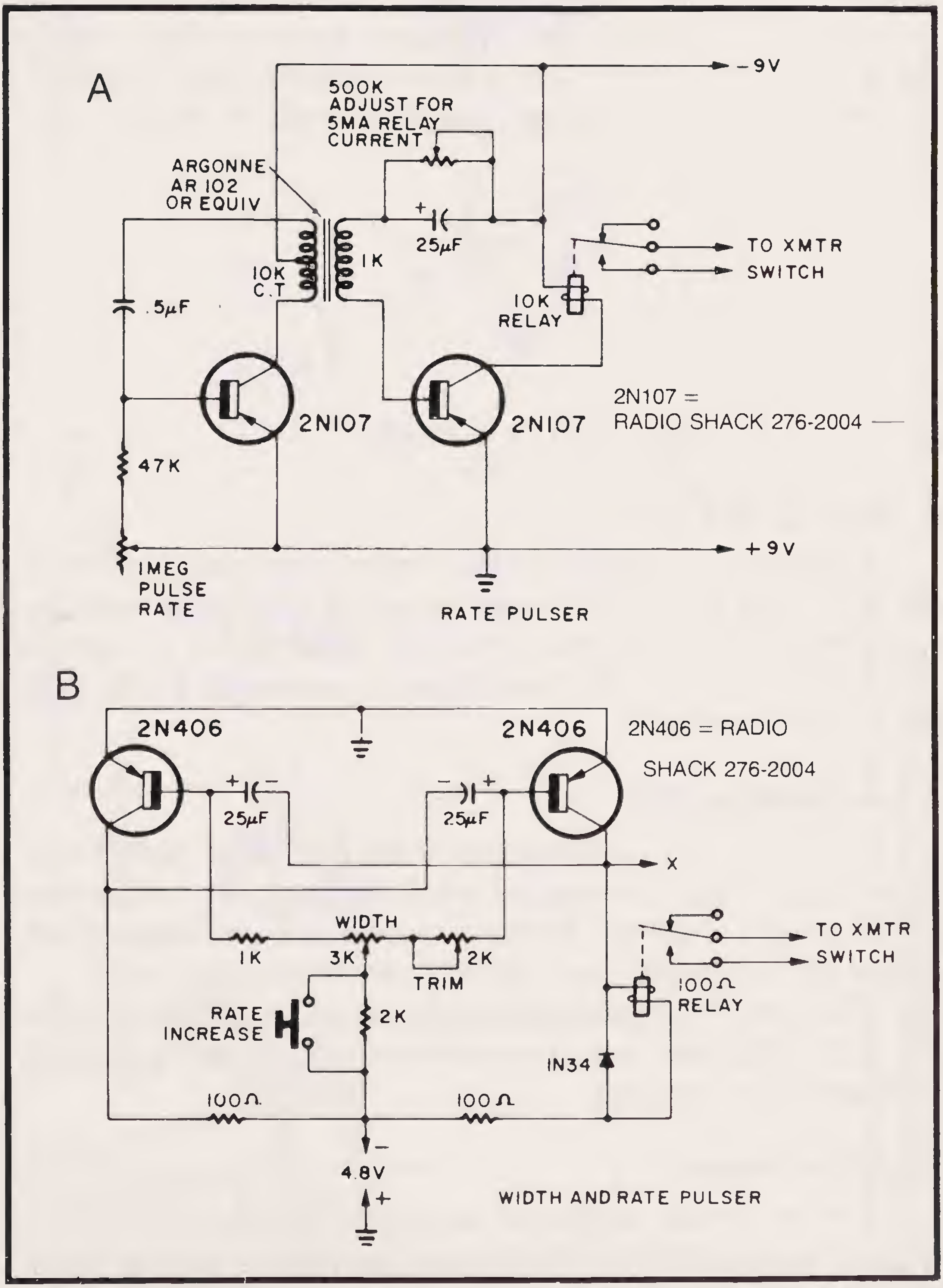


Fig. 3-19. Two electronic pulser circuits for pulse-width/pulse-rate radio-control systems using low-speed pulses.

A Unijunction Tone Oscillator

Figure 3-25 shows a unijunction oscillator which is so simple that it would taken only a minute or two to assemble. It might be used as the foundation for any kind of radio-control system which needs a tone or multitones for its operation.

Twin T Oscillator Circuit

The use of resistors and capacitors to provide the proper phase feedback to give a notch acceptance of a signal makes possible a tone generator which is quite stable. The circuit is shown in Fig. 3-26. As can be seen from the little table, you can adjust the values of R and C to get different tones. An approximate formula for the tone frequency is:

$$F = \frac{1}{(12)\ RC}$$

$$R = R3$$
$$C = C1$$

Of course R is in ohms and C is in farads.

A Two Stage Oscillator

If you provide positive feedback around two transistor stages the circuit will oscillate at some frequency depending upon the aggregate of the circuit values. Here the values of R1, R3, and C1 will govern, primarily, the tone frequency generated. In Fig. 3-27 the circuit is shown.

A Tone Selective Filter

If you use tones to govern control functions, then you will want some circuit on the receiving end which will pass only a single tone and none other. One type of frequency-selective active filter is built around the integrated circuit N5741V, as shown in Fig. 3-28.

While we are on the subject of relay circuits, examine the one in Fig. 3-29, which uses diodes to rectify the input tone and operate the Darlington relay amplifier.

The Optical Coupler

It is not beyond imagination to consider that there are certain types of control systems where the sensor input to a circuit which will control a relay or power stage must be isolated from the power circuits totally. The way to do this is to use the optical-coupler

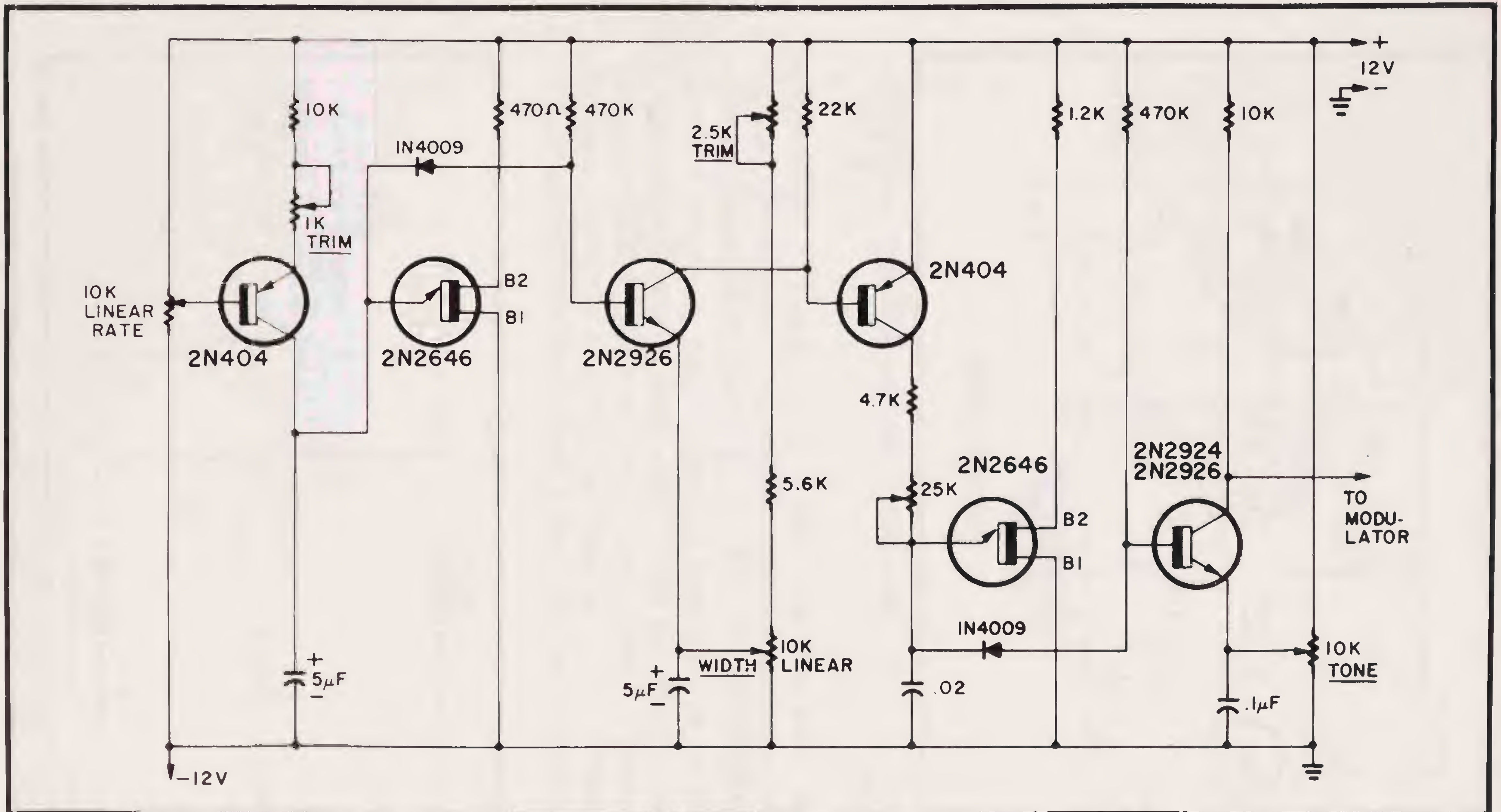


Fig. 3-20. A high-stability rate and width pulser without a relay.

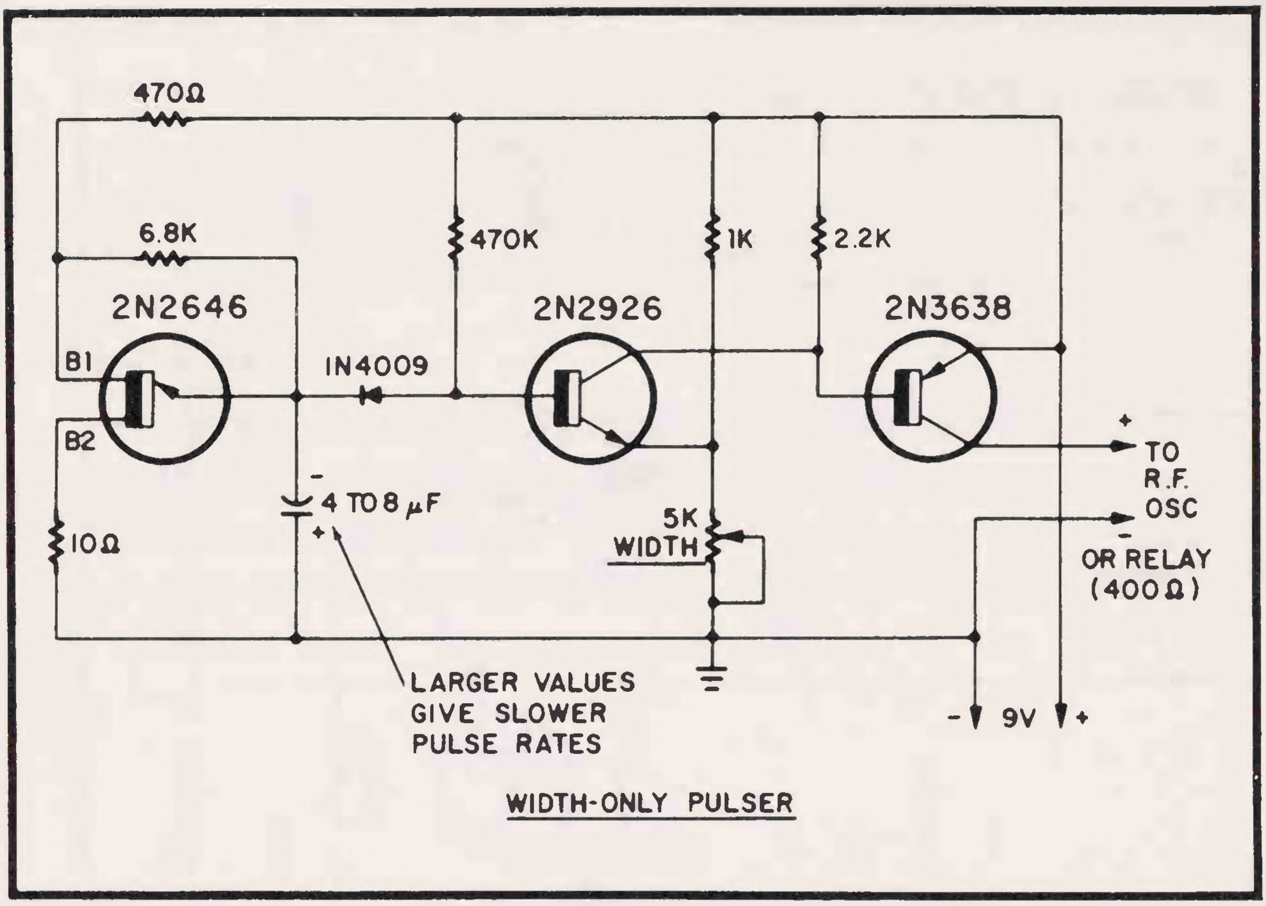


Fig. 3-21. A three-transistor pulser for either relay or no-relay operation of the transmitter.

circuit. In integrated form this is shown in Fig. 3-30. Of course you might use just the LED separately and then a photosensitive transistor (Radio Shack 276-130) to operate a relay or a Darlington amplifier which in turn might power a relay. In part (a) you see a possible circuit to operate the light-emitting diode. There are many kinds of light-emitting diodes so you choose one which will fulfill your needs. We have listed two possible types. In (b) is a possible relay stage operated from the light-emitting diode. You'll have to experiment to

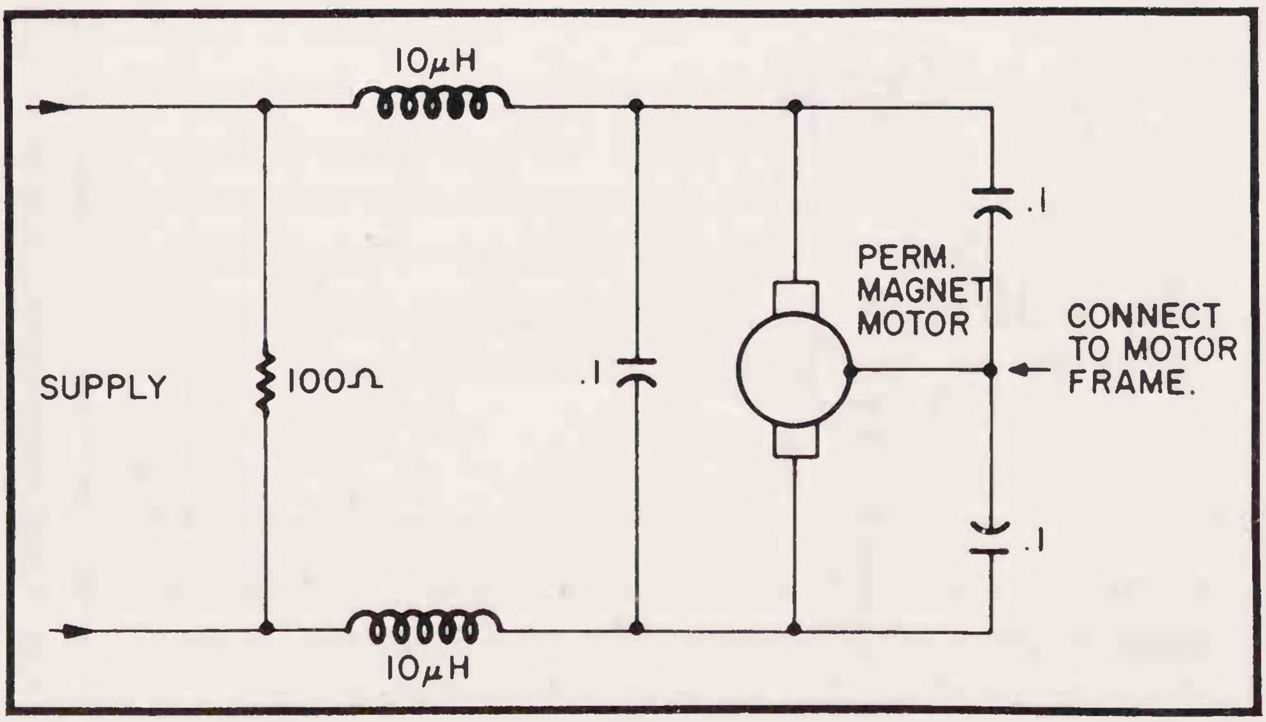


Fig. 3-22. A filter circuit for electric motors in radio-control systems.

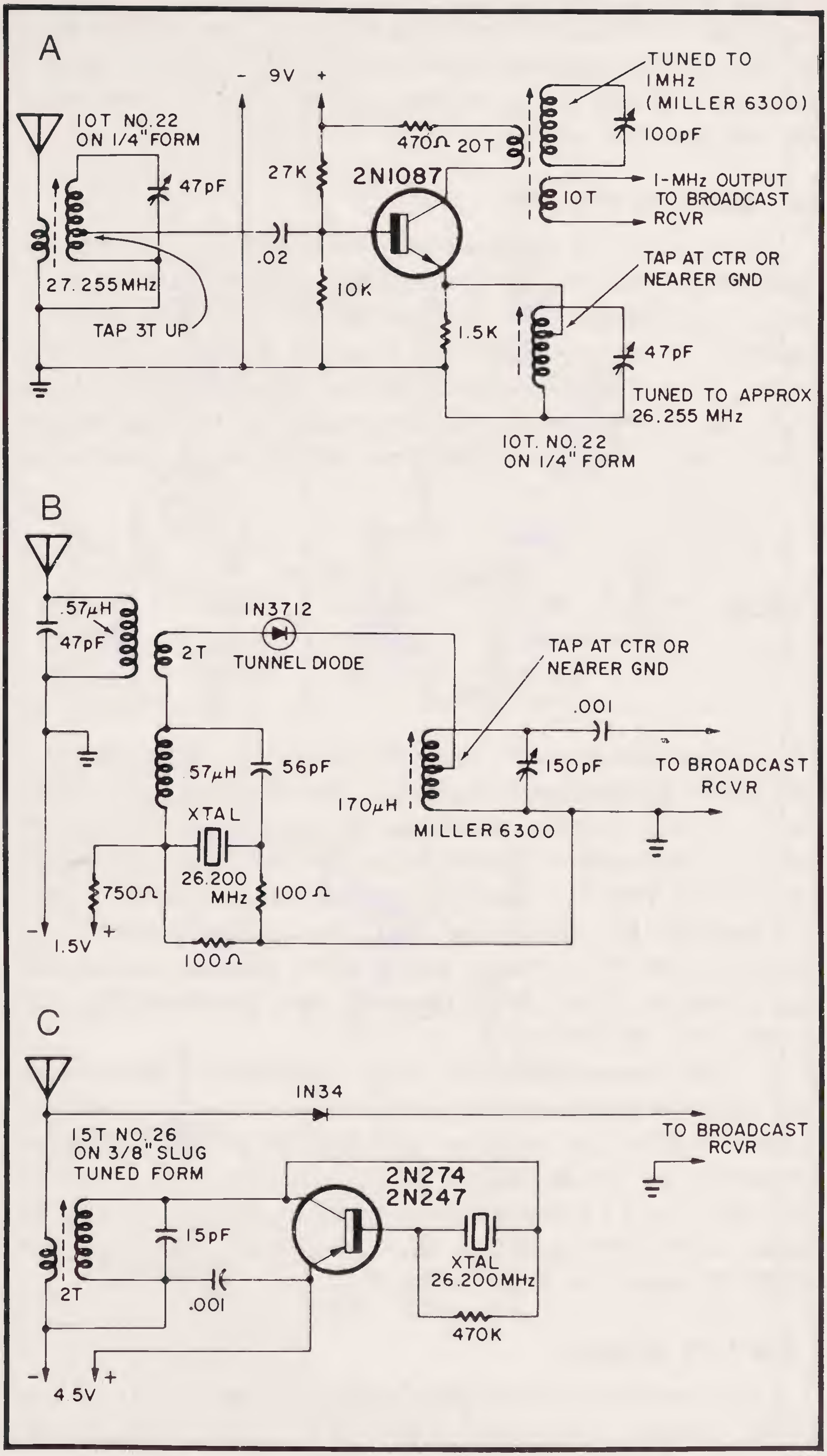


Fig. 3-23. Some converter circuits to allow reception of radio control (CB also) signals on broadcast portable.

find a relay which has the right value in coil ohms and current rating to work with your selected output transistor. In (c) is an integrated circuit LED coupler already set up to operate for you. It will isolate the input from the output.

The Touch Tone Generator

It is of interest in advanced radio control and other wireless and wired control systems that the telephone company has invented the touch-tone generator. We use these daily to connect ourselves to various other phones anywhere in the world. The touch-tone pads, as they are called, will generate 12 tone combinations of 2 tones each; thus, a 2-tone decoder is necessary in order to obtain function selection using this system. Let's examine the tones generated:

LOW TONES:	697	770	852	941
HIGH TONES:	1209(1)	1209(4)	1209(7)	1209(*)
	1336(2)	1336(5)	1336(8)	1336(0)
	1477(3)	1477(6)	1477(9)	1477(#)

The numbers and symbols in parenthesis after the higher frequencies shows the number or symbol on the touch-tone key. When depressed these give the combination of tones shown. For example, depressing the number (1) on the pad produces the two tones 697 Hz and 1209 Hz. These are of course produced simultaneously. Touch-tone pads may be purchased at radio parts and supply stores. The frequencies are very constant and accurate, and thus you can use highly selective filters at the receiving ends to channel the tone commands as you desire.

If radio transmission of the tones is desired as in the development of a radio control system, you must be sure that the modulation is linear and that the tones are not made to generate undesired frequencies because of nonlinearities in the system. The best way to check this is with a scope at the receiving end, attached to the audio output of the receiving device. One connection for the touch tone (ARRL Handbook) is shown in Fig. 3-31.

A Two Tone Decoder

One type of two-tone decoder is shown in Fig. 3-32. Here, two NE567 decoders are connected in tandem. These will handle the two-tone signals from any input source. When the correct two-tone signal (to which the decoder is adjusted) is fed into the input, the

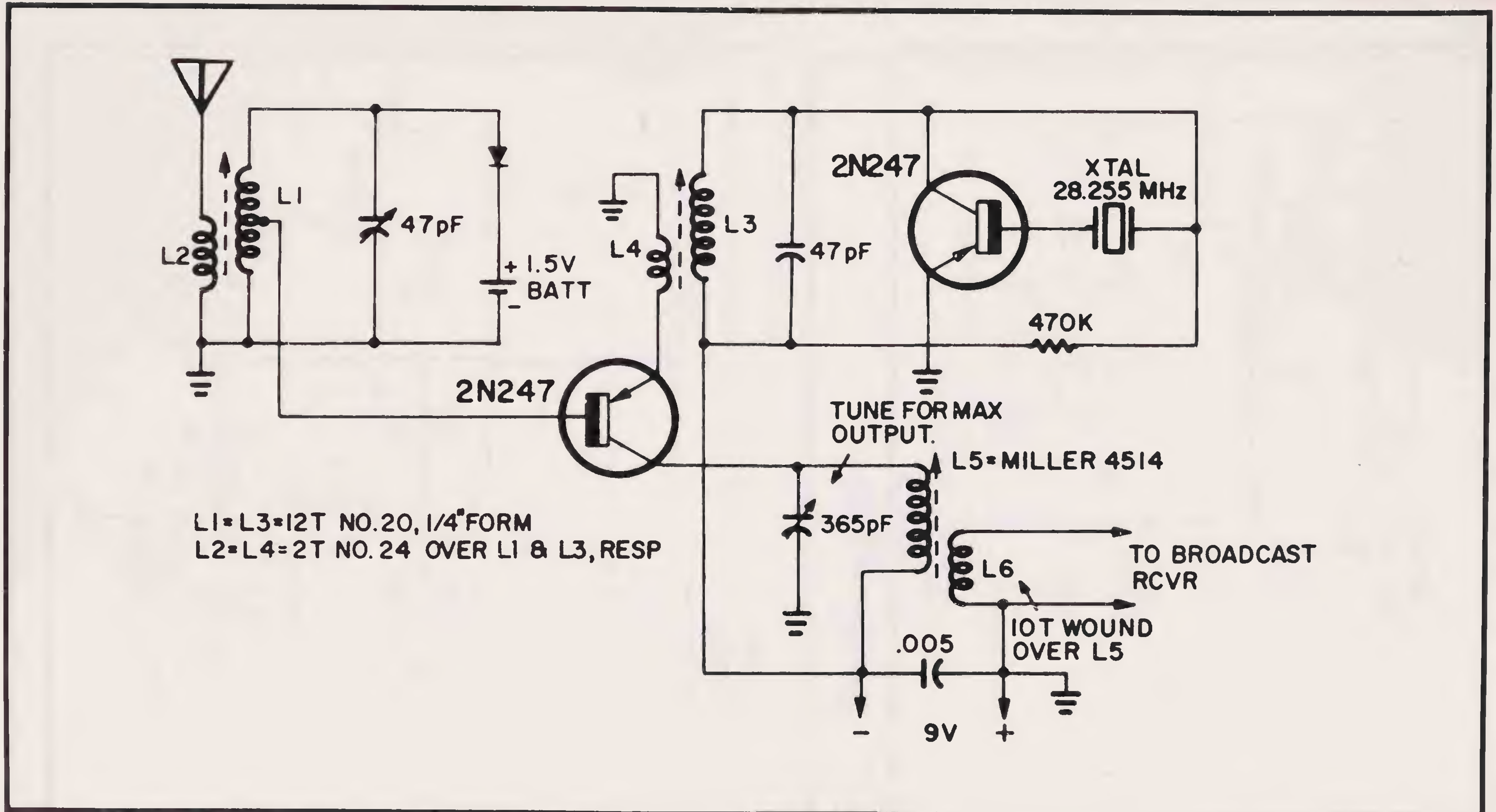


Fig. 3-24. One converter circuit to allow reception of radio-control signals on broadcast transistor receivers is crystal controlled.

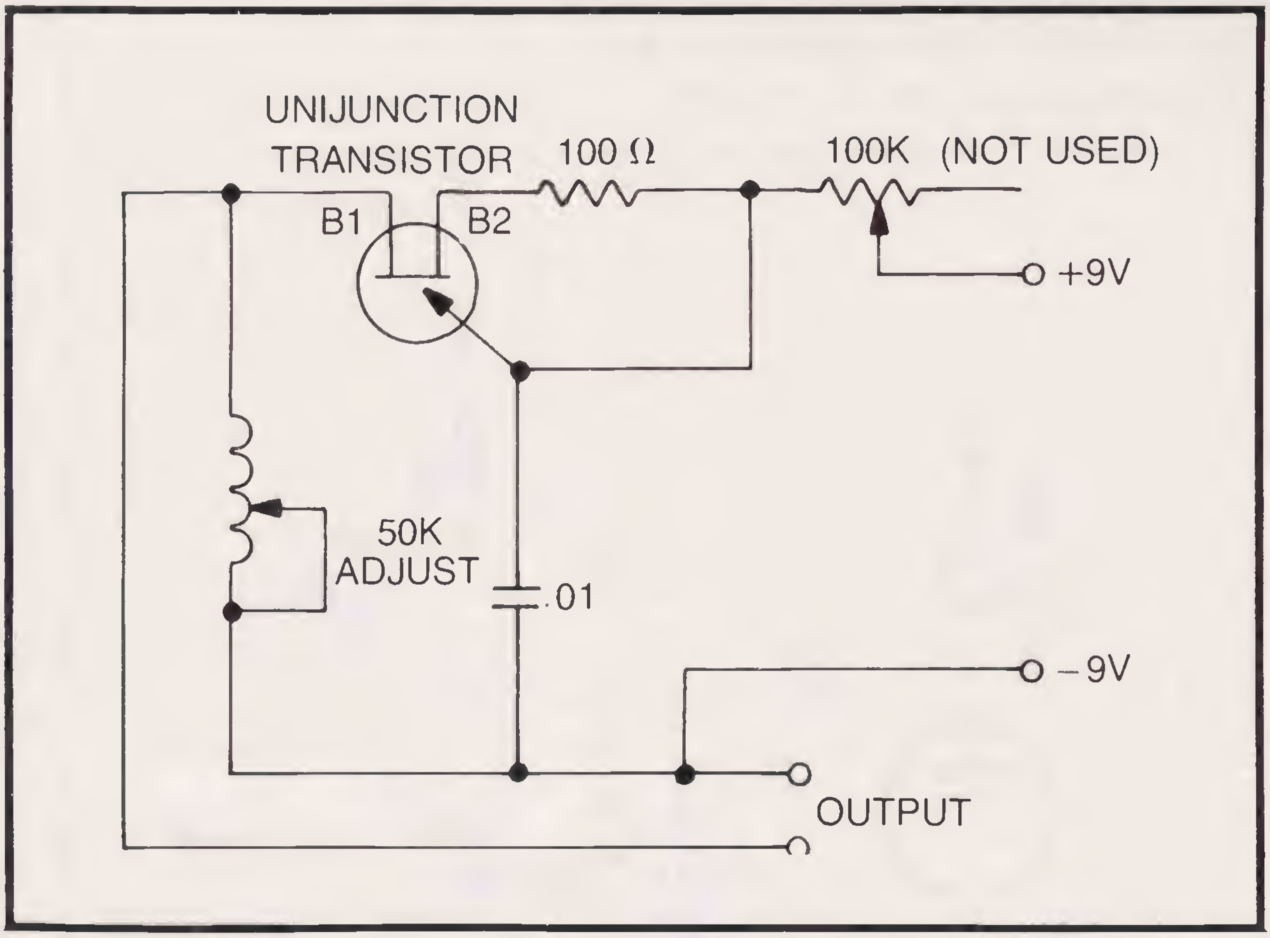


Fig. 3-25. A unijunction tone generator.

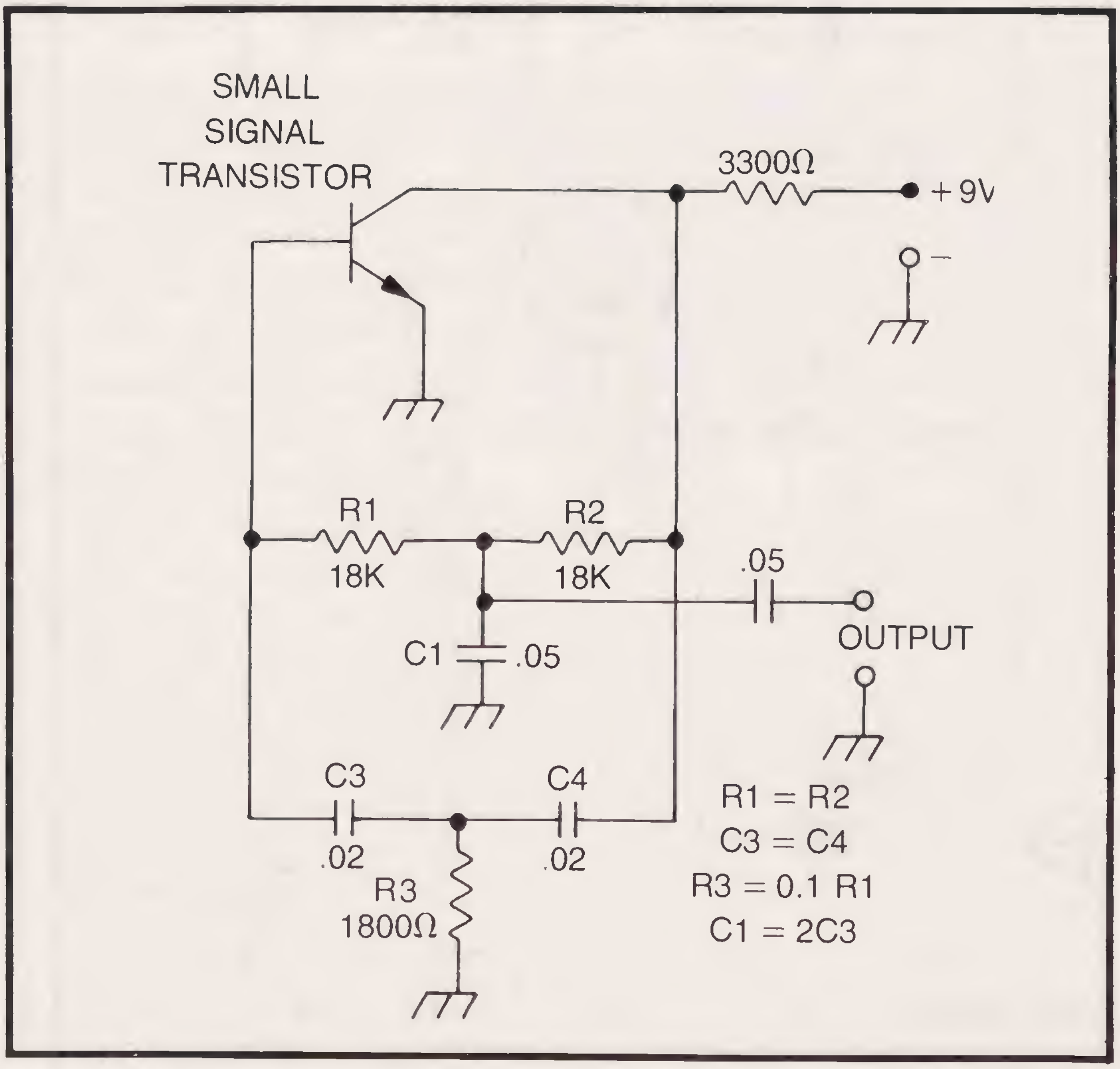


Fig. 3-26. Twin T Tone Generator.

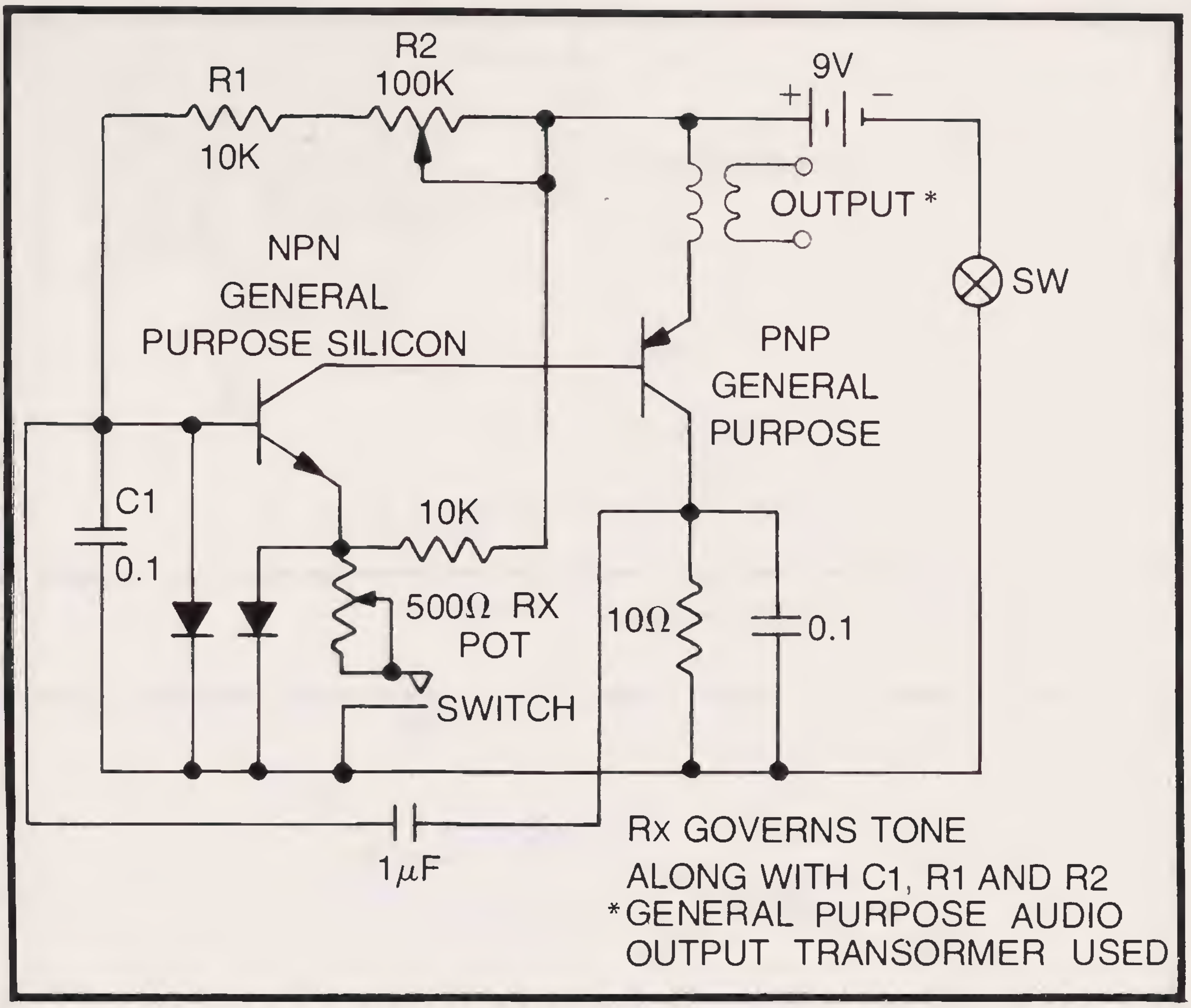


Fig. 3-27. A two stage tone generator.

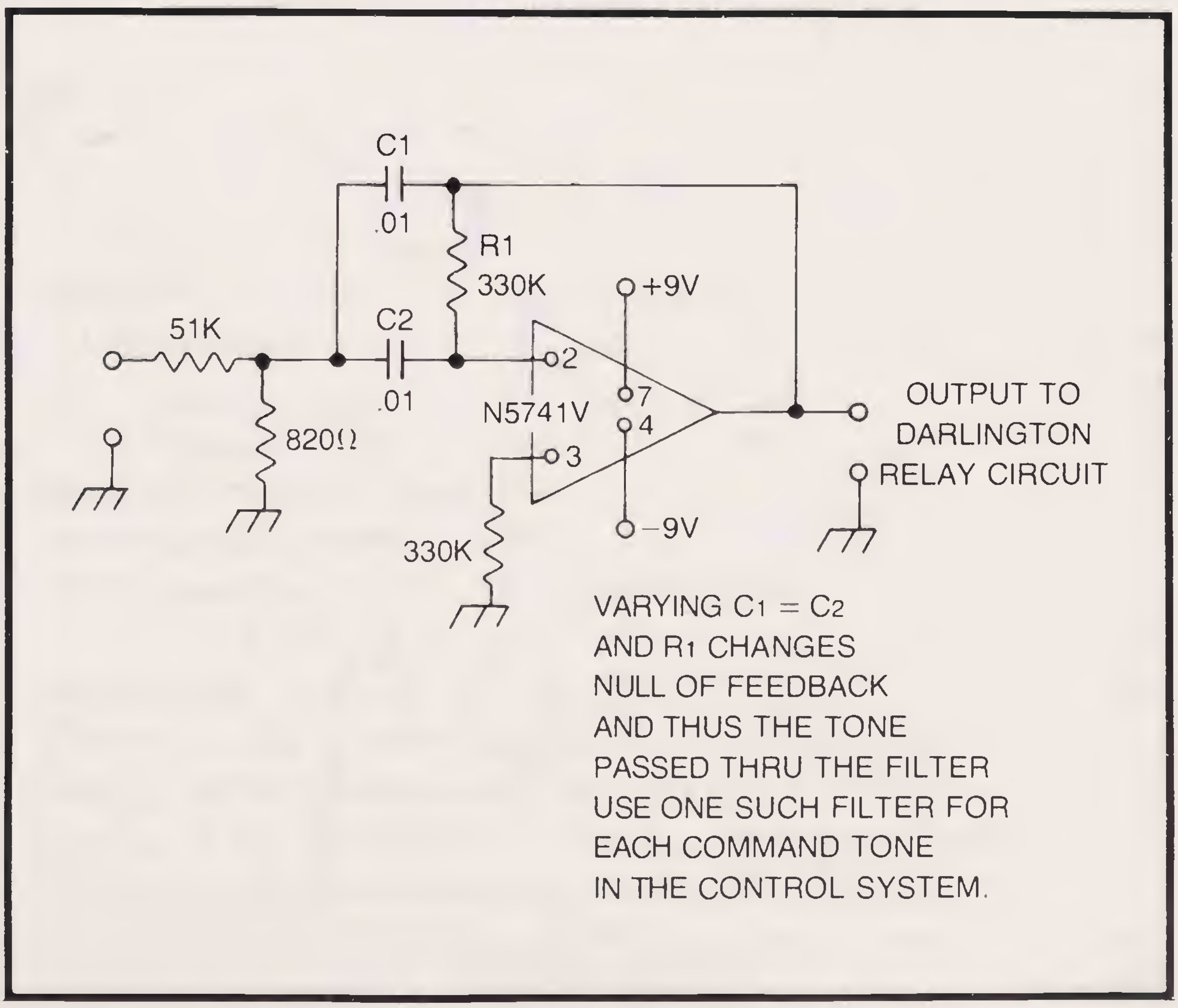


Fig. 3-28. An active tone filter for reception.

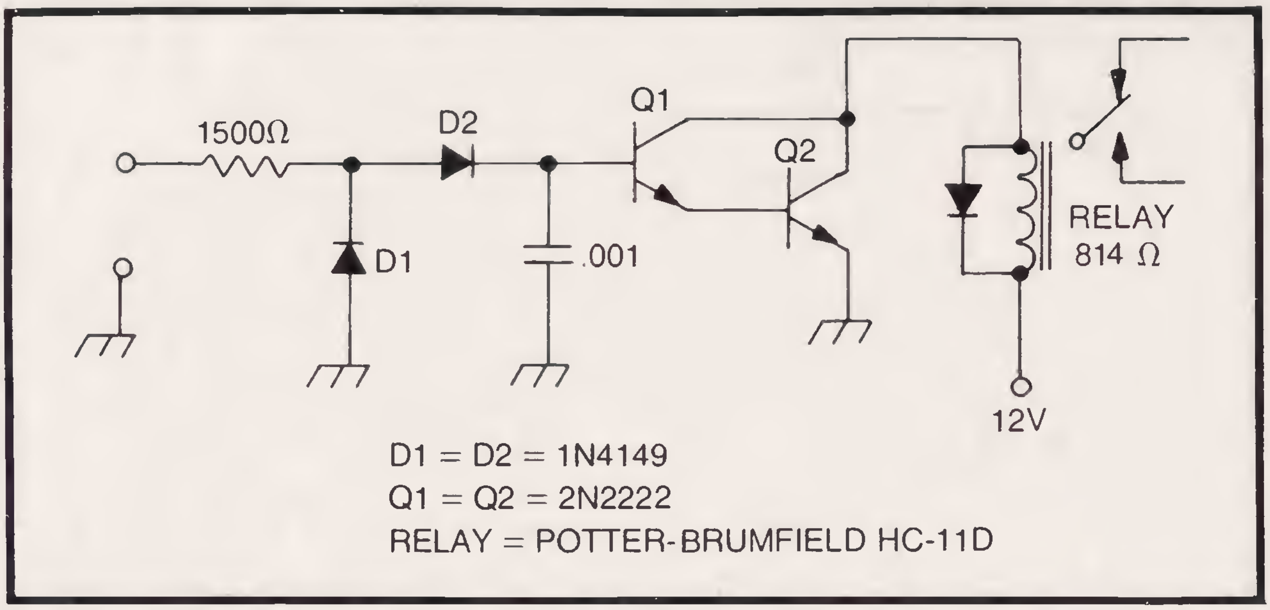


Fig. 3-29. A relay stage operable from a tone input.

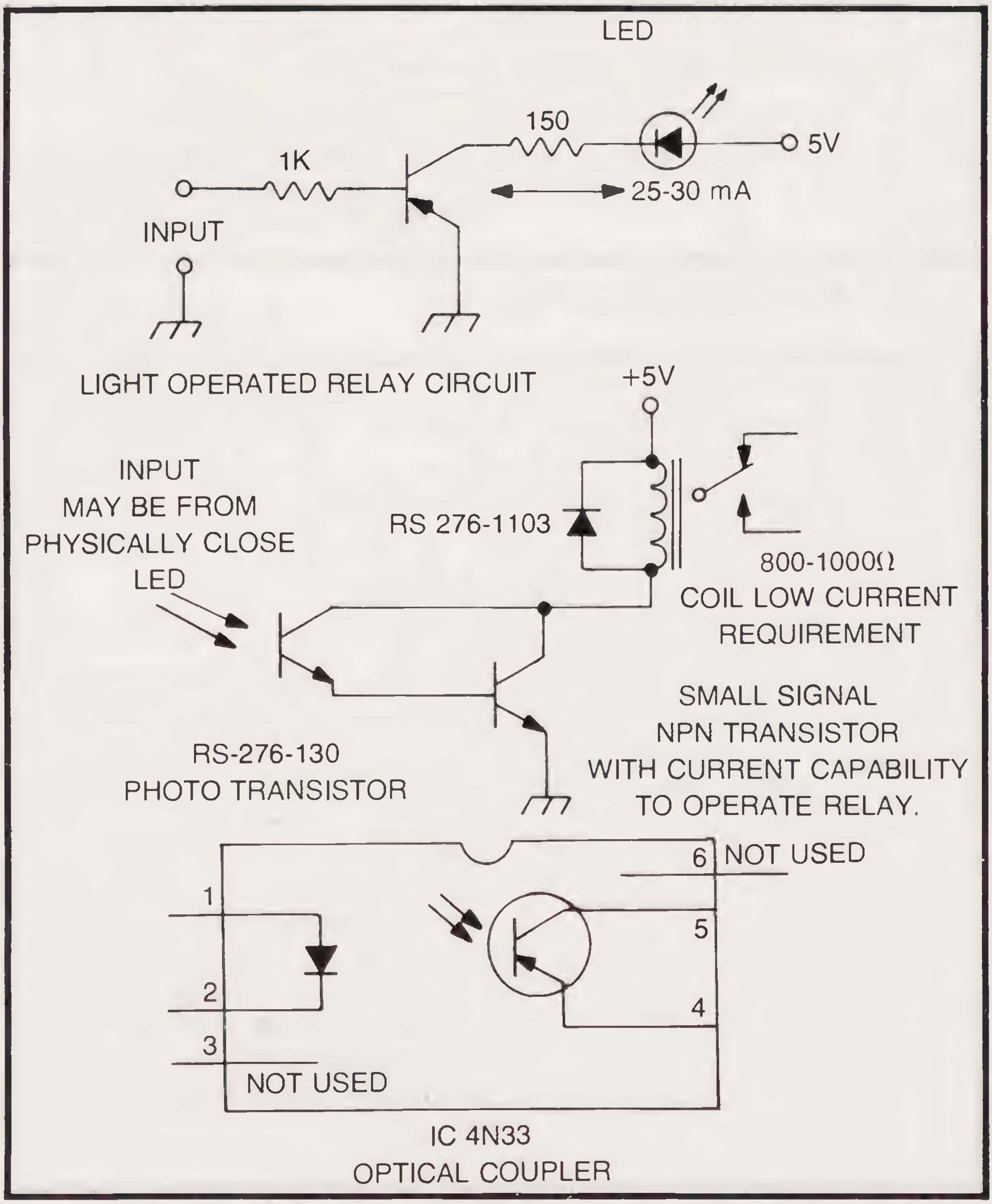


Fig. 3-30. Some optical-coupler circuits.

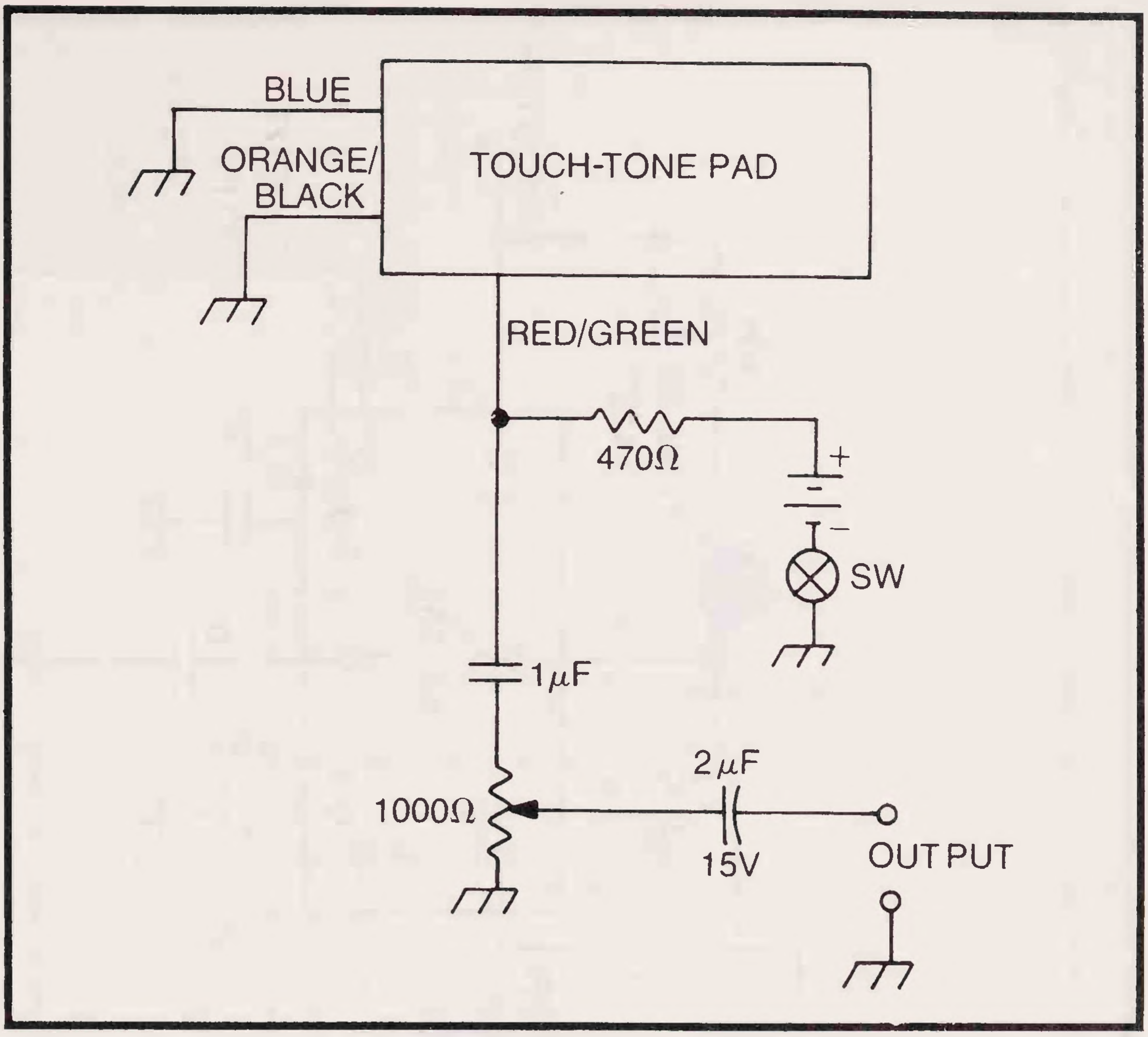


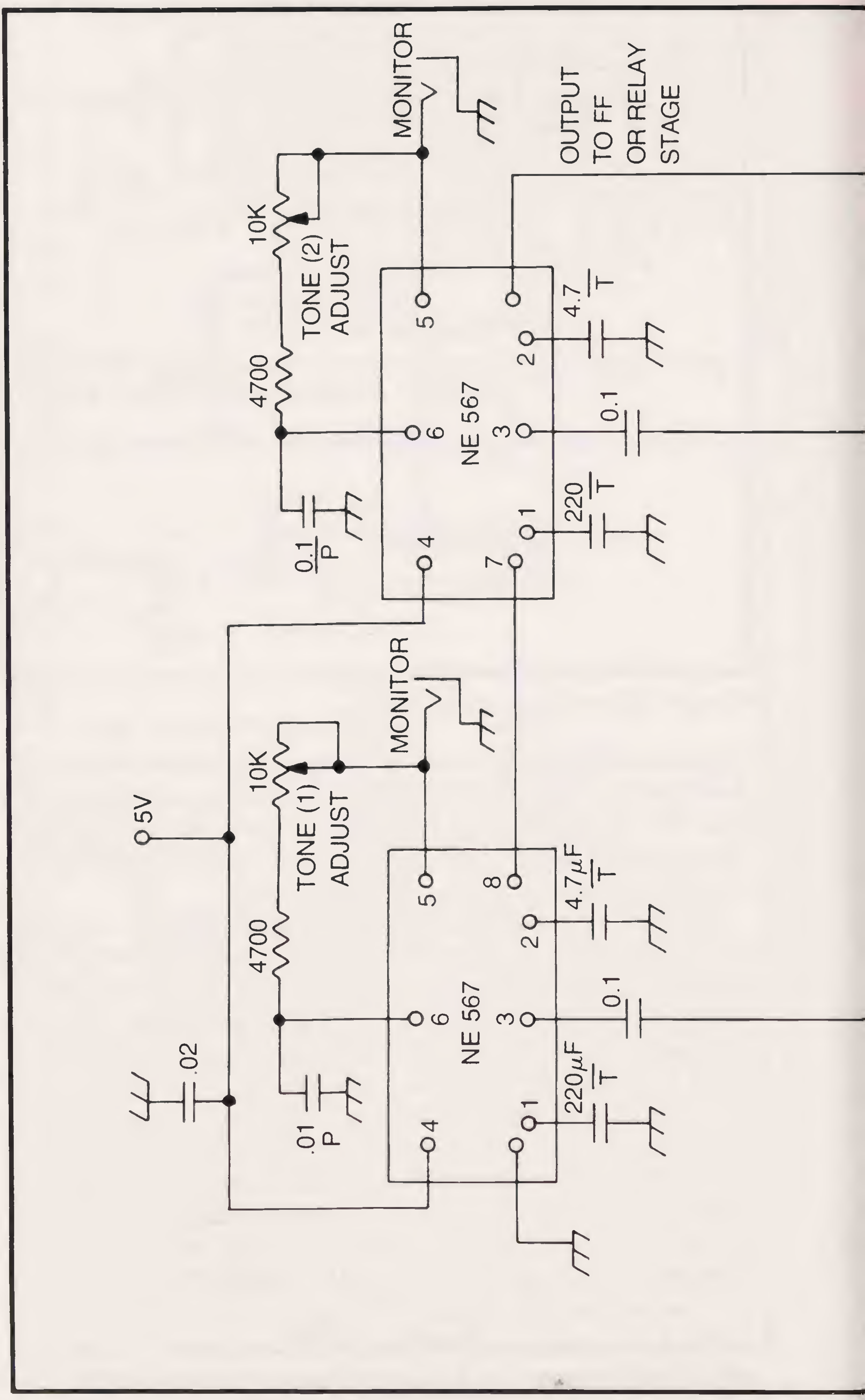
Fig. 3-31. Connections to touch tone pad.

decoder switching is accomplished through a link between pins 7 and 8 of the units. The second decoder can key a relay-activating circuit, or a 7473 dual J-K flip-flop. If the latter is used, the first set of two tones sets the flip-flop, and the second set of the same two tones unsets it, restoring it back to its original state.

A group of these decoders can be used to make up a selective filtering circuit for all the combinations of tones which the touch-tone pad can generate. Be aware that you must experiment with circuit values of this decoder in order to tune to the proper tones. As noted, you might well use a light-coupler connected to the flip-flop (7473) in order to oeprate a relay. That would be an integrated circuit.

There is a tone decoder available from Radio Shack which is also an integrated circuit. It is the RS-567 or RS-276-1721. This can have a variety of uses in radio and remote control applications. A dual J-K flip-flop which might be used with the preceeding two-tone-circuit decoder is the RS-276-2427. You can investigate other types of integrated circuits to find those which will fulfill your needs.

Just as a kind of final item in this grouping of circuits, we show, in Fig. 3-33 a simple tone decoder which can operate a relay. The relay should operate on 6 volts and may be either a double pole


MONITOR
OUTPUT TO FF OR RELAY STAGE
10K
TONE (2) ADJUST
4700
NE 567
0.1
P
4.7
T
220
T
0.1
5V
MONITOR
10K
TONE (1) ADJUST
4700
NE 567
4.7μF
T
0.1
220μF
T
.02
.01
P

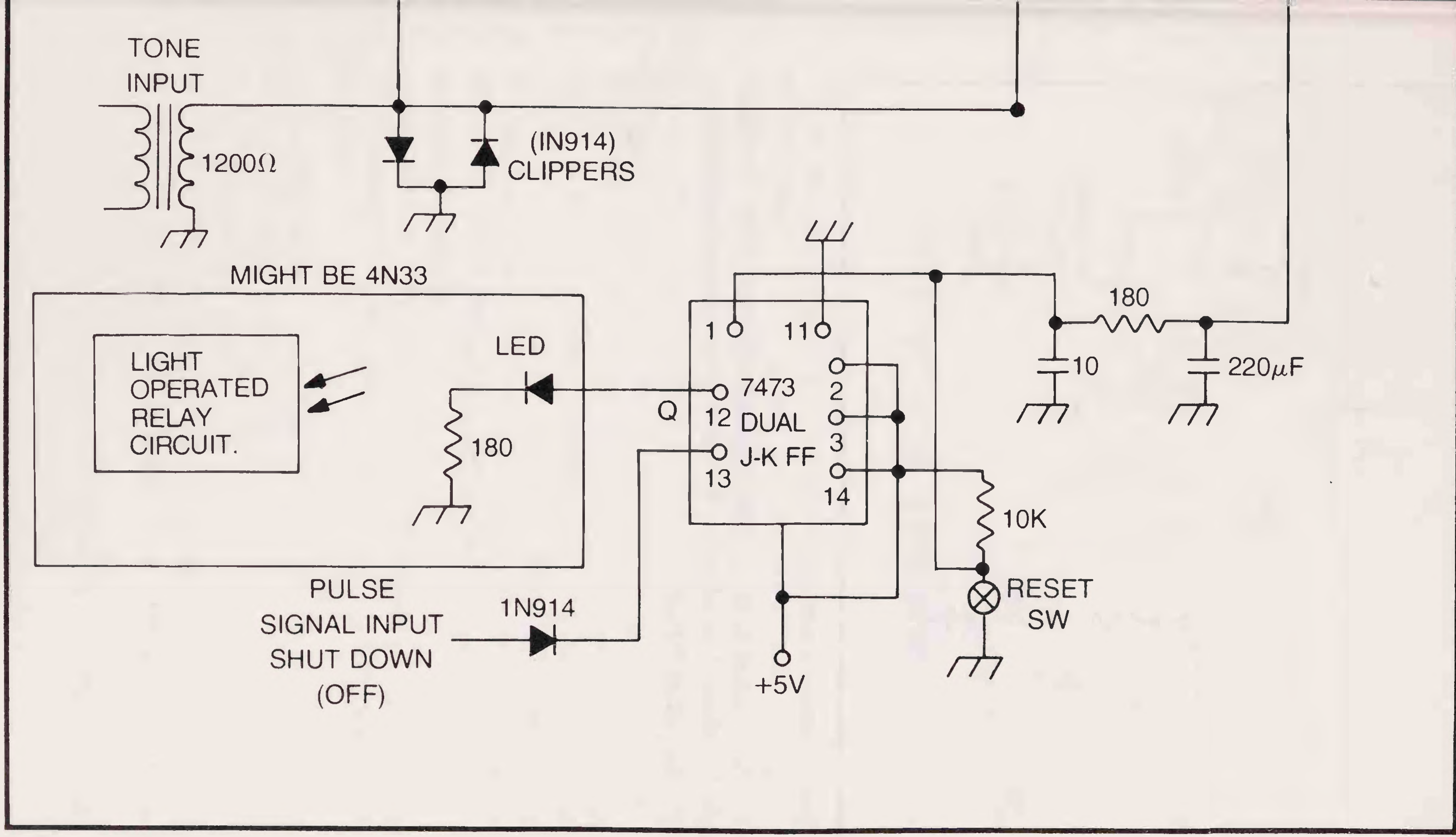


Fig. 3-32. A two tone decoder.

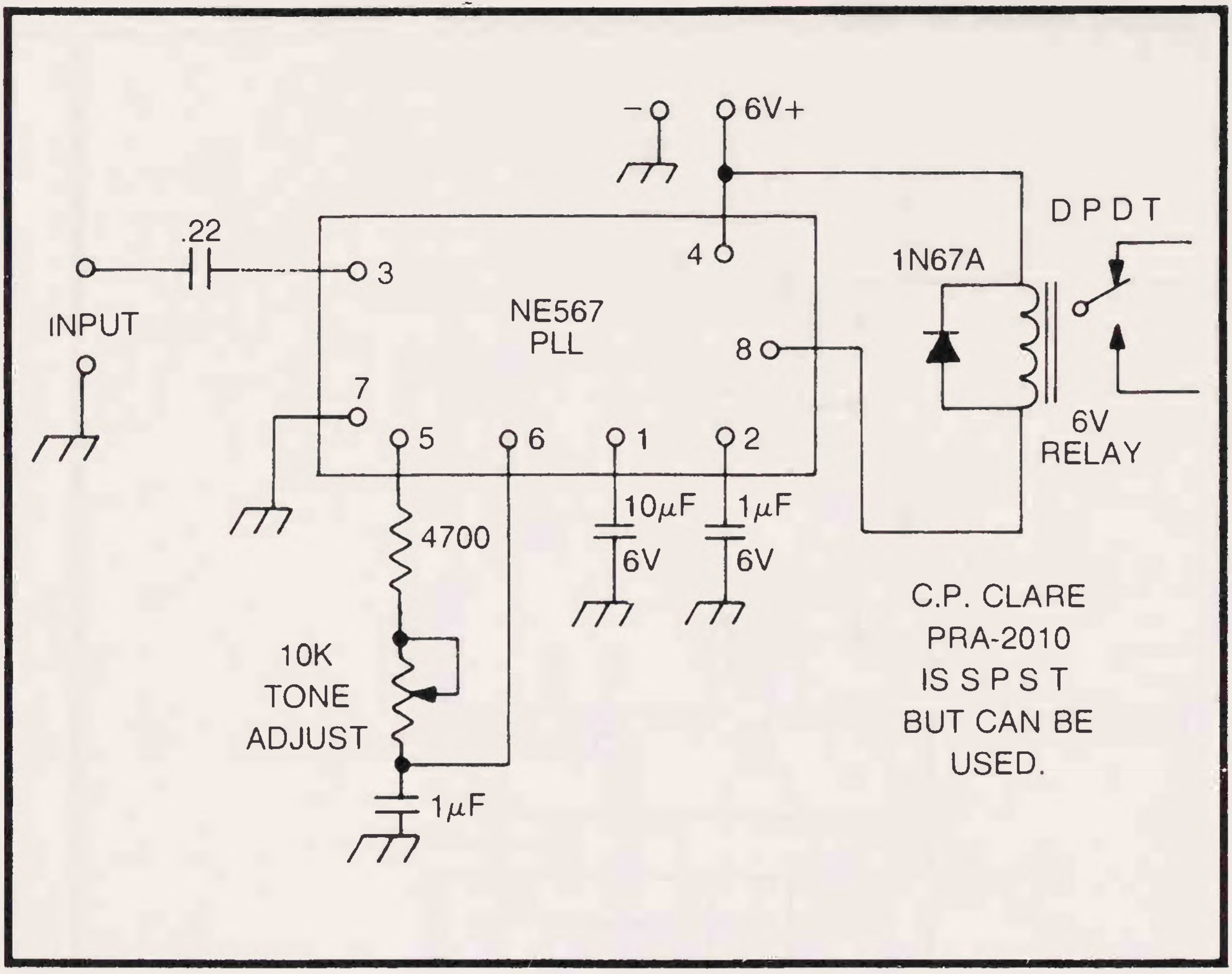
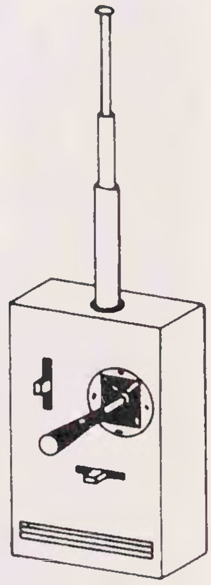


Fig. 3-33. A simple tone decoder.

double throw (shown) or a single pole single throw (listed). The PLL stands for phase locked loop. This is an arrangement around the integrated circuit NE576.

4
Tools, Testing, and Soldering



We devote this chapter to some basic information which may or may not be familiar to you. If you want to construct a radio-control system from a kit or from purchased parts, you will have printed-circuit techniques facing you, as well as wire and parts soldering. Sometimes it is nice to buy small experimenters boards. These permit the interconnection of parts without soldering so that you can see if the circuit will work, or you can experiment with component changes easily. In any event, we now give you some construction tips. Remember that most kits have test methods and adjustments as part of the construction procedure, using the meters or devices included in the kit; so all you need additionally are the tools and a knowledge of soldering techniques.

Most of the tools we will need are illustrated in Fig. 4-1. These will be familiar, with the exception perhaps of the soldering iron and the solder.

- Screwdriver, ¼-inch tip
- Screwdriver, ⅛-inch tip
- Needle-nose pliers
- Wire-cutting pliers; diagonal cutters
- Insulated alignment tools with ¼-inch tip (get these from a radio parts store)
- Assorted drills (1/16 to ¼ inch) and an electric or hand drill
- Soldering iron, 37-watt pencil type
- Box of *rosin-core* solder (not acid-core!)

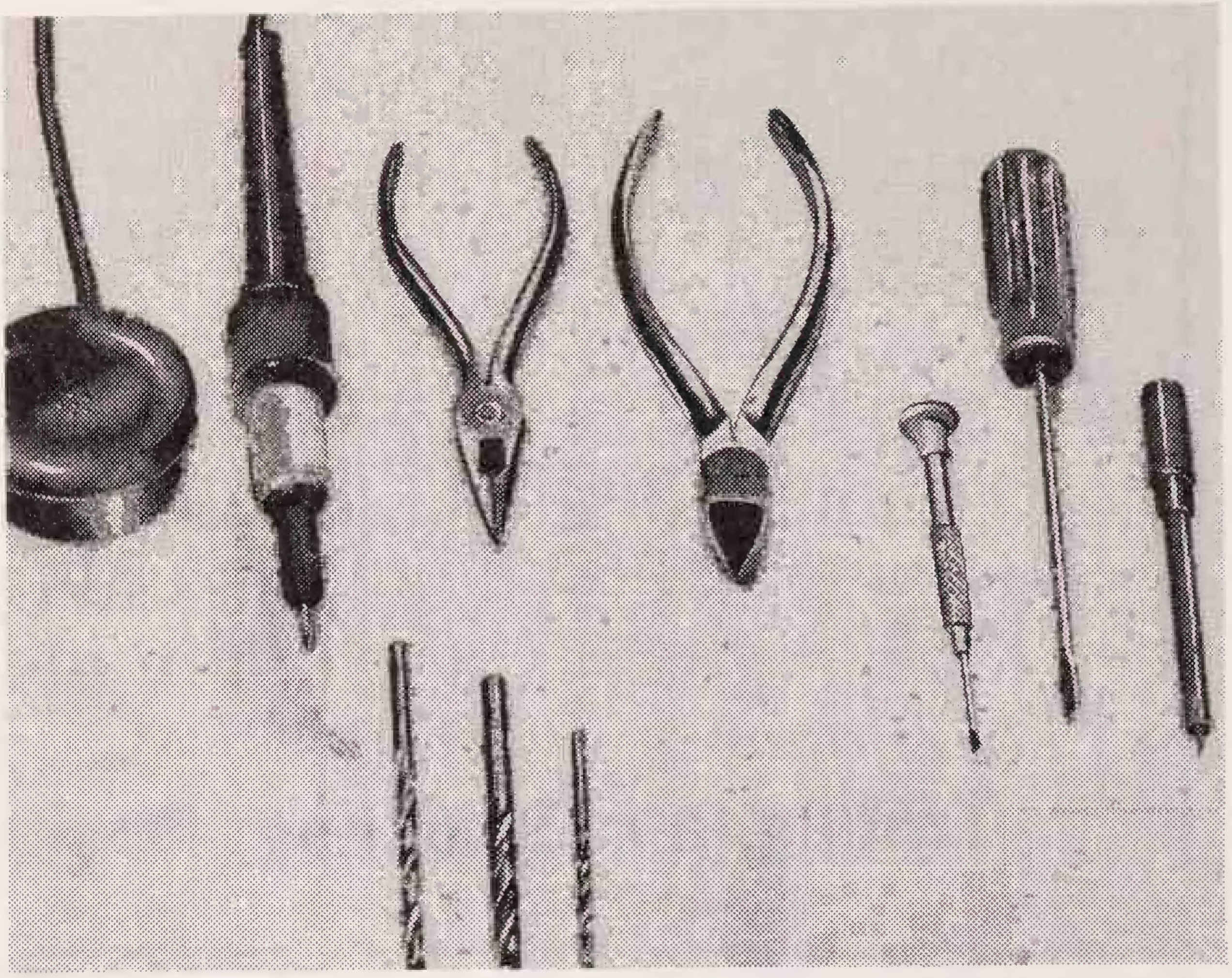


Fig. 4-1. Most needed tools for radio-control construction.

- Pocket knife
- Wire-cutter/stripper, such as K. Miller 100 or 100-S
- Small, fine file
- Roll of 18-gauge flexible, tinned, insulated hookup wire
- Carpenter's brace and a ¾-inch metal drill bit
- A good large magnifying glass

SOLDERING

Because more than 60% of the troubles encountered in constructing any type of radio-control or electronic equipment are caused by improper soldering or bad connections, let's learn how to

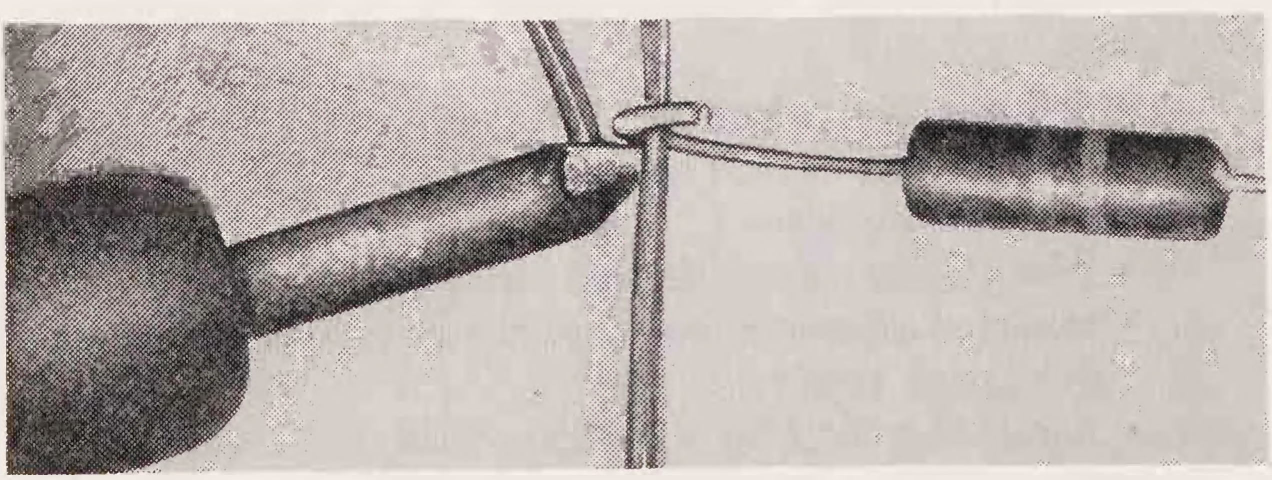


Fig. 4-2. Correct way of making a good solder joint. The solder must be applied to the junction at the same time the iron tip is applied.

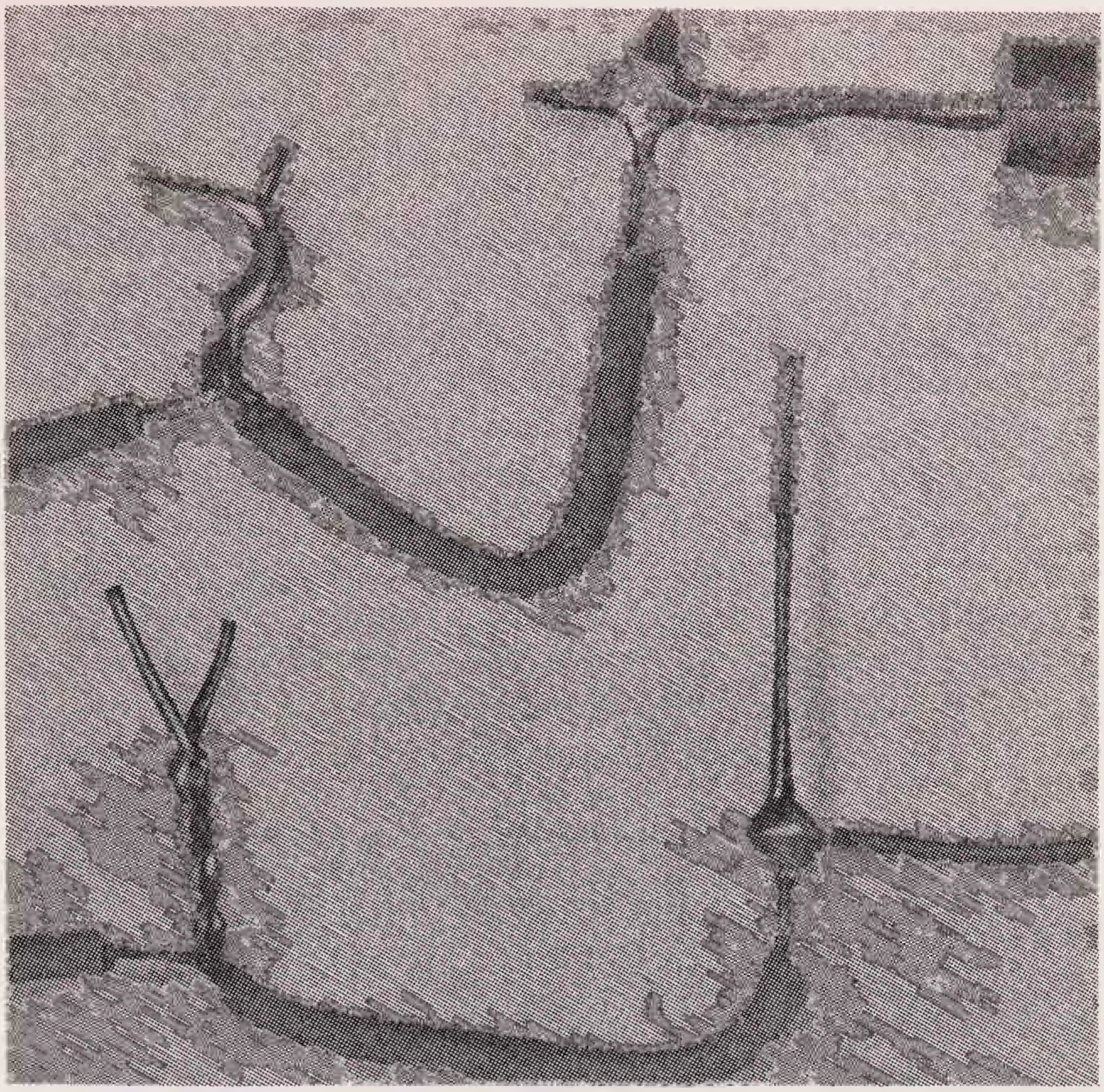


Fig. 4-3. Examples of a good and a bad solder joint. The bad one, obviously, is at the top. Note how the solder is unevenly melted.

solder before we go a step further. It is not difficult; it just takes practice—so let's practice.

The first step is to plug the iron into an outlet and allow it about five minutes to heat. In the meantime, prepare two scraps of wire. Most wires have a rubber, plastic or enamel coating for insulation, and we must remove this from the two ends to be soldered together. A wire stripper, like the Miller 100 or 100-S, is handiest. A knife will do, but be careful not to nick the wire. All we want to do is remove the insulation or scrape the enamel until the wire shows bright and clean. "Tinned" wire is best—the tin coating makes soldering easier because there is (usually) no layer of tarnish to remove.

The next step is to twist these two cleaned ends together to make a joint. This will apply to any parts we use later on. Most have wire leads that must be cleaned, and when they are connected to other parts, the joint must be strong mechanically.

Take your iron and touch the tip to the end of a 6-inch length of the solder. See how it runs and flows down over the tip. It's bright and silvery and smooth. Don't use too much, just enough to coat the tip of the iron. Wipe away the excess with a cloth. If the solder forms little gobs instead of coating the tip, file the tip shiny and quickly reapply the solder.

Now apply the tinned tip of the iron to the cleaned wire joint and at the same time apply the solder so that the melted solder runs down onto the two wires (Fig. 4-2). This helps to heat the joint. In just a second, you will be able to apply the solder directly to the joint (keeping the soldering-iron tip against it), and the joint of the two wires will be hot enough to melt the solder.

Don't use too much solder—just enough to coat the joined wires smoothly and evenly. Remove the iron. Hold the wires absolutely still until the joint cools. Now examine the connection. Twist it. Is it stiff and hard and firm? Is the solder smooth and evenly melted? Is there just enough solder to cover the joint and no more? If your answers are yes, you have made a good soldered connection.

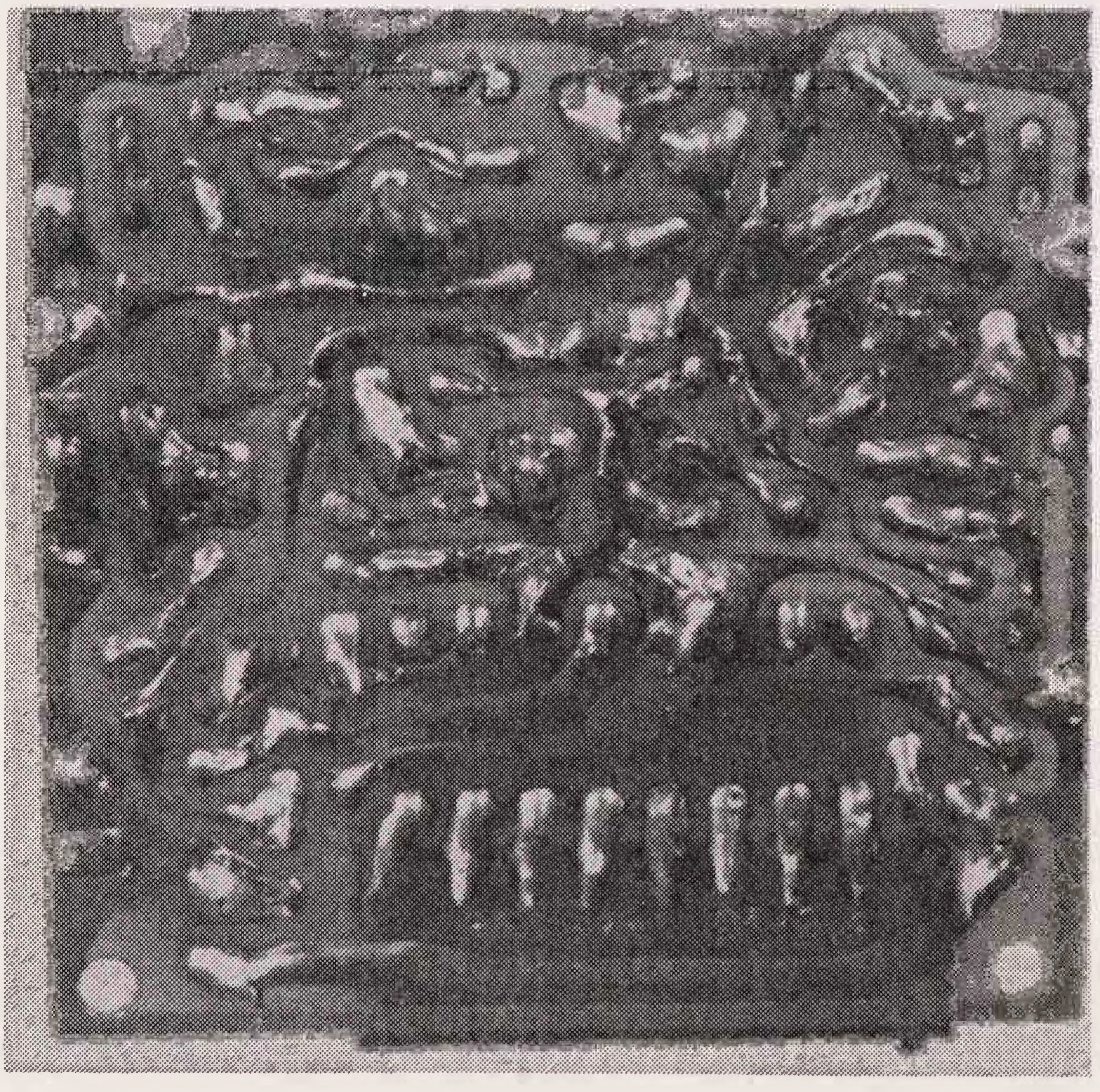


Fig. 4-4. Printed circuit soldering requires carefully applied solder so it doesn't smear across insulated breaks. Not too much heat, either, but enough to get a good "melt" and bonding. Use your magnifying glass for inspection often.

Fig. 4-3 shows a good and a bad solder joint. Practice soldering until you get this step thoroughly mastered before going ahead.

The purpose of soldering is to make a perfect electrical connection. When you have a bad joint, you have added resistance in the circuit, or you have no circuit at all. Either means failure.

A final word. Always keep the tip of your iron bright and clean. As you use it, it will erode and pit and you will have to use your file to keep the tip squared up, as it was when new. A good system is to keep an old cloth around when using the iron. Every now and then wipe the tip, cleaning off the corrosion and excess solder that somehow always accumulates and blackens the tip.

Printed Circuits

Some of the circuits in this text will be built around printed-circuit boards. You should learn something about this type of construction especially if you (like me) are of the "old school" of point-to-point wired electronic construction. See Fig. 4-4.

The first and probably the most important idea is that we can buy printed-circuit (actually etched-circuit) kits from any electronic mailorder house. A typical kit is shown in Fig. 4-5. This kit contains everything that's necessary so all you have to do is make a layout of the circuit you want to do up as an etched circuit. Use the resist paint or adhesive resist tape, and then follow the directions supplied with the kit to make your board. Of course you will want to be extremely careful about making your soldered connections perfectly tight, and you will want to be sure that all connections have the necessary copper link between them. The printed-circuit boards do make the construction simpler and often more sturdy, but you can use the wired type of construction with excellent results.

SUBSTITUTIONS FOR TRANSISTORS

It is impossible to list all the substitute types available for a particular transistor. I found a simple solution that I'll pass on to you: Visit a radio supply house such as Radio Shack, or write to one of the big ones and ask them to send you a complete set of transistor substitution pamphlets. There is a small cost for most of these, but they are well worth it.

Once you have a replacement or substitution list, don't be afraid to use alternate transistor types and experiment with them. Then, when I suggest a transistor you cannot get, you will know what to use in its place. The *circuits* shown are ageless—that is, they will be useful and usable forever. Only the numbers, names and physical

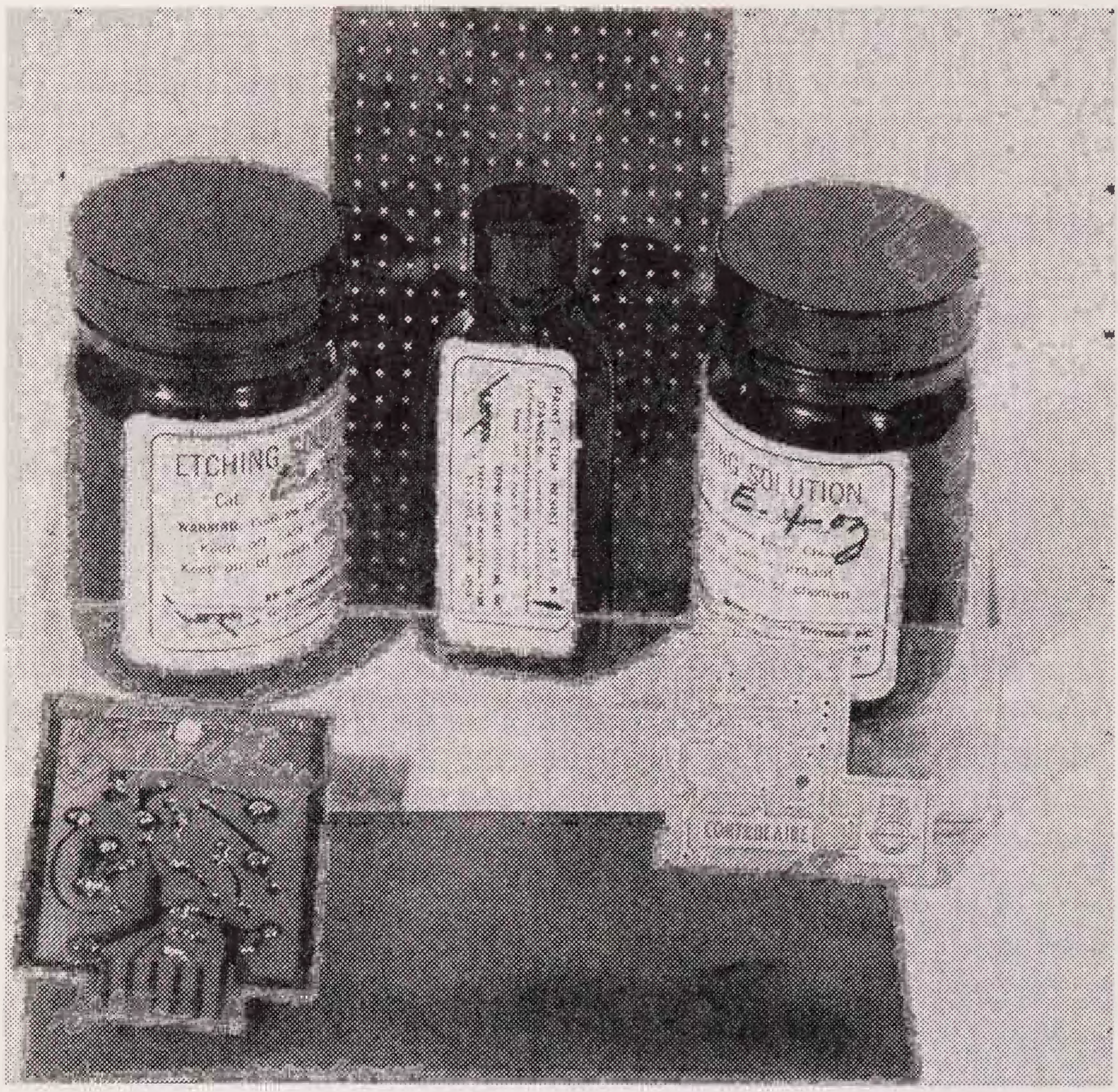


Fig. 4-5. An etched-circuit kit.

sizes of the parts may change, so eliminate trouble by getting transistor replacement pamphlets and keeping them up to date.

TEST INSTRUMENTS

To work seriously with radio control, you should have a good volt-ohm-amp-meter (Fig. 4-6) which can measure continuity of cables and switch contacts, give resistor value indications, measure battery voltages, and determine charger currents. You might build a "quickie" tester as is diagramed in Fig. 4-7. This will at least give you something to use as a help in arriving at approximate parts values and battery and current values. You must calibrate it. And that takes a little doing. I have taken the meter apart and made a paper scale, gluing it to the meter face. Then using parts of known values—such as resistors of 100-, 1000-, 5000-, 10,000-, 25,000- and 50,000-ohm values—made marks to show where the meter needle will be on these values. I can then guess at in-between values. I do battery voltages the same way and also the currents. This is not an accurate checker, but it can be a help under some circumstances.

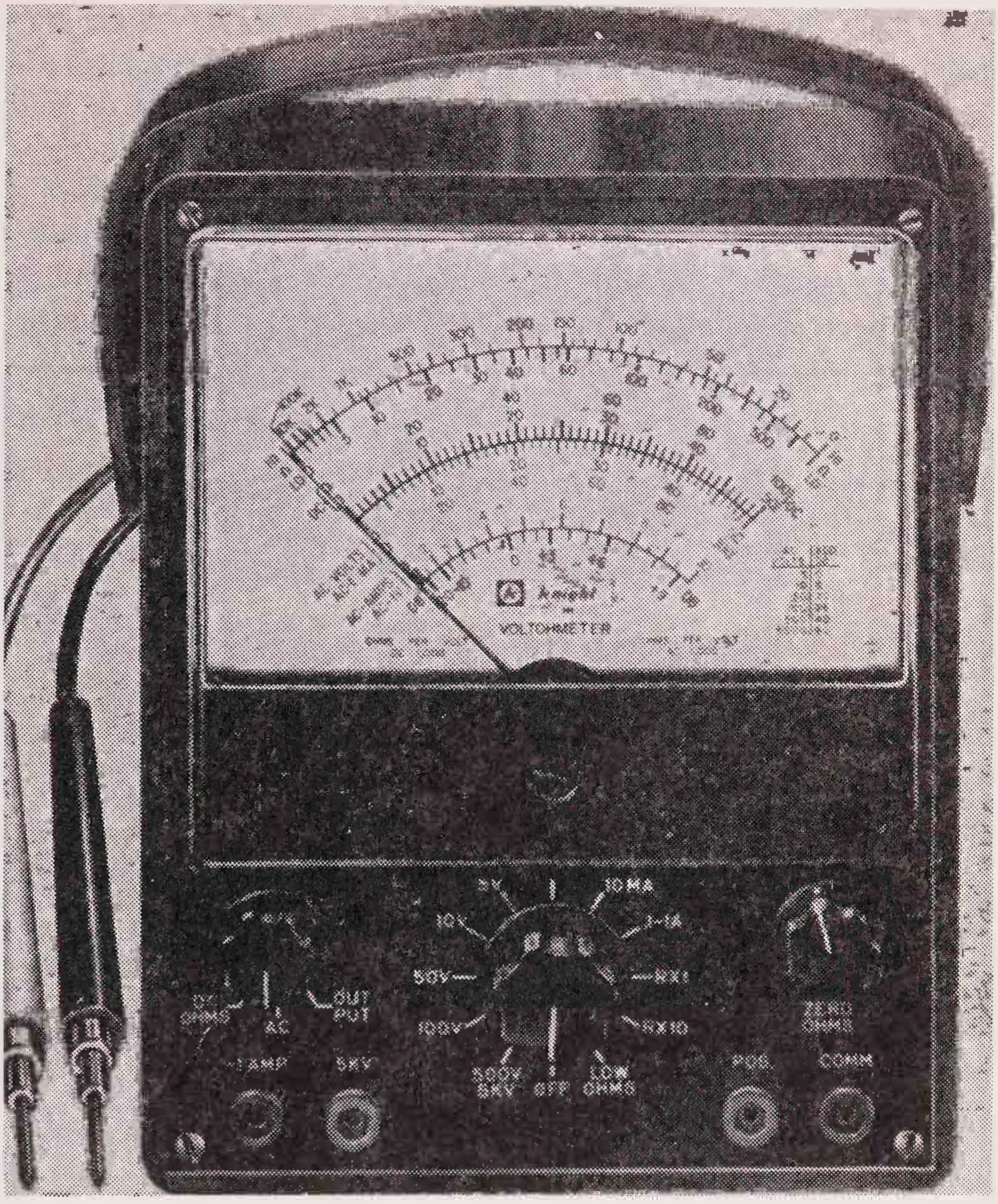


Fig. 4-6. A volt-ohmmeter built from a kit.

It is always best to have the best kind of test instrument in as good a meter as you can afford; you can rely on it for accurate value determination then. Of course if you go in for construction of a complete system built from scratch you will want a good oscilloscope and perhaps a VTVM and grid-dip meter and signal generators. You might need to examine waveforms such as shown in Fig. 4-8. These are of a modern digital receiver decoder.

Just a little more information about the tester of Figure 4-7.

In Fig. 4-7a, the meter is used to measure current. Switches S1 and S2 should normally be closed so that you will not damage the meter by connecting it into a circuit that passes too much current through it. If the reading is too low, you would open S2 first. If the reading is still too low, *then* open S1. The meter is most sensitive (measures the lowest current) when both switches are open. It is easily damaged by passing too much current through it in this most sensitive condition. Be careful! The logical choice for S1 and S2 is to use normally-closed spring-return pushbuttons.

As a voltmeter, the circuit in Fig. 4-7b works nicely. With a rotary switch you can select the range you want. The circuit in 4-7c is for measuring resistance or continuity. The 4.5-volt battery shown here will allow measuring ohms with reasonable accuracy up

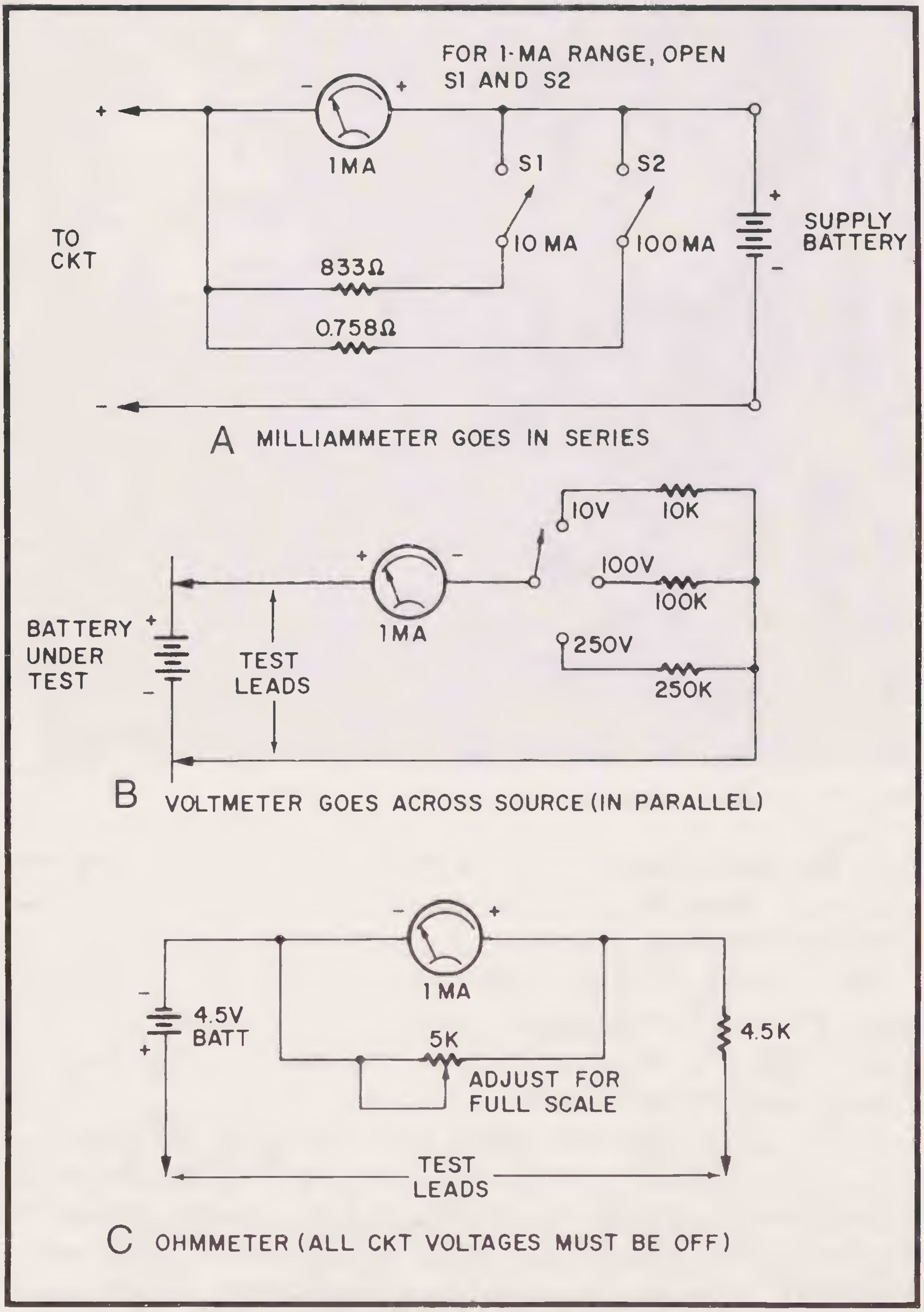


Fig. 4-7. Basic volt-ohmmeter circuits.

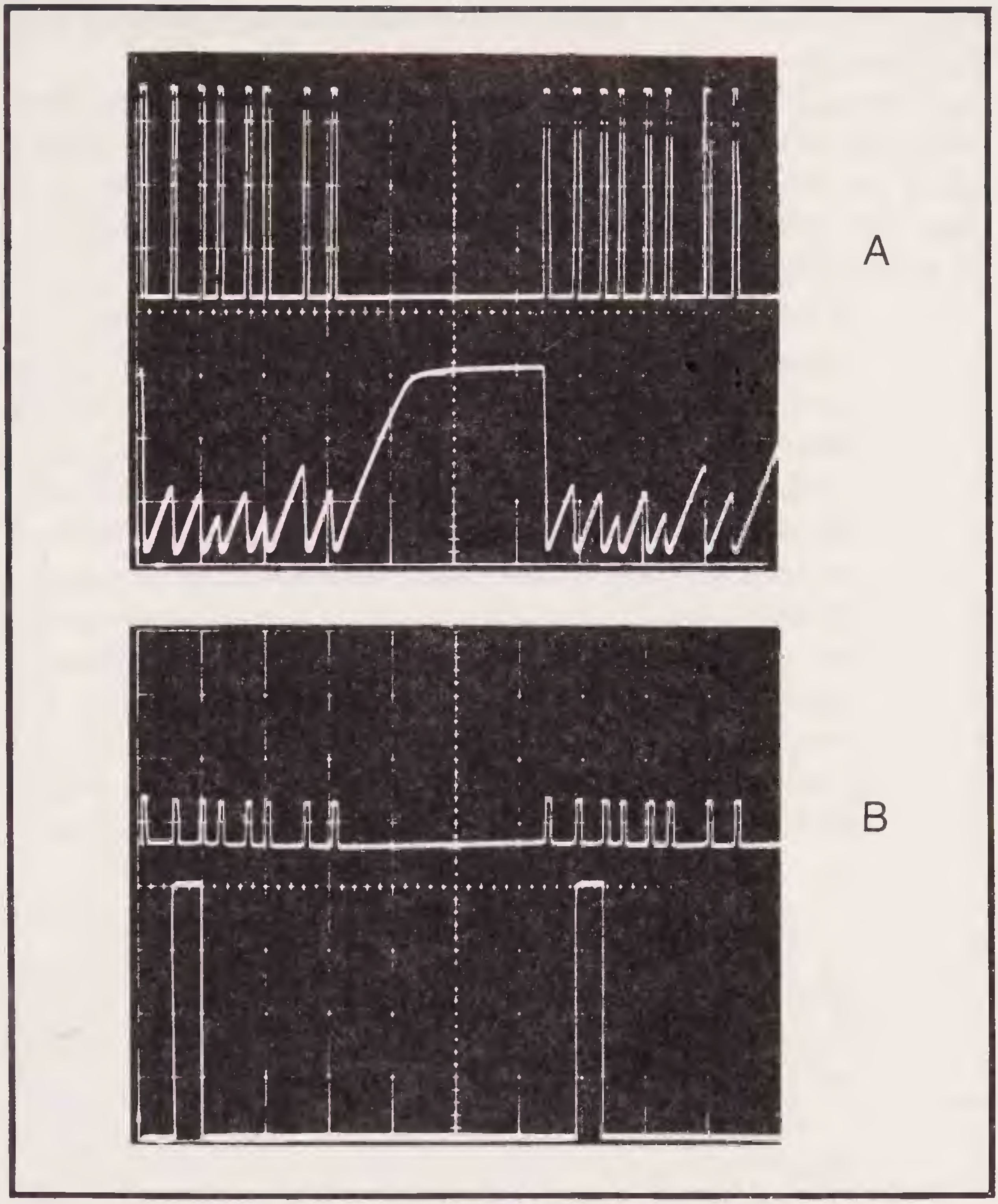


Fig. 4-8. Waveforms of a modern digital decoder.

to about 50,000 ohms, and will give a usable indication of higher resistances up to about 500,000. To measure these high volues accurately requires a higher-voltage battery.

PRINTED CIRCUIT SOLDERING TECHNIQUES

Because almost all electronic construction nowadays is involved on printed circuit boards, let us examine for a few moments some of the techniques and concepts which are accepted practice in putting together such soldered circuits. We want to remember that there is involved not only the assembly, but often the removal and replacement of parts from a printed circuit board. Usually this latter is done at a factory or service repair shop, but you might do it if you know how or cannot get to one of the other agencies which do this kind of work.

In a printed circuit it is essential that you remove solder from each joint so it doesn't flow around and make a mess on the board and short out the printed circuit wiring when you are assembling or replacing parts. There are some methods of doing this, neatly and professionally. Let's examine them.

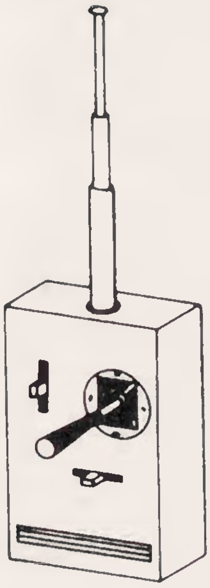
- *Wicking*. In this method, stranded copper wire or braiding saturated with flux is applied to the solder joint between the solder and a heated soldering iron tip. The combination of heat, molten solder, and the air space in the wick causes the solder to run up into the wick so that an excessive amount doesn't appear on and around the joint. Also, this method can be used to attract solder when it is necessary to remove old solder from a joint which has been soldered only on one side of a printed board. This kind of soldering attraction should not be used for through-the-hole solder joints because the hole-type joint will hold the solder more firmly and it will not go into the wick. Of course you must always saturate the wick with liquid-resin flux and use a new section each time you want to attract solder from a joint.
- *The suction method.* This is a very common type of operation with printed circuits. There is a bulb, hand squeezed, which has a nozzle which is applied to the joint, and the bulb is then squeezed. The joint is heated, solder flows, and the bulb is released so it sucks up the solder from around and through the joint area. The process can be repeated as many times as is necessary to get the joint loose to remove a part.

  Sometimes, when the part lead is through a hole, the solder cannot all be removed and so the lead is not free. You must then remove the lead by application of the soldering iron tip long enough to get the solder flowing inside the hole and pull the lead out with some tweezers or sharp tipped pliers. If the part has many leads and you cannot do this, as with some integrated circuit components, you must work at it by heating and vacuum suction of solder until you do get the leads free, or heat the board and shake it or tap it vigorously to cause the solder to run out of the hole area.
- *Just heating.* Sometimes you can just heat the soldered area and pull the part lead out. This applied when you have, say, a resistor or capacitor lead to extract. Then you must go back and remove all the excess solder from the joint location by the bulb vacuum or the heat-and-tap or heat-and-shake

method. In some factory applications it has been found that when a part has multiple leads, one can dip the soldered area, carefully, into molten solder and thus heat all joints simultaneously and then pull the part out of its multiconnection socket or printed circuit location. We don't recommend trying this, for radio control experimenters may not have the facilities or experience to do this without damaging the parts.

- *The manufacturers' method.* These agencies use a device which is a combination soldering iron, air blower, vacuum suction tip, and a collecting chamber for the excess solder in the instrument handle. With this you can apply heat at the same time you get suction to pull the solder away from the joint. Some parts stores, such as Radio Shack, have devices which approximate this operation and which you can get and use to assemble printed circuit systems. It is also to be noted that sometimes a blast of air through a tiny hole will blow the solder away from a joint to free a part lead. So you might use your suction bulb in this reverse manner, but be careful not to blow the solder onto undesired areas of the printed-circuit board.

We have found in our own experimentation that it was necessary to inspect the area in which we were soldering very carefully with a magnifying glass to be sure we didn't get solder flowing too freely and thus overlap the printed-circuit conductors in places where this shorting was not supposed to take place. Sometimes we had to use a combination of heat and a small scraper made from a sharp knife tip to remove these little, dangerous, and undesired devils. Of course we had to be careful also not to cut into the board or printed wiring and thus make other problems. We suggest that you use great care, patience, and work only a short time interval before taking a rest break if you are assembling printed circuits. Thus you may not have difficulty. Use only the wattage soldering iron recommended, or at best not over 47 watts, and keep its tip sharp, chisel sharp, clean, and tinned. Wipe off any excess solder on it every time you use it. Apply the heat carefully and no longer than necessary to get a good joint. Use the smallest diameter solder—with a flux built into it—resin core of course, that you can get. Good luck.



5

Building A Simple Short-Range R/C System

You read about radio-control systems and soon find that they are used with model airplanes and boats and cars. Then you realize that you're unable to get a location where you can operate such a model, or unable to invest the amount of money required for such models and equipment. So you might feel you can't experiment with radio control. Not true!

THE HOME SYSTEM

The system described in this chapter was designed (if we can consider it to be a designed system) with that very thought in mind. I felt that you might want to try your hand radio-controlling some small model in your living room. A racer, or several, might be built using this idea. The basic ingredient is simply a small five- or six-transistor broadcast radio you can usually buy for around $4 to $8.

You might also use a dime store walkie talkie which can send a tone by button control. Two of these may sell for about $15 as of this writing so you might use one as transmitter control station and one for radio-control receiver station. The modification to the output to operate a small relay is the same for broadcast or CB type units. You will probably get some interference if you use the CB units, but if you control a small car, no damage will result and you can try your hand at construction of a small radio-control system. Give it a try:

Figure 5-1 shows how you can take such a receiver, disconnect one lead from the speaker (or both if you don't want to hear your signals) and connect the leads to a small transistor output trans-

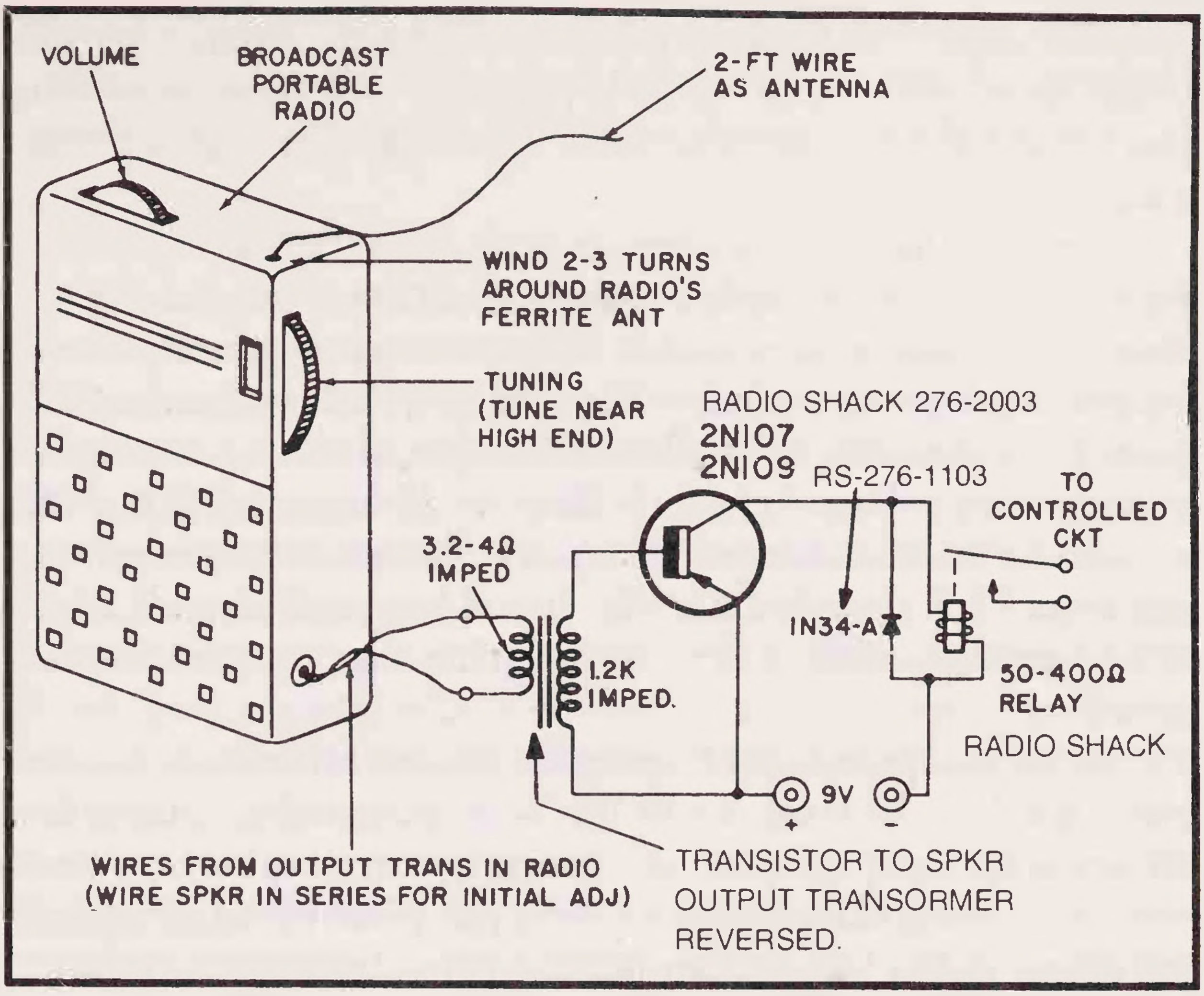


Fig. 5-1. Small transistor portable modified for short-range radio control.

former. This in turn is connected to a transistor and a relay and a separate nine-volt battery as shown. The connection in the inset drawing is to show how to connect the transformer's 3.2-ohm winding in series with the speaker. We use this method so we can hear the signals as the receiver gets them, and thus tell that we have the transmitter and receiver in tune.

The transmitter for this system is a simple short-range "wireless microphone" type of circuit, modified to include a tone oscillator. It operates at the high end of the broadcast band (around 1,500 kHz). Figure 5-2 is the schematic.

This circuit is exceptionally easy to adjust. Simply tune the receiver to a spot at the high end of the dial where there is no station. You will probably need to open the case and wrap a turn or two of insulated wire around the tuning antenna coil (the black powdered-iron bar near the top of the receiver case). Bring out about two feet of this wire for an antenna. You can leave the other end free, connect it to the receiver ground (or common). Tune the receiver to high end of dial, turn volume full on. Now tune the *transmitter coil* by adjusting the slug until you hear the tone in the receiver. Tune the transmitter to get the loudest tone from the receiver. With the receiver volume control at maximum the receiver relay should now close. If you open and close the tone switch, the relay should open and close.

Use about 6 to 8 feet of antenna on your transmitter, for the power output of this transmitter is very low. Low power is used to stay within the FCC restrictions for the wireless-microphone-type transmission.

Once you have the receiver and transmitter adjusted, you can disconnect the speaker by shorting across its terminals so that the connection from the receiver output transformer to the relay circuit transformer is direct. I chose to leave the speaker in so I could tell if I needed to retune the transmitter. I found some drift, so when the tone got weak or the relay circuit didn't work, I simply adjusted the transmitter for loudest tone again. You will have to experiment with this circuit, but you'll find it's easy to build and operate, and it will radio-control a number of devices around the house in addition to the models.

If you want to increase the range of this kind of system, you can either purchase or build one of the tone-transmitting devices described in this book and then add a converter circuit to the broadcast receiver. You will already have the relay part of the circuit completed and tested. In this way you can increase range and stability and get a good system for cars or boats. I do *not* recommend this type system for aircraft. Aircraft are too touchy and need the best kind of

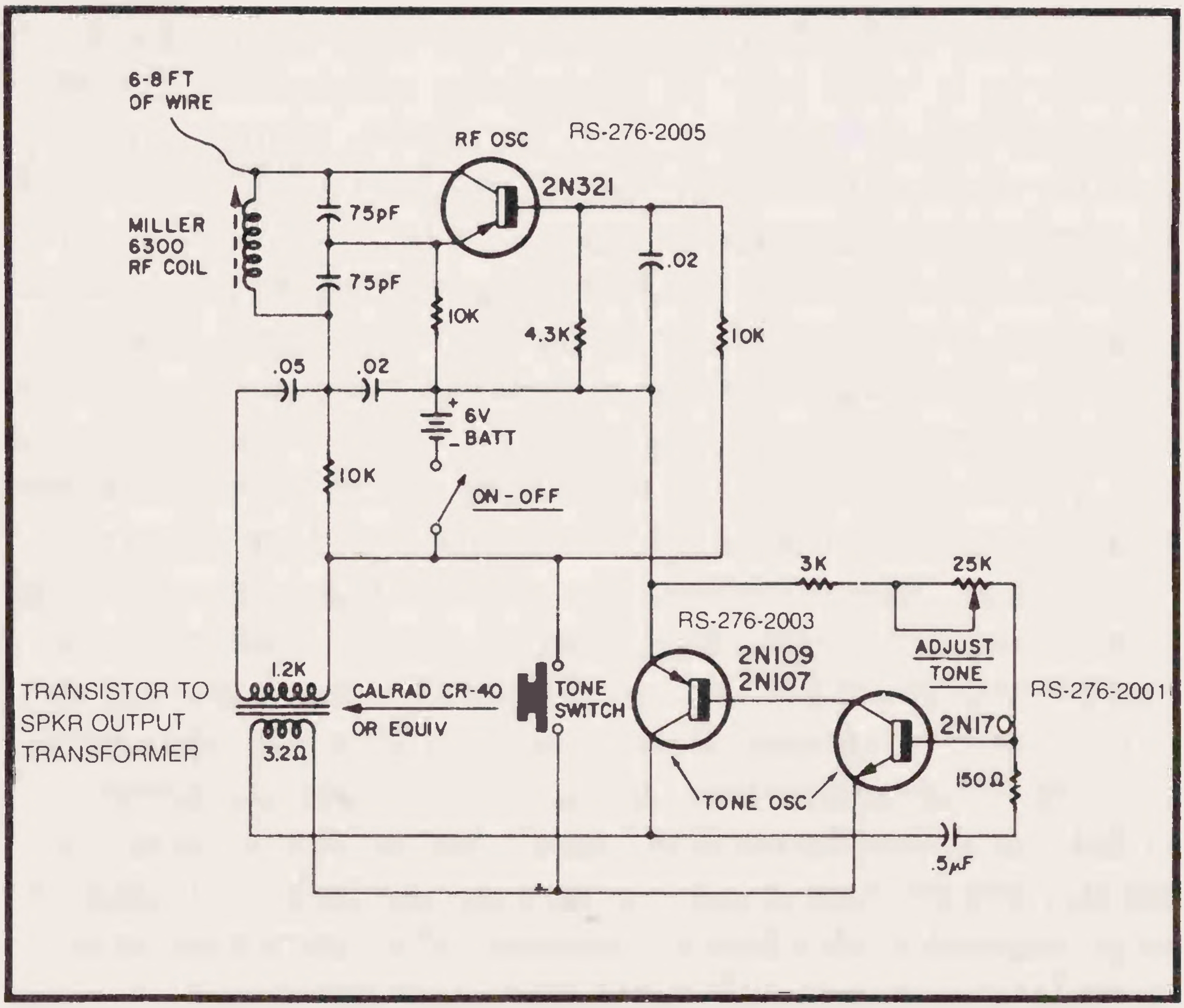
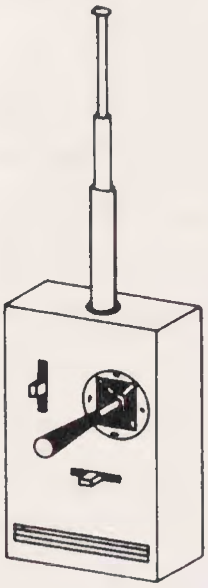


Fig. 5-2. Schematic of the wireless broadcast transmitter.

equipment all the way through for satisfactory operation. The other radio-control receivers described in this book *are* suitable for planes and usable with the radio-control transmitters described later.

COMMERCIAL UNITS

We do recognize that there are on the market, especially in toy stores, little radio controlled cars which have a receiver and transmitter as a part of their system. They are very simple and they too sell, as of this writing, for around $12 to $16. You might get one of these and play around with it as it is, then take out the transmitter and receiver units and adapt them to some other device you want to radio control. They use below 100 mW which is the license free citizens band spot under Part 15 of the FCC Rules and Regulations. You'll get some interference also at times using these units, but not enough to keep you from enjoying the fun of operation and experimentation.



6 Transistor Transmitters

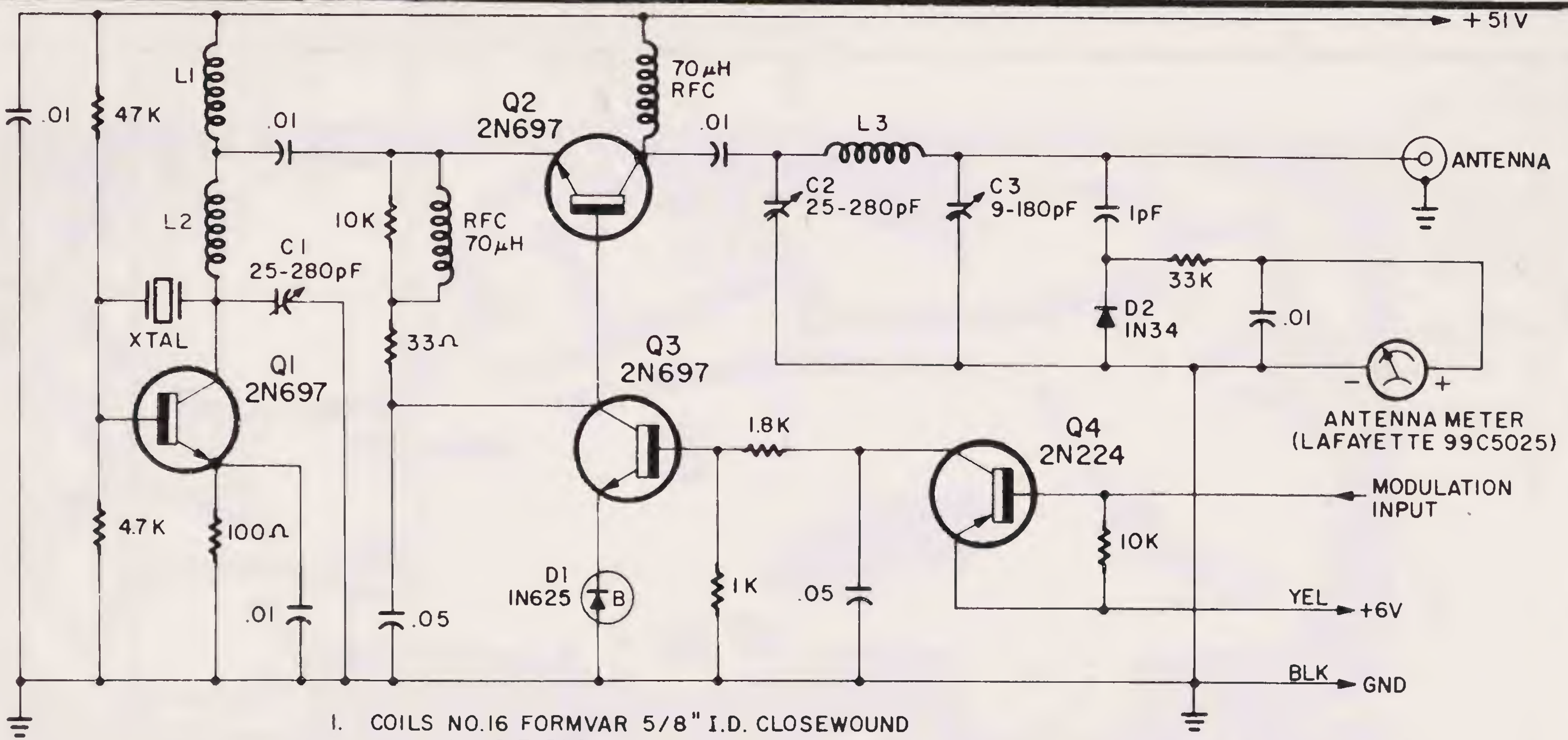
This transmitter is a fine example of an up-to-date unit with excellent radio-control capabilities. It is included here by courtesy of David Jansson and Grid-Leaks. The circuit (Fig. 6-1) consists of a common-emitter overtone oscillator at 27 MHz followed by an unneutralized common-base power amplifier. The method of modulation (Q3) minimizes the effect of peak modulator current on the batteries to keep the current drain low. Because it cannot modulate 100%, however, the range of the unit is somewhat limited when used with a super-regenerative type receiver. Still, it should be adequate. There is plenty of modulation for superhet receivers.

The power supply for the transmitter can be of either type shown in Fig. 6-2.

The tone section of the modulator produces a tone of about 3,600 Hz which is pulsed at about 20 Hz in such a manner that the width or transmission time of each pulse can be varied. This is the type signal used in the pulse-width-rate variation control system.

The basic circuit of the tone unit is a low-rate multivibrator (Q5, Q6) with a control stick that operates a potentiometer to vary the pulse width. This multivibrator drives a transistor switch (Q7) which turns on and off another (tone) multivibrator (Q8, Q9) whose frequency is stabilized by a tuned circuit. You might have to wind your own coils, but you can try buying them from Ace Radio Co., Higginsville, Mo. A two-transistor switch coupled to the tone modulator modulates the final power amplifier.

The transmitter is constructed on a printed-circuit base. You can cut out Fig. 6-3 and use it as a template to put the tape or paint



1. COILS NO.16 FORMVAR 5/8" I.D. CLOSEWOUND
   L1 = 2 TURNS
   L2 = 8 TURNS
   L3 = 10 TURNS
2. RFC = 70μH RF CHOKE (ACE RADIO CO.) HEAT SINKS (WAKEFIELD ENG., WAKEFIELD, MASS.)
3. TRANSISTORS Q1, Q2, Q3 REQUIRE CLIP-ON
   USE TYPE NF-207 FOR Q1 AND Q3; TYPE NF-209 FOR Q2. (ORDER FROM ALLIED RADIO CORP.)
4. C1 AND C2 = ARCO 464, C3 = ARCO 463 (SCREW-TYPE TRIMMERS.)

2N224 = RS(RADIO SHACK) 276-2005
2N697 = RADIO SHACK 276-2030

Fig. 6-1. Circuit of transistor radio-control transmitter.

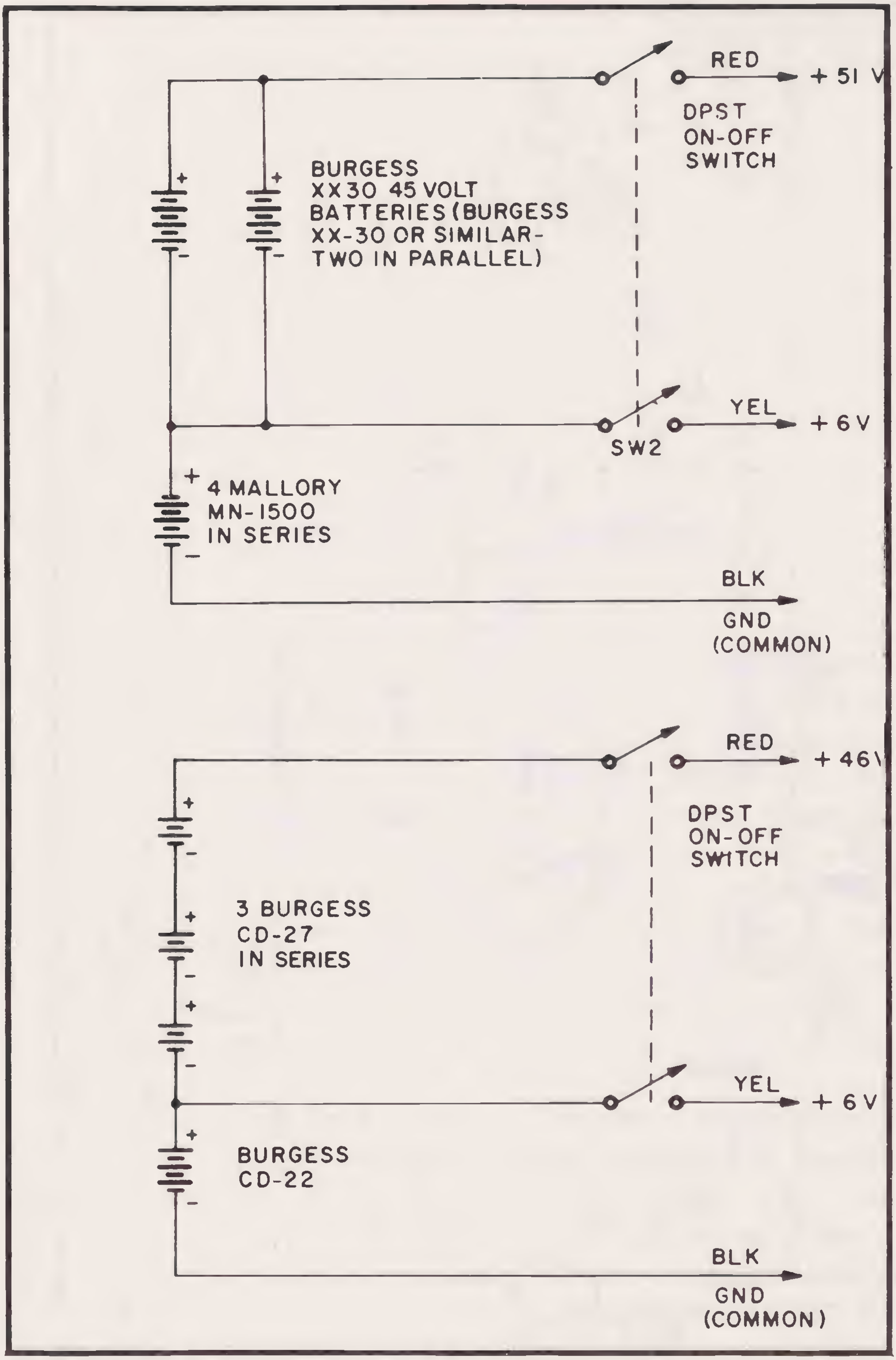


Fig. 6-2. Power supply circuits for transistor transmitter.

resist on your printed-circuit kit board. The pattern as presented here is about ⅔ actual size.

Notice that the dark sections of the board are metal that remains after the etching solution has dissolved away the unprotected areas.

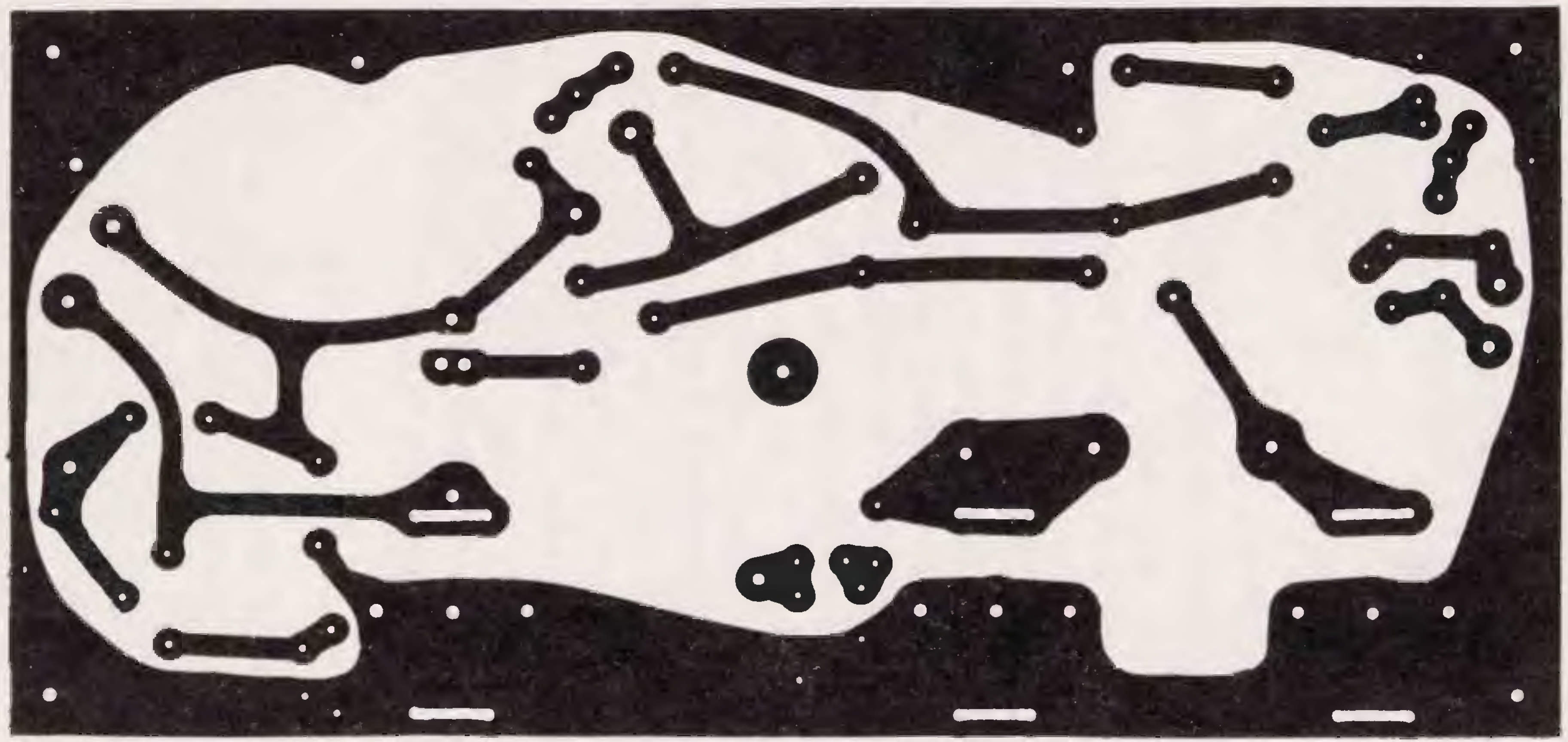


Fig. 6-3. Transmitter circuit-board layout.

Figure 6-4 shows how the components are placed on *top* of the circuit board. This is the *insulated* side of the board—the side without foil. If your components are not quite the same as the ones sketched in Fig. 6-3, you may have some trouble fitting them to the board. You may want to collect all the parts first and then make any necessary changes in the etch pattern (Fig. 6-3). The tuning procedure for this transmitter applies to almost any transistor transmitter. It is similar to the method used with tube transmitters. Carefully check your construction against the circuit diagram before you start tuning up.

TUNING UP

1. Connect the antenna.
2. Back off the adjustment screw of C1 three turns, C2 one turn and C3 about ¾ turn.
3. Place a 50-mA meter in series with the 51-volt supply lead so you can head the oscillator current. Adjust C1 for a "dip" or minimum reading. This should be 15–20 mA. Back away slightly from the absolute minimum, just as you do with a tube oscillator, so the oscillator will start readily.
4. Adjust C2 for maximum antenna-meter reading.
5. Adjust the antenna tuning network (C2 and C3) by trial and error. Repeat until you get maximum loading. Change C3 in small steps. For each small adjustment of C3 the antenna meter must be peaked (set to maximum reading) by adjusting C2. You're looking for the highest maximum reading you can get, between half and full deflection.
6. Have your transmitter checked by a commercial radio operator who has precision measuring equipment and a First- or Second-Class Radiotelephone license (*not* a ham license) according to FCC regulations.

THE TONE SECTION

The second part of this transmitter is the tone and pulsing section. The circuit is shown in Fig. 6-5; the printed-circuit base layout in Fig. 6-6.

The parts layout on the circuit board is shown in Fig. 6-7. A Rameco SMTF filter was used in the original model. You might use the 3,500-Hz filter described in Fig. 1-25 instead of the SMTF coil and .01-μF capacitor across it.

Wire the tone section, inserting the transistors last. Check your connections and soldering, then connect the tone section to the transmitter.

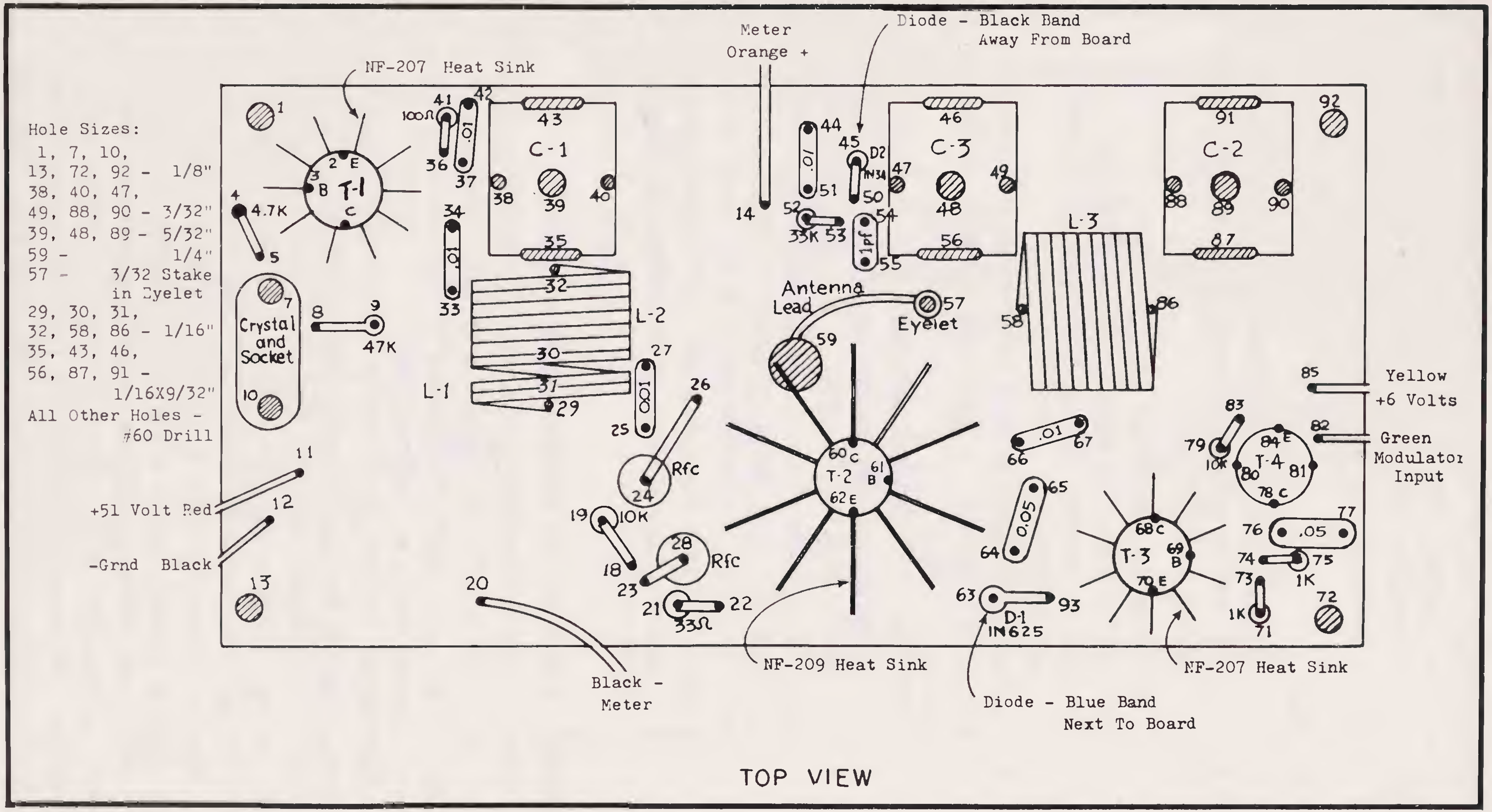


Fig. 6-4. Parts layout for the transistor transmitter rf section.

When you apply power to the circuit now you may hear a pulsing tone if you listen closely. The antenna meter should be pulsing slightly, if the transmitter is being properly modulated. You may hear the pulsing in a nearby broadcast receiver.

THE ANTENNA

The antenna is one of the most important parts of the transmitter. It must be correct if you want maximum range. The details of the antenna used are shown in Fig. 6-8.

1. End knob of wood or plastic.
2. This section from 1/16 music wire, 33 inches long.
3. Put small bends in the wire here to make a tight fit into the brass-tubing section.
4. A piece of ½-inch polystyrene rod to support the antenna sections and loading coil. Bore each end with a 5/32-inch drill, ¾ inch deep.
5. Solder the end of the music wire into a piece of tubing 5/32 inch outside diameter and put this into the loading coil core.
6. Wind the loading coil, 35 turns of No. 22 magnet wire, closewound. Connect one end to the antenna top section and the other end to the top of the lower antenna section (which is 22 inches overall length of ⅛-inch music wire).
7. Connect the end of the ⅛-inch music wire (bottom section) to an antenna plug so it can be connected and disconnected from the transmitter.

A SECOND VERSION OF THE TRANSISTOR TRANSMITTER

The basic transistor transmitter just described can be modified for use on 54 Mhz and 72 MHz, as well as 27 MHz. Its tone-pulser section can also be changed to eliminate the coil-capacitor filter. Figure 6-9 shows the new circuit diagram.

This diagram includes the rf section and the basic modulation section. Notice that the input from the pulser in Fig. 6-10 is labeled A, at the left side of the circuit. Q5 operates when the escapement control option is used, so the pulser of Fig. 6-10 is not necessary. When the pulser of Fig. 6-10 is used, Q5 is bypassed.

There are options available. You can choose the type circuit you want, depending upon whether you want escapement control only, pulse rudder with either fast pulse or tone off-on engine control, or pulse-width-pulse-rate rudder-elevator control with tone off-on engine control. Option no. 1 is escapement (Fig. 6-10b); option 2 uses circuits Fig. 6-10c and d; and option 3, Fig. 6-10e and f. Note that

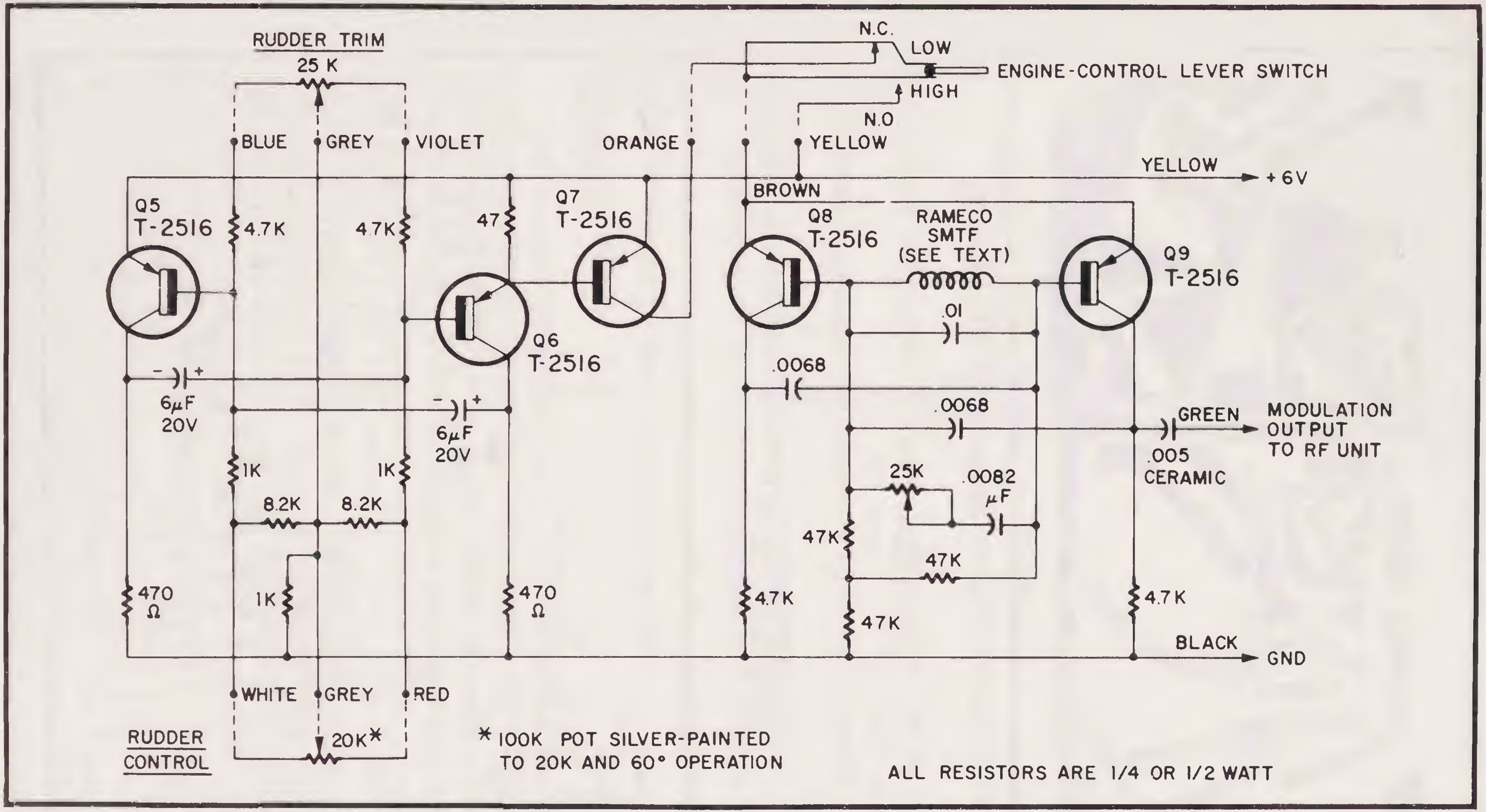


Fig. 6-5. The circuit diagram for the tone section.

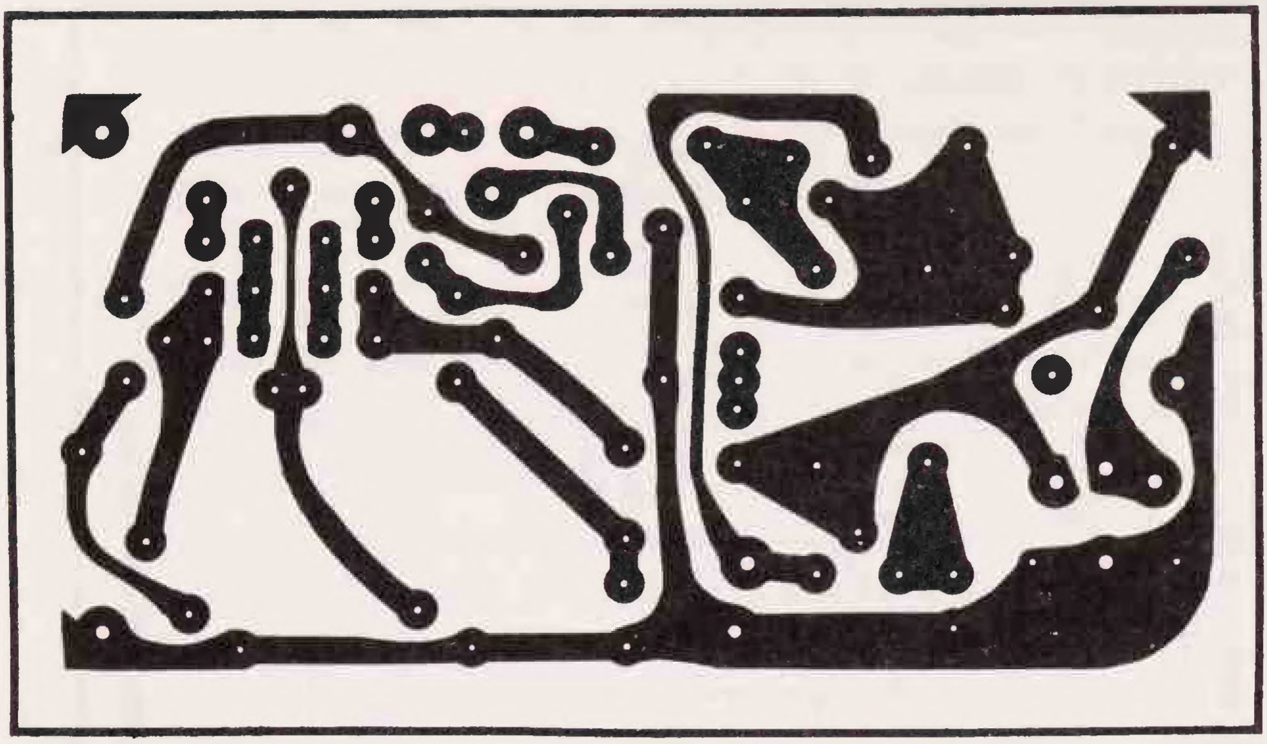


Fig. 6-6. Printed-circuit base for the tone section of the transmitter.

these option circuits connect to the modulator of Fig. 6-9 and to the circuit of Fig. 6-10.

Figure 6-11 is the printed-circuit pattern for the transmitter and pulser.

Figure 6-12 illustrates the parts layout on top of the base board. The pulser is built onto the same board as the transmitter.

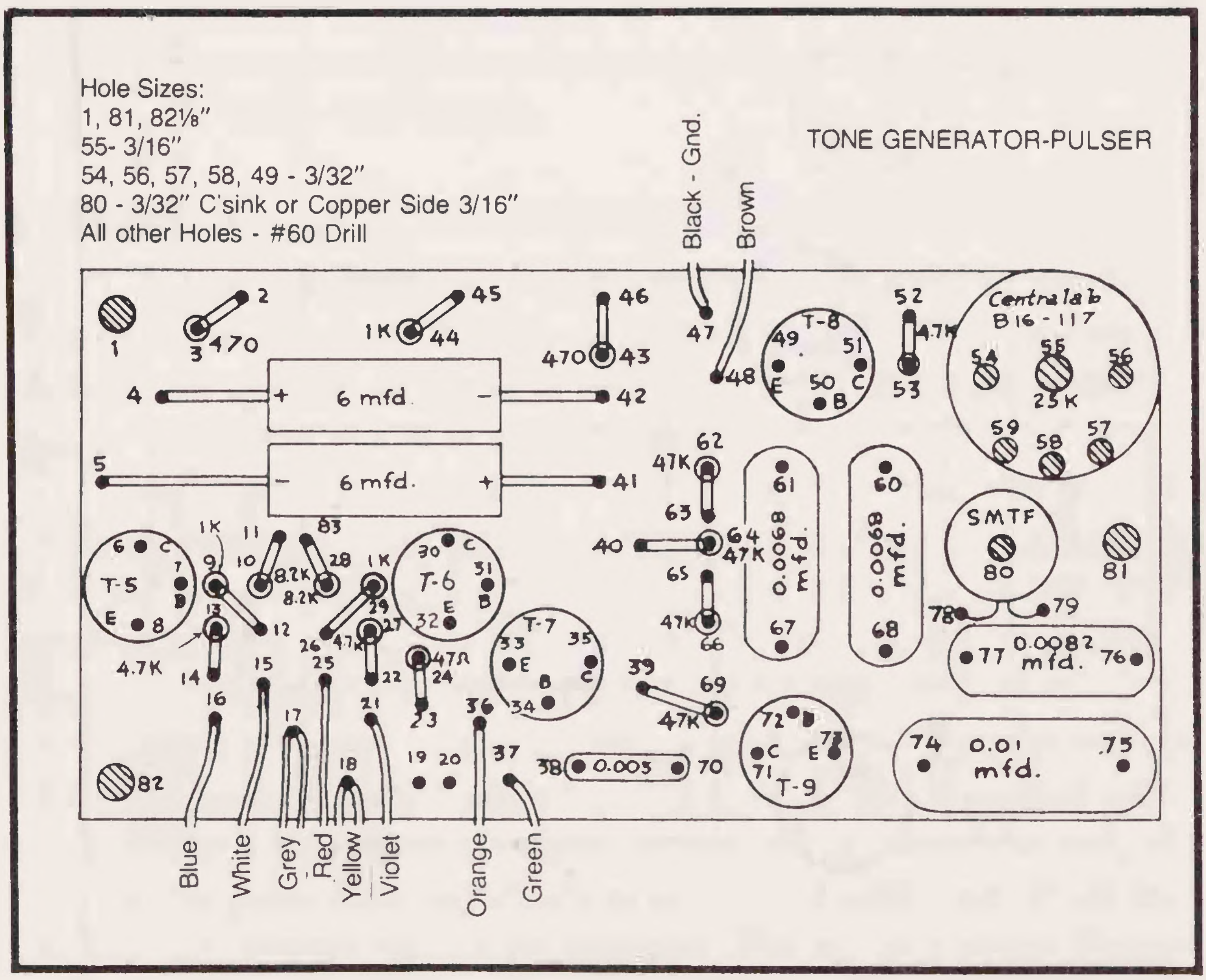


Fig. 6-7. The parts layout (top view).

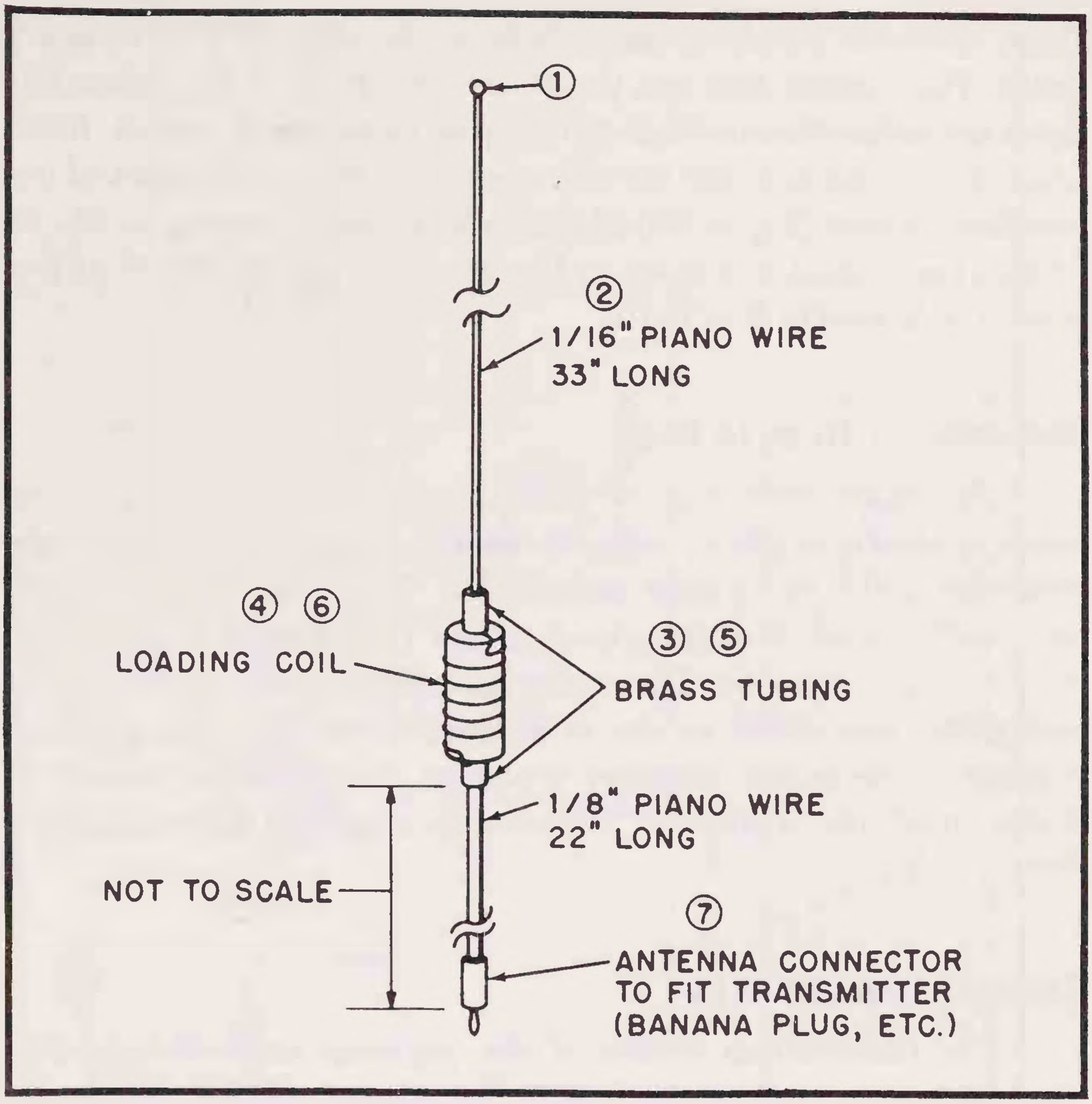


Fig. 6-8. The half-wave antenna for the transistor transmitter.

Circuit Notes

Again the transmitter uses a biased common-emitter oscillator that drives the final through an impedance-matching link coupling for maximum energy transfer. To operate on 54 MHz the crystal-oscillator emitter resistor R2 (Fig. 6-9) must be reduced to 47 ohms from 100, and the base resistor R1 to 10K from 12K if the crystal is not too active.

The final operates in Class C and is 100% downward-modulated by modulation-transistor Q3 at the tone frequency. The antenna connection and tuning are the same as the previous transmitter except that at 54 MHz the antenna must be changed to a half wave at that frequency, which is 9 feet 2 inches. A loading coil would reduce the required length.

The tone oscillator uses a unijunction transistor coupled to an npn transistor biased to act as a switch. This switch is in turn coupled to the transistor modulator. Resistor R9 in the built-in tone oscillator insures a sharp turnoff when the connection point (A) is removed from the 9-volt supply by the switching transistor or by an ordinary relay. The variable-bias npn transistor-switch Q7 in the pulser follows the unijunction oscillator to provide pulse-width control. If the capacitor is changed, the variable resistor in the RC network of the oscillator option (Fig. 6-10f) allows variable pulse rates up to 40–50 pulses per second, and down to 15–20 pulses per second. Note the values indicated in Fig. 6-10.

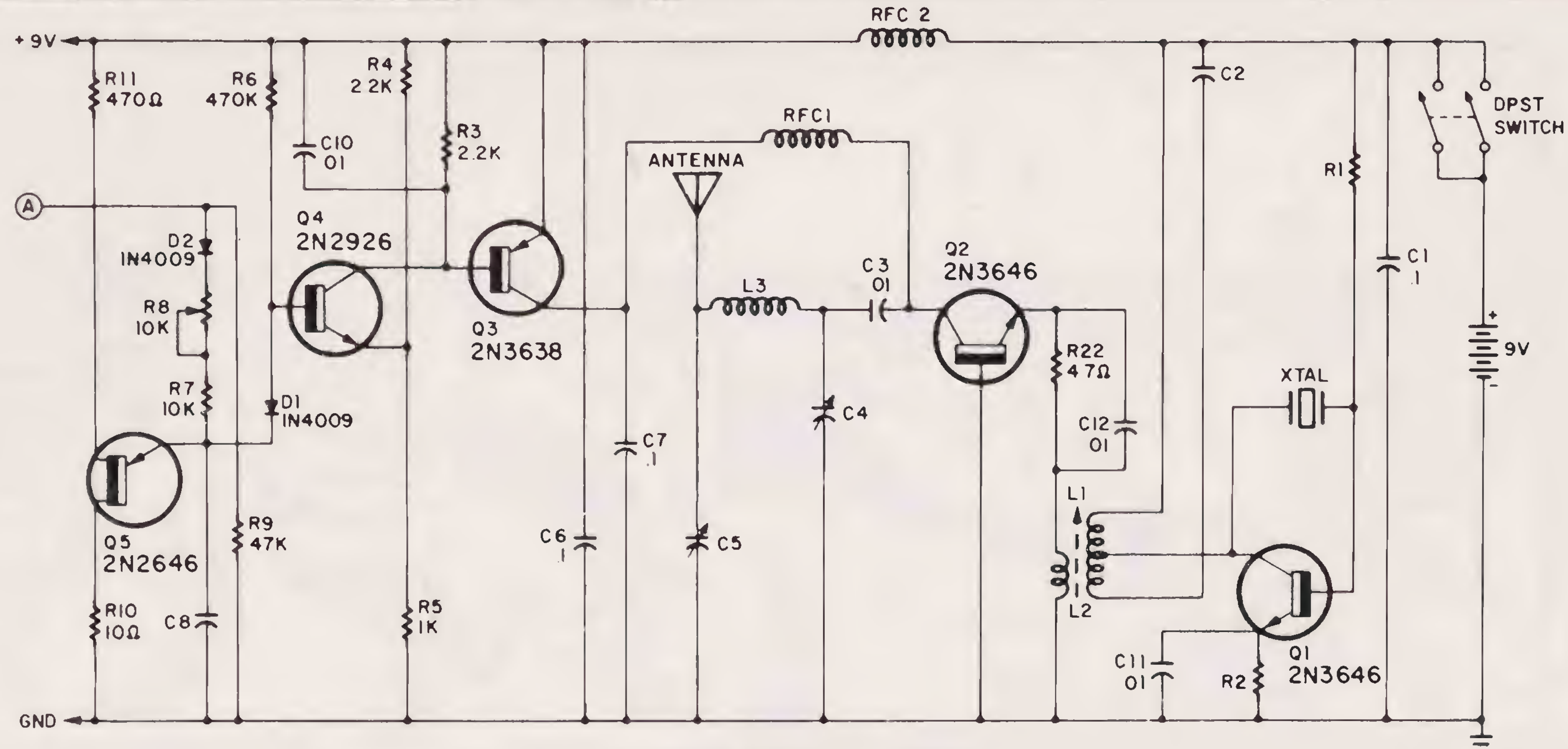
Operation on 70 to 74 Mhz

The transmitter can be redesigned to operate on the new radio-control channels by using the oscillator described earlier in the book for a 70- to 74-MHz output, Fig. 2-1c. You might obtain a complete crystal oscillator, such as the OT-61 from International Crystal Co., Oklahoma City, and then build a power amplifier for it along the same lines as the ones described here. The principal change to the power amplifier would be to reduce the number of turns on L3, the tuning coil. The antenna should be cut to about 3¼ feet.

TRANSMITTER CIRCUITS

The construction details of the previous transmitters have given you some concepts of how to use printed circuits and how to assemble the transistor transmitters which are used nowadays. The way to develop a printed circuit is to get the parts specified in a diagram, lay them out in the best wiring arrangement, then determine what printed-circuit lines need be used to connect the parts together. You may have to use several sheets of paper and black lines connecting the parts before you come up with what you consider to be the best arrangement. Then you transfer your diagram onto a printed-circuit board. These are available from Radio Shack or elsewhere; use their instructions and kit in making your printed-circuit board base. It isn't difficult, but it takes a little planning, imagination, and experimentation and perserverance to come up with a nice neat arrangement. Do it on paper first, then transfer the idea and circuit connections to the printed-circuit board base.

With this idea in mind, then, we give you some circuits which will form a basis for good radio-control transmitters. You can develop the physical layout from these circuits. Please realize that the layouts may have many different arrangements; for example, one transmitter printed circuit designed to fit over a control stick gimbel system is shown in Fig. 6-13.



VALUES NOT SPECIFIED IN DIAGRAM

C8 – 082μF (450-900 Hz)
047μF (800-1600 Hz)
027μF (1400-2600 Hz)
.015 μF (2500-4900 Hz)
MALLORY 1603 OR EQUIVALENT

L1 – 8 1/4 TURNS NO 26 WIRE TAPPED 4 1/8 TURNS FROM UPPER (+9V) END ON CTC 2173-3-3 FORM

L2 – 2 1/4 TURNS NO 26 WIRE OVER CENTER OF L1.

FOR 26-28 MHz:

CRYSTAL	-3rd OVERTONE 27 MHz
RFC1	-20μH (MILLER)
RFC2	-20μH (MILLER)
L3	-9 TURNS NO 22 1/2" I D
C2	-75pf SILVER MICA
C4	-ARCO 426 (37-250pF)
C5	-ARCO 424 (14-150pF)
R1	-22K
R2	-100 OHMS

CENTER-LOADED ANTENNA

FOR 50-54 MHz

CRYSTAL	-25-27 MC DOUBLER TYPE
RFC1	-10μH (CTC)
RFC2	-10μH (CTC)
L3	-4 TURNS NO 20 1/2" I D
C2	-15pf SILVER MICA
C4	-ARCO 423 (7-100pF)
C5	-ARCO 422 (4-40pF)
R1	-12K
R2	-100 OHMS

ANTENNA WITHOUT CENTER LOAD

Fig. 6-9. Modified transistor transmitter.

Now examine the two circuits of Fig. 6-14. In (a) you see a simple oscillator which might be tone modulated, and at (b) you see a simple transmitter which already has a simple tone modulator included. These are for short-range, low-power applications, and are

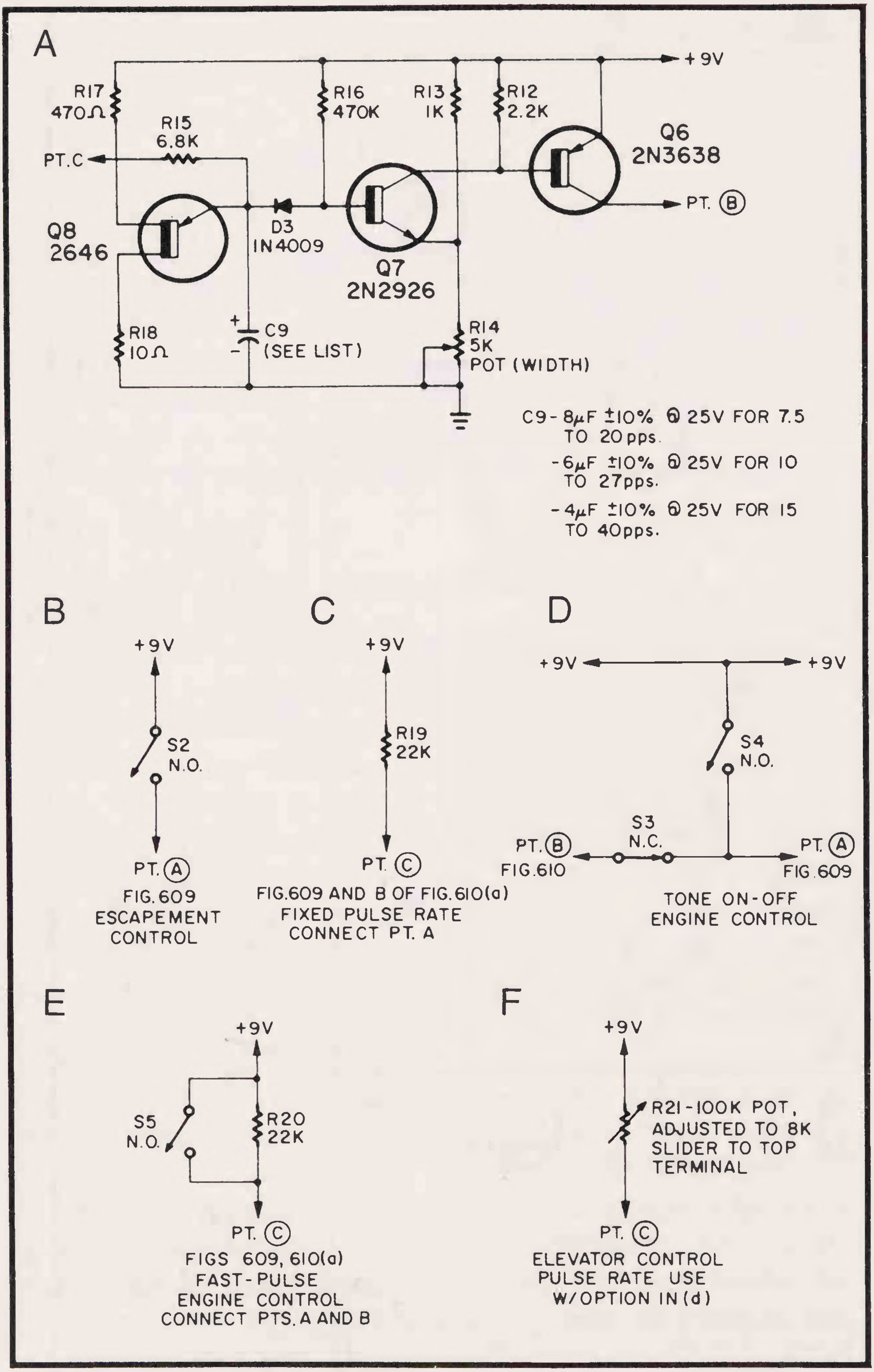


Fig. 6-10. The pulser section with various options.

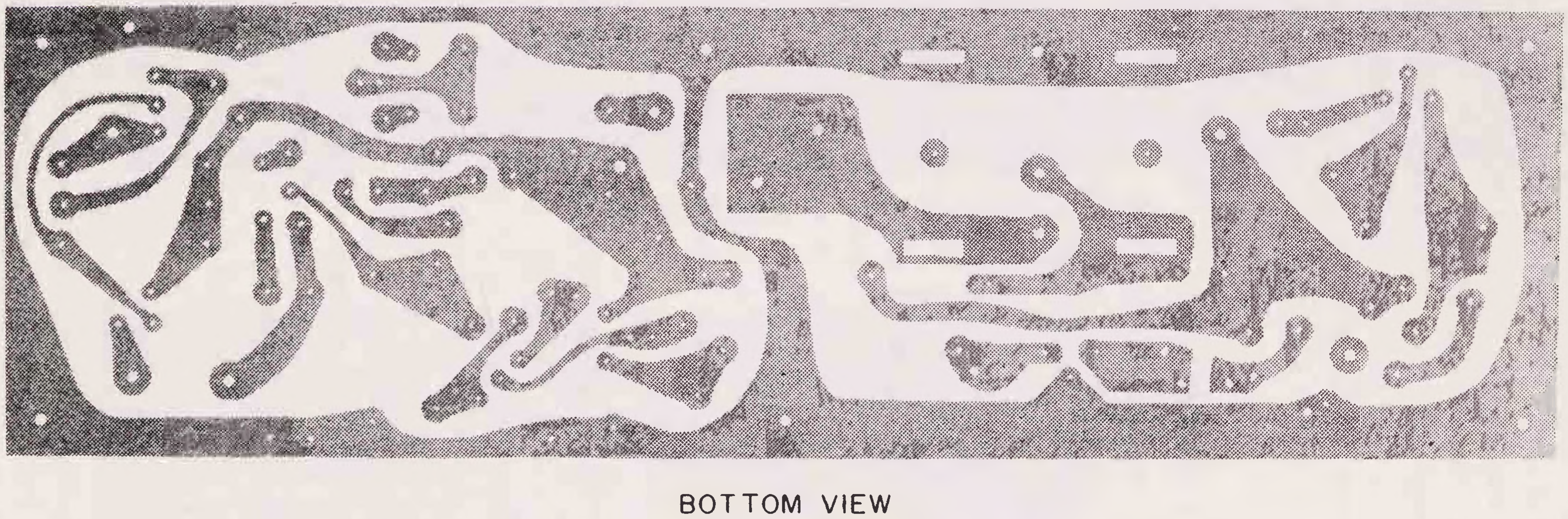


Fig. 6-11. Transmitter printed-circuit base layout.

designed to operate in the 27 MHz band of spot frequencies allocated by the FCC. If coil changes are made and appropriate crystals used, they could operate in the higher frequency ranges of 53 and 72 MHz.

Since these transmitters may have an output of less than 100 milliwatt, they can fall into that category specified in Part 15 of the FCC Rules and Regulations for the non-licensed type of transmitter. You might use a shorter antenna than the ¼-wave type to keep emissions from going beyond the permissible range. A loading coil in the antenna will reduce its physical length to 2 to 3 feet for home experimentation use.

TWO MULTISTAGE TRANSMITTERS

The two transmitter circuits shown in Figs. 6-15 and 6-16 (courtesy Kraft) have been used with digital modulation. Thus they are adaptable for high-speed pulsing if such off-on type signals are applied at the modulation points, or they could be amplitude modulated with tones by a slight adjustment of the circuit. Of course if you apply a multivibrator output to the specified modulation points and set this multivibrator to run at, say, 1,000 Hz or less or slightly more—in the audio range at least—then you will have good modulation by a tone which the receiver can interpret as such. Coils are wound on ¼-inch slug-tuned forms.

With a change in tuning these same circuits can apply to the 72-Mhz band. Note that there are some changes in the values of the coil tuning capacitors.

A TRANSMITTER WITH A WIDTH CONTROL TONE PULSER

Ace R/C makes this unit as a kit. They also supply a receiver and actuators (Adams actuators) to go with the unit. It has as an output a tone whose width can be varied to operate the tail wagging, nervous, type of proportional-control system. In this system the rudder moves all the time and its dwell time on either side is controlled by the pulse width of the tone which is transmitted. The airplane will then turn in the direction that the rudder spends most time in, slowly for a slight difference, and quickly for a full and nonmoving rudder, which occurs at the width extremes of full-on tone and no tone transmitted.

The circuit can be adapted by the experimenter to a kind of single-tone transmitted system by taking the output of the tone section at the bottom and making its tone output constant at equal on and off intervals. You might also adjust the multivibrator using the 2N5129s so that it gives a constant tone of about 1,000 Hz and key this. You can then use a receiver to detect the tone, and cause a relay

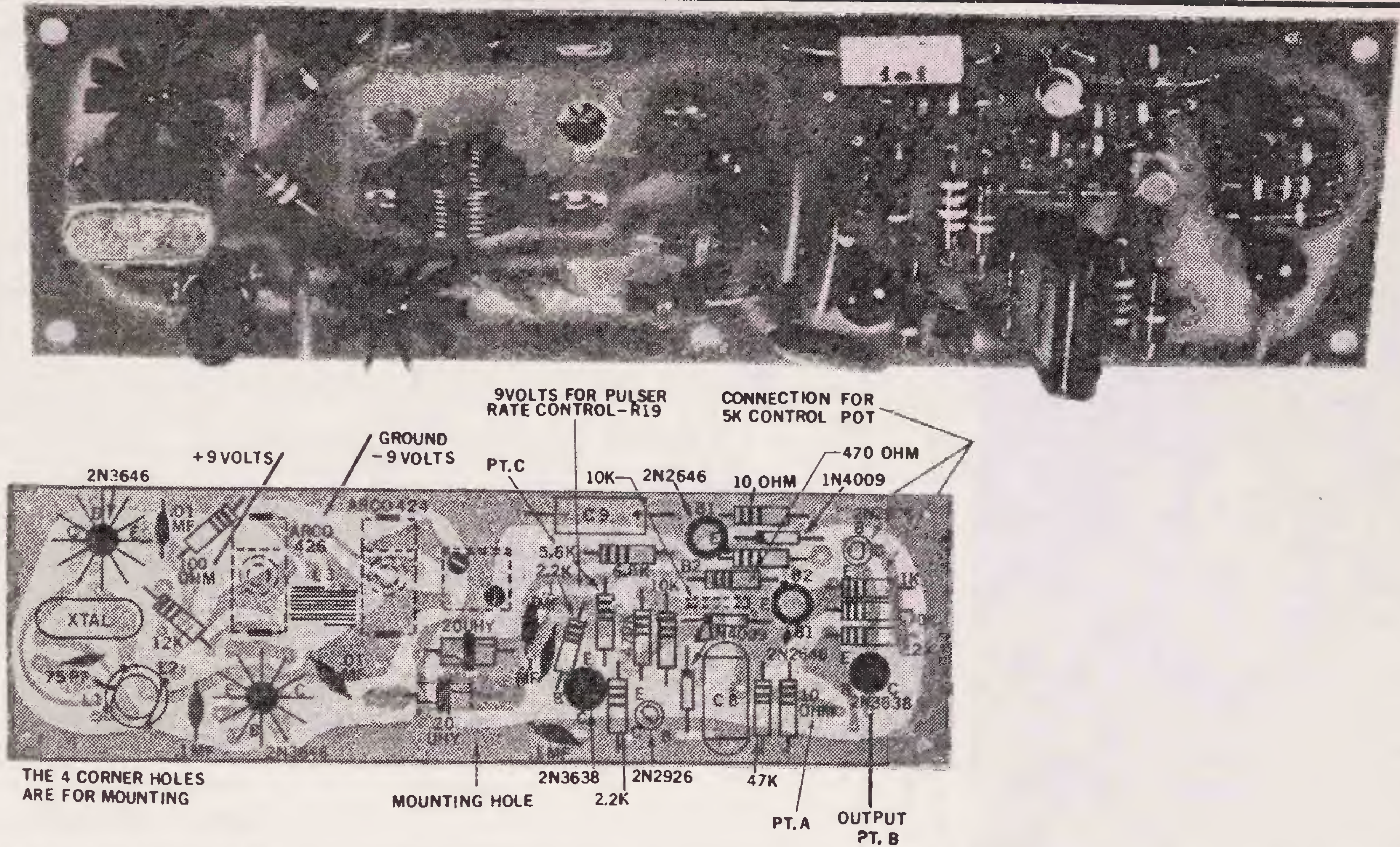


Fig. 6-12. The parts layout for the transmitter and pulser.

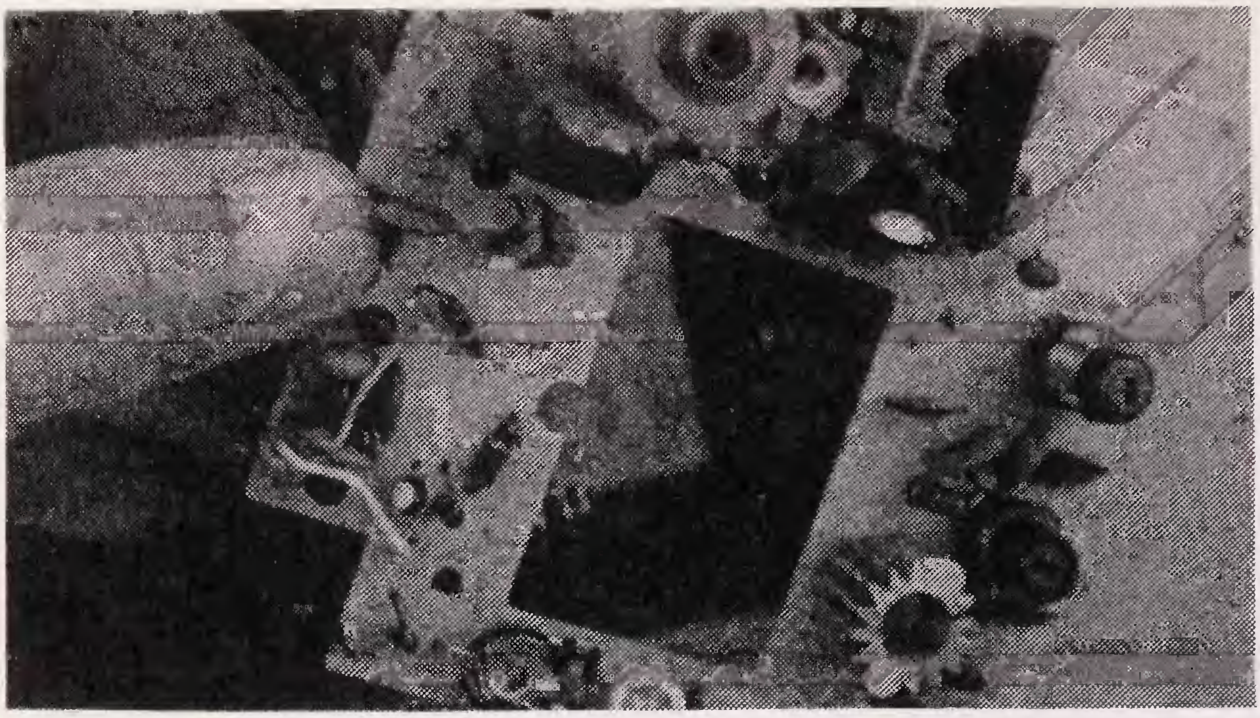


Fig. 6-13. A single channel transmitter, tone operated, on a printed circuit board base. (Courtesy Ace R/C)

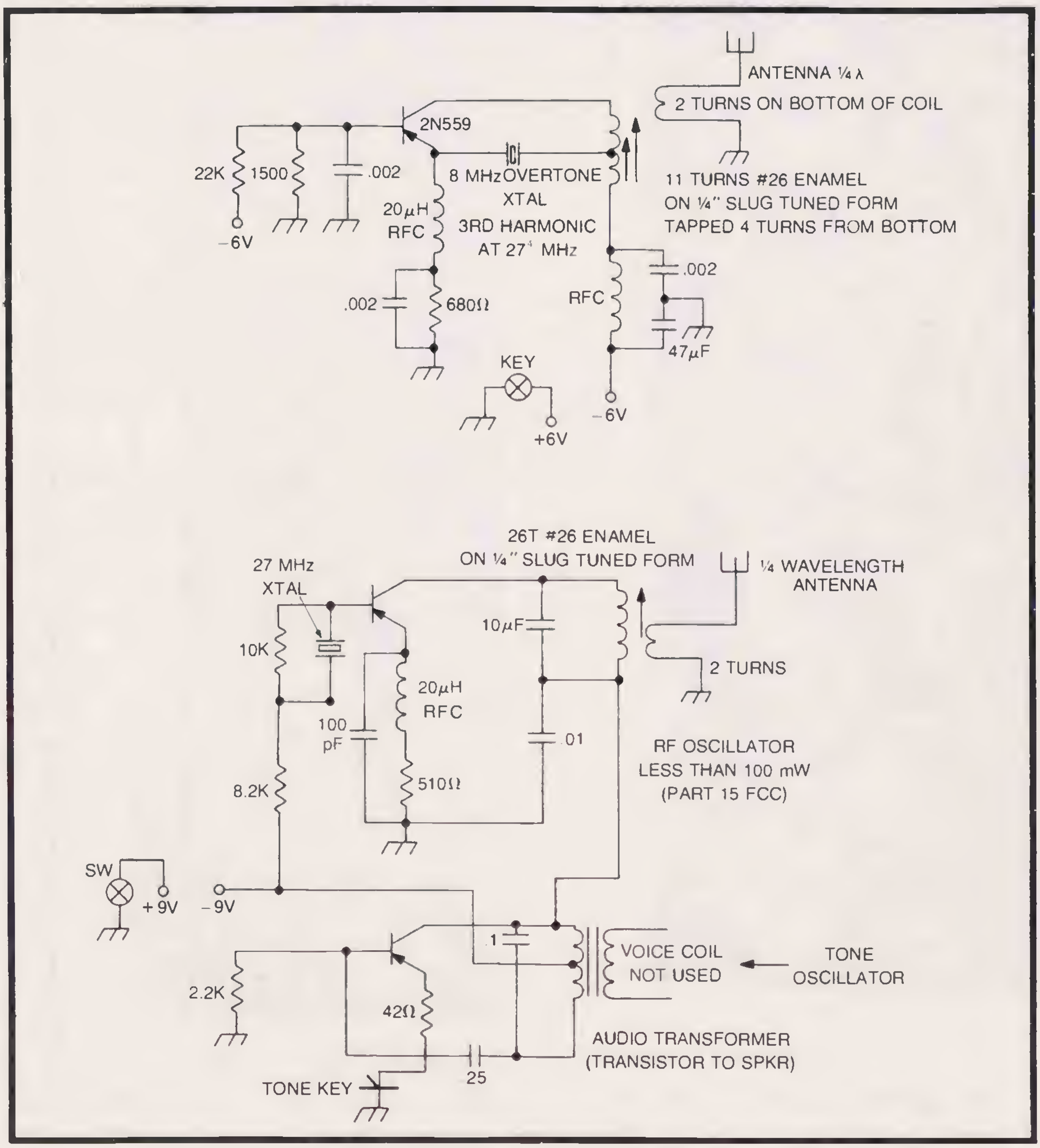


Fig. 6-14. Two single-stage radio-control transmitters.

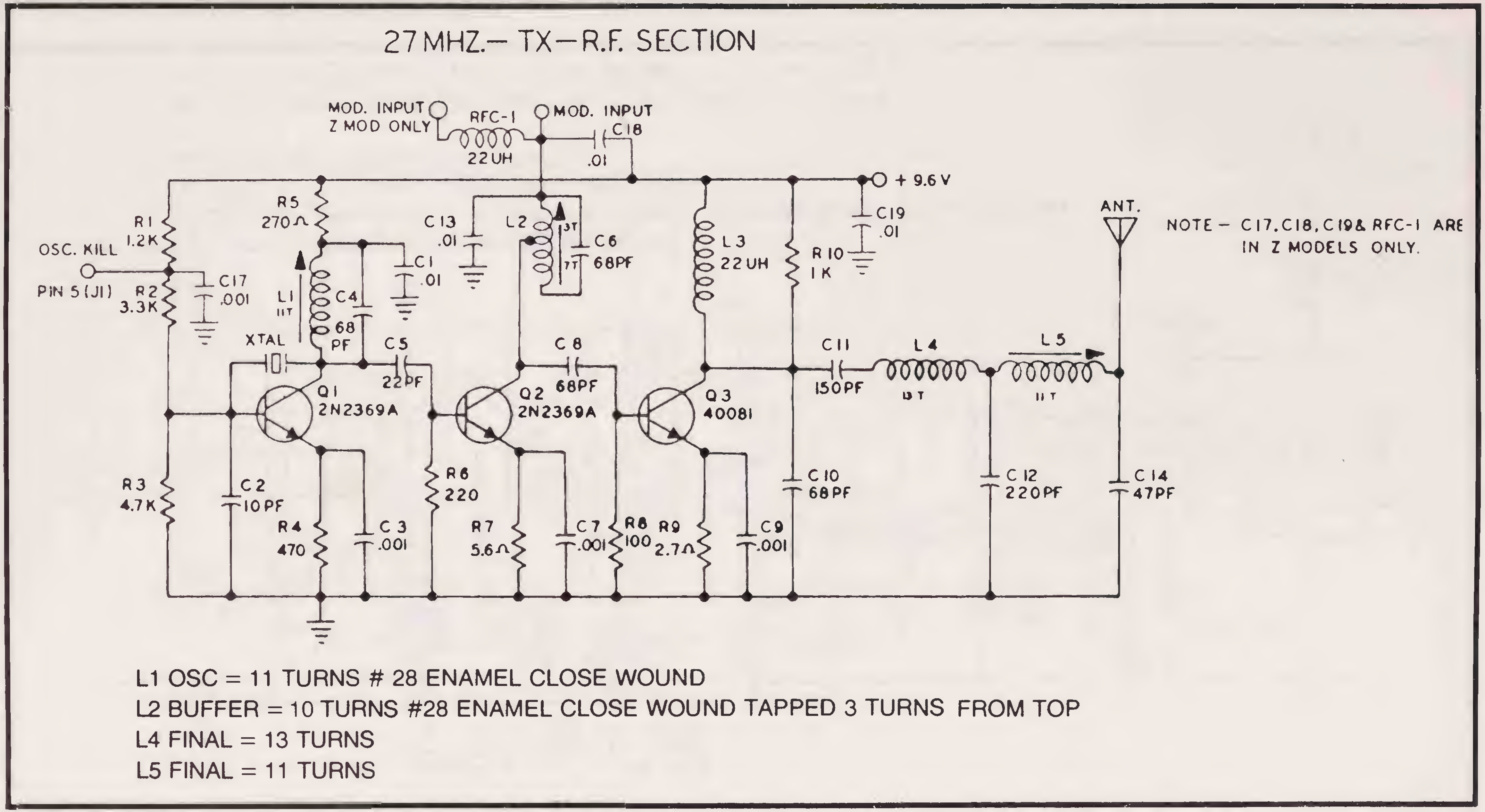
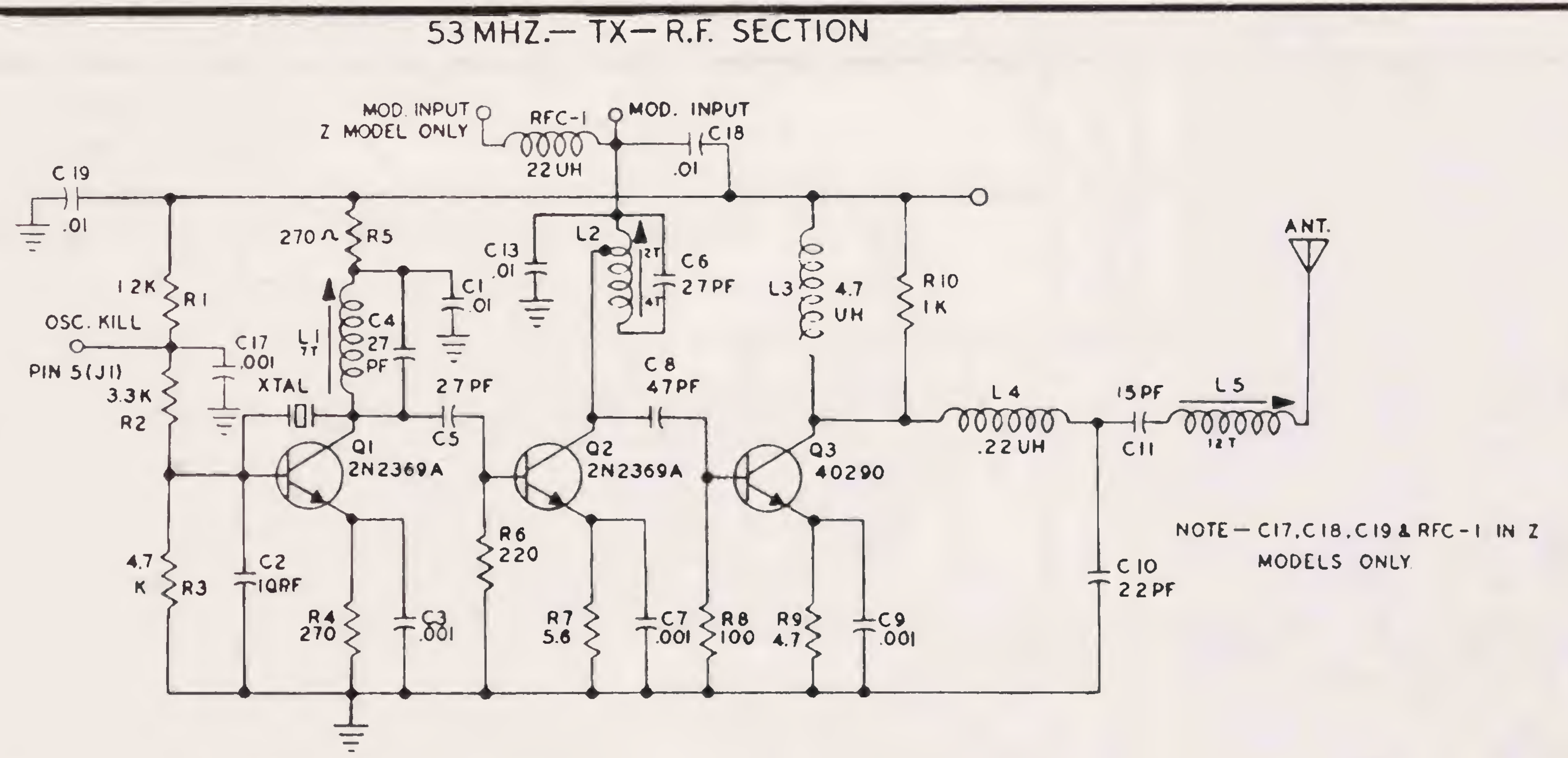


Fig. 6-15. A 27 MHz multistage transmitter circuit.



L1 = OSC = 7 TURNS CLOSE WOUND #26 ENAMEL
L2 = BUF = 6 TURNS CLOSE WOUND #26 ENAMEL TAPPED 2 TURNS FROM BOTTOM
L5 = FINAL = 12 TURNS CLOSE WOUND #26 ENAMEL
(ALL COILS ON ¼" SLUG TUNED FORM)

NOTE: USE SAME COILS FOR 72 MHz, BUT THEY TUNE DIFFERENTLY
C4 = 56 pF, C6 = 22 pF, C-10 = 15 pF and ADD 10 pF ACROSS L4

Fig. 6-16. A 53 MHz multistage transmitter circuit.

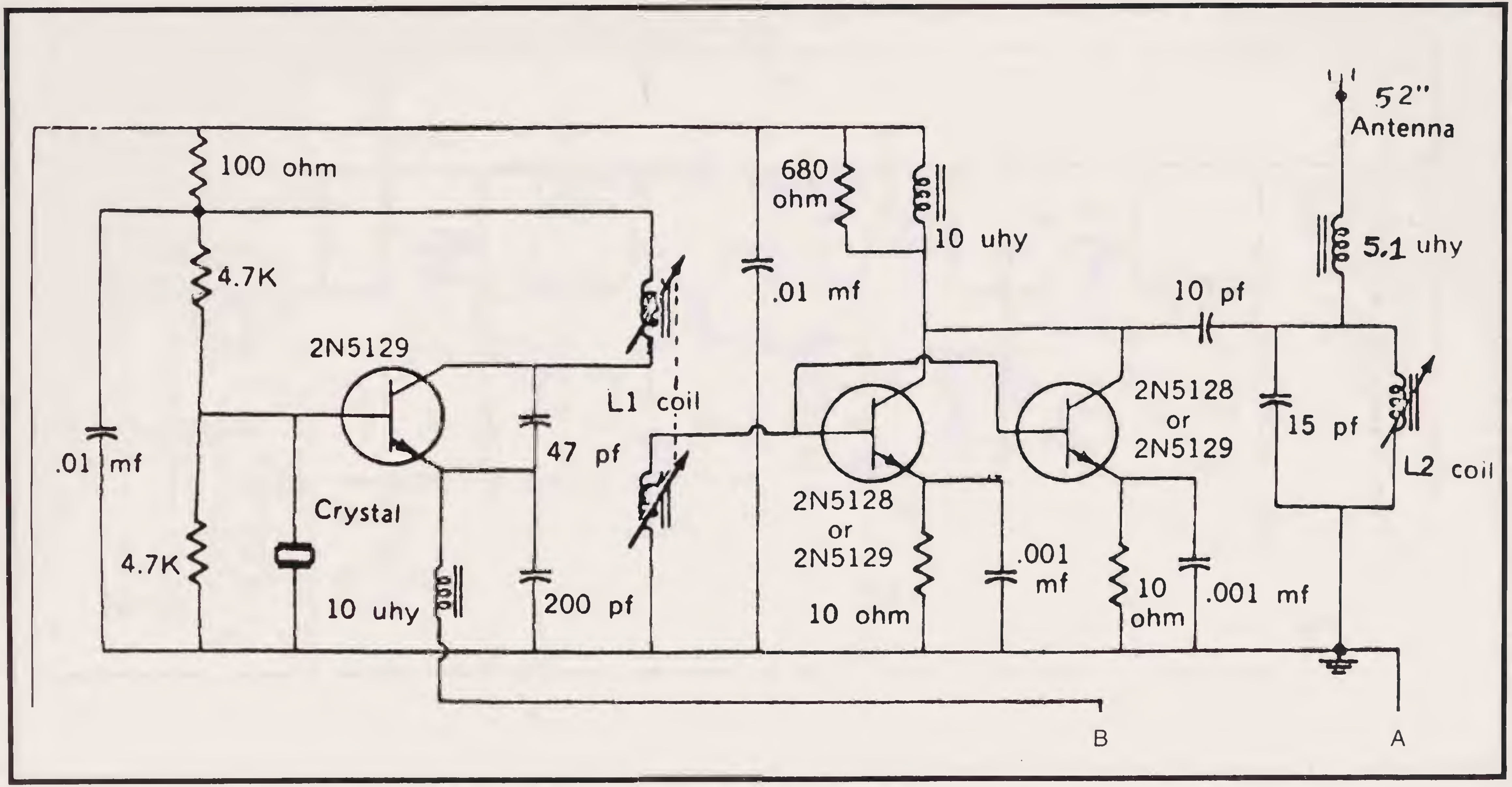
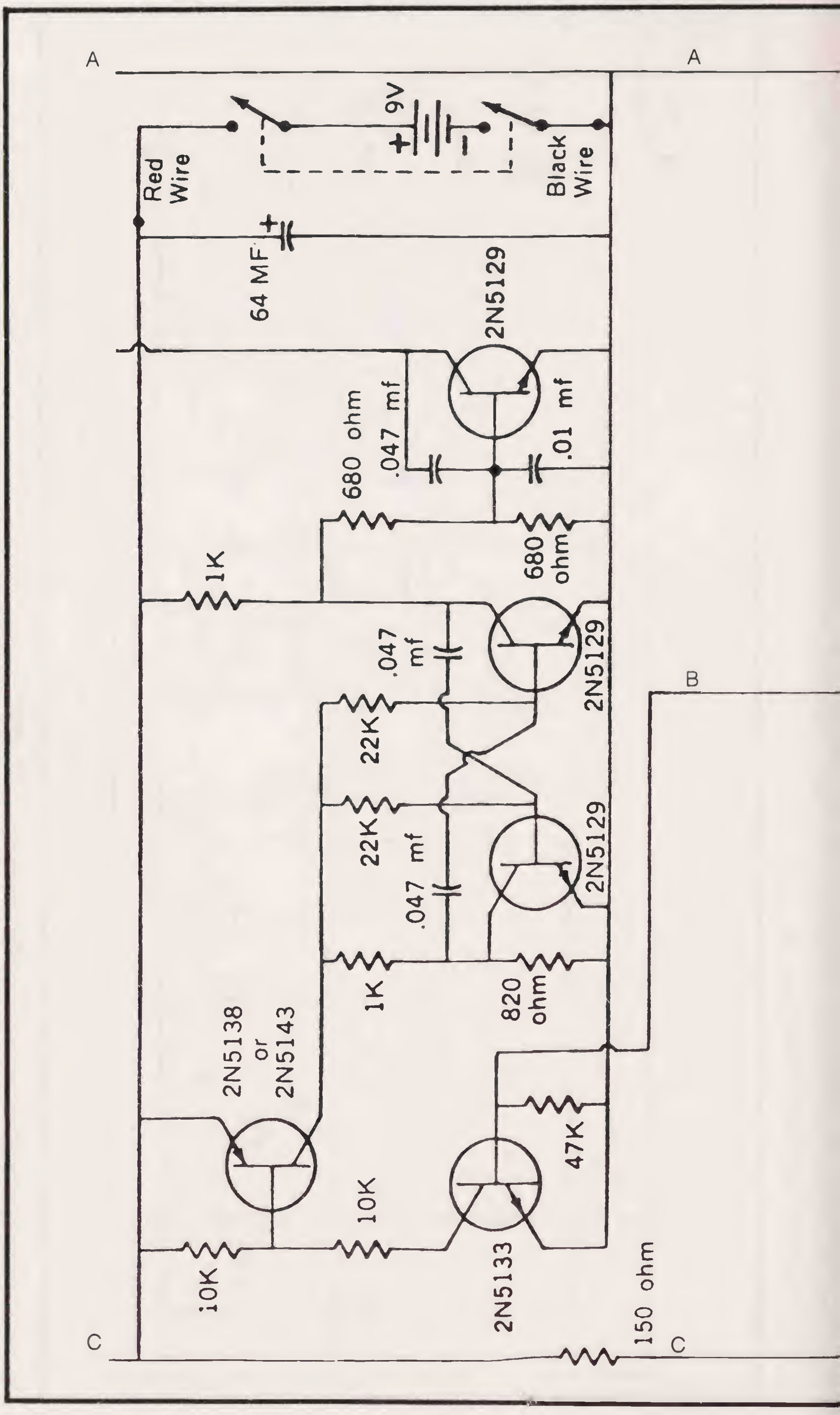


Fig. 6-17. Pulsing tone width circuit. (Continued on pages 164 and 165.)


A
A
9V
Red Wire
Black Wire
64 MF
2N5129
680 ohm
.047 mf
.01 mf
680 ohm
1K
.047 mf
2N5129
B
22K
22K
.047 mf
2N5129
1K
820 ohm
2N5138 or 2N5143
10K
47K
10K
2N5133
150 ohm
C
C

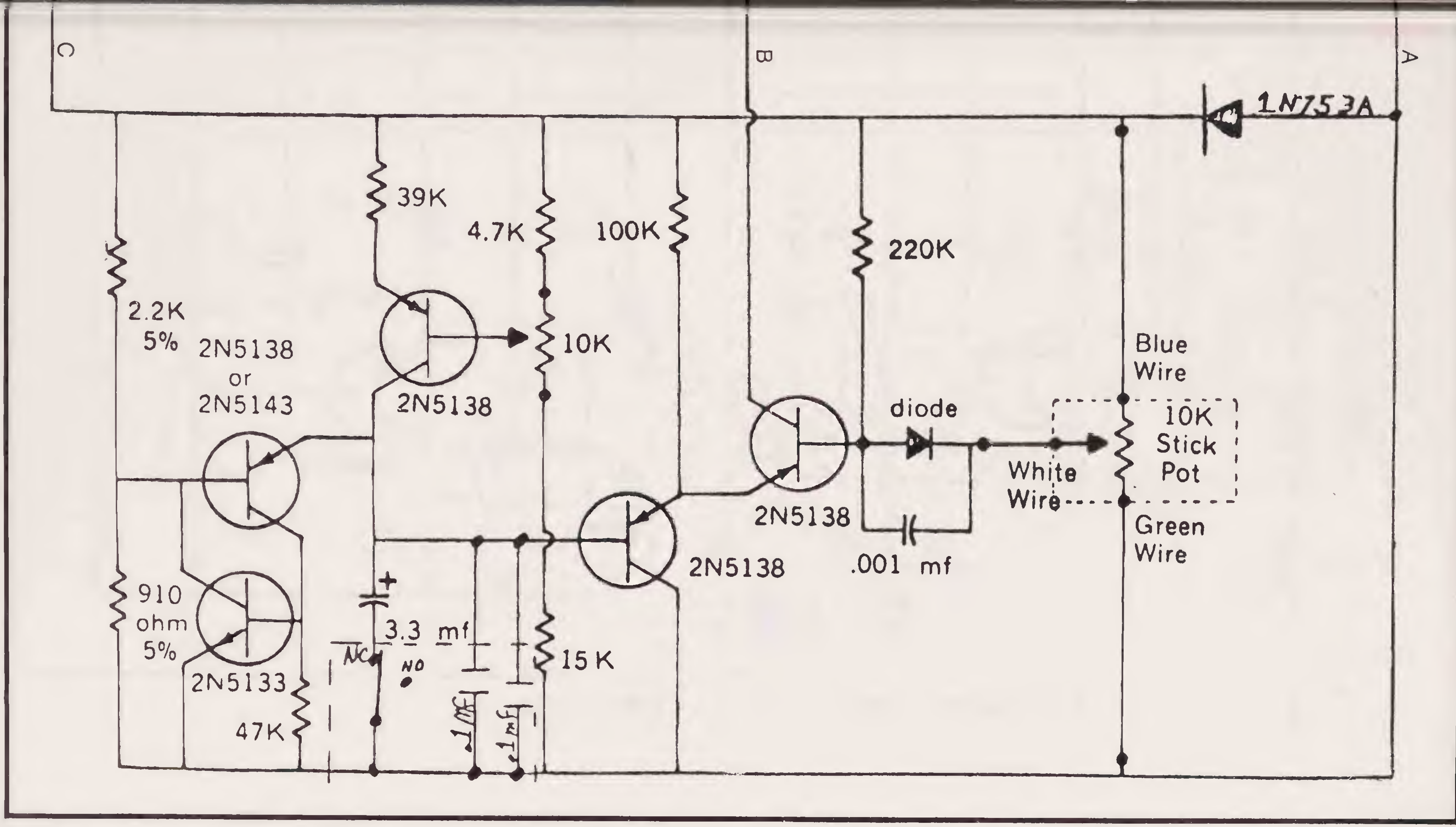
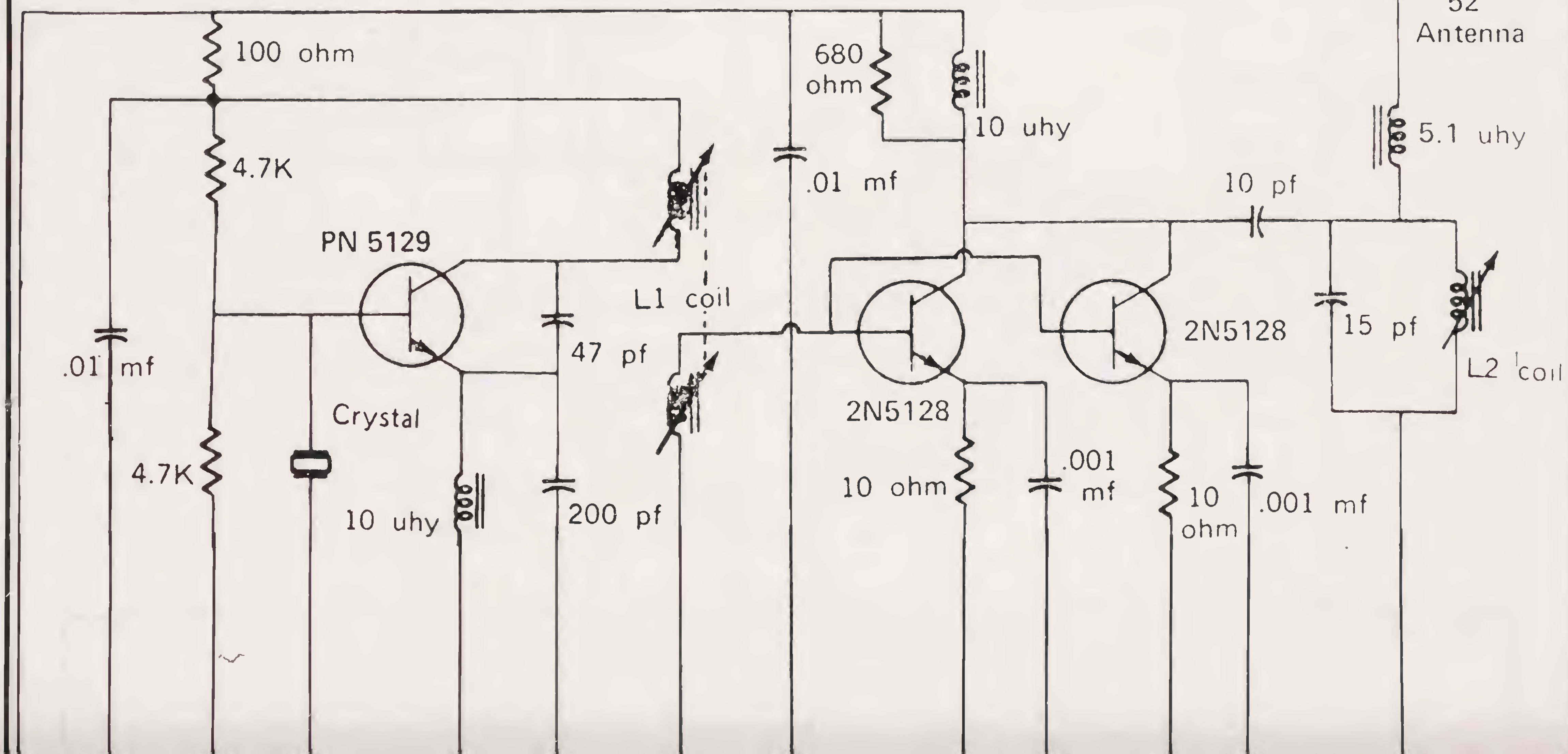


Fig. 6-17. Pulsing tone width circuit. (Continued from pages 163 and 164.)

WEE I SINGLE CHANNEL TONE TRANSMITTER



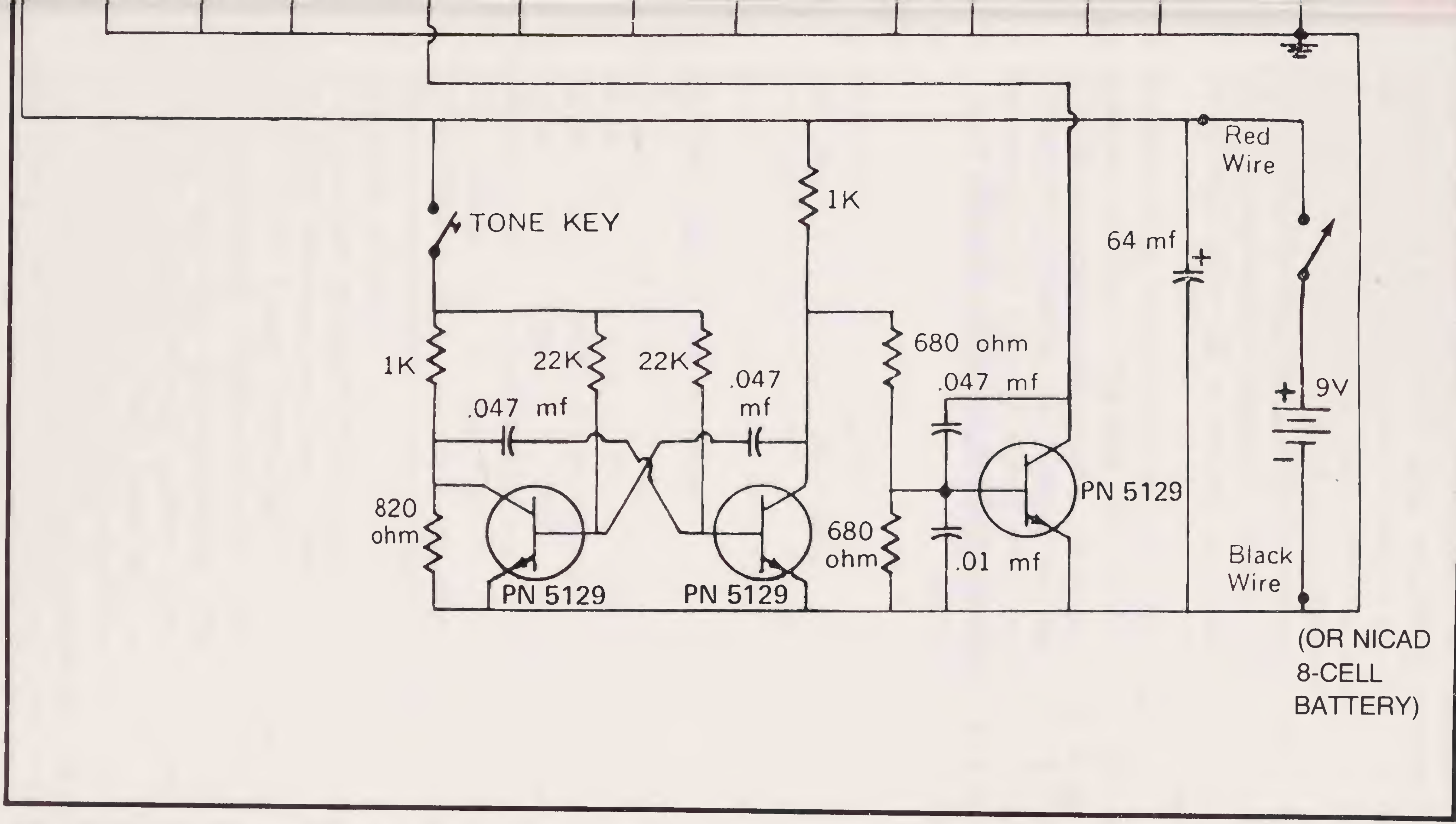


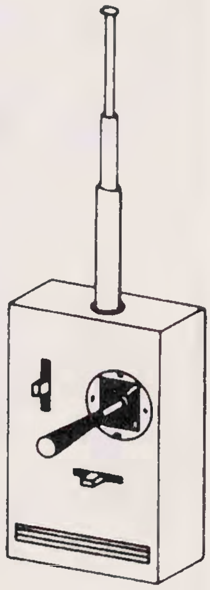
Fig. 6-18. Wee I single channel tone transmitter.

to be operated by a transistor, or operate an escapement by a transistor directly. We give you this circuit for your general information, and if you want to build a kit of it or the next circuit, write Ace R/C. The pulsing tone width circuit is shown in Fig. 6-17.

And the little circuit shown in Fig. 6-18, also a kit from Ace R/C does just that; it produces a single tone and has a key to operate the tone when you want to send it. It uses an 8.6 volt rechargeable ni-cad battery supply and can be obtained on any of the radio control frequencies.

Transmitters are relatively easy to construct, but be careful not to violate the FCC regulations. Have yours checked by a properly licensed engineer so you don't build one that has more than Part 15 of the Rules and Regulations permit. You might want to write the FCC and get a copy of the Parts 95 and 97, which are concerned with amateur and citizens-band (which radio control falls into) requirements and specifications.

7
Radio-Control Receivers



There are two basic types of radio-control receivers. They are the superregenerative-detector, audio-amplifier type and the conventional superheterodyne type, which uses i-f bandpass filters followed by a detector and amplifier, just as the broadcast receivers use.

THE SUPERREGENERATIVE RECEIVER

The superregenerator, which has a very high sensitivity and automatic gain control (AGC) action in that it will select and pass only the loudest or strongest signal it receives, also has a primary disadvantage. It does radiate a signal, which is weak, but which can be received on the very sensitive superheterodynes and thus cause them to malfunction. You cannot use a superhet and a superregenerator on the same or even close spot frequencies at the same time at the same flying field or race or yacht basin without having interference problems.

In days past the regenerator was preferred over the superhet because of size and economy of battery drain. It was very small, as shown in Fig. 7-1. I always liked this kind of receiver. It had a broad tuning characteristic, attractive because if your transmitter got slightly off tune it didn't affect the operation. Also the AGC action made it nice because it rejected spurious signals and interference pretty well. It is easy to build, being simply a detector, audio amplifiers, and some rectifier to change the audio to DC to operate a relay stage, such as the Darlington pair of transistors followed by a relay. And so it has been used, and still is, in some areas for some

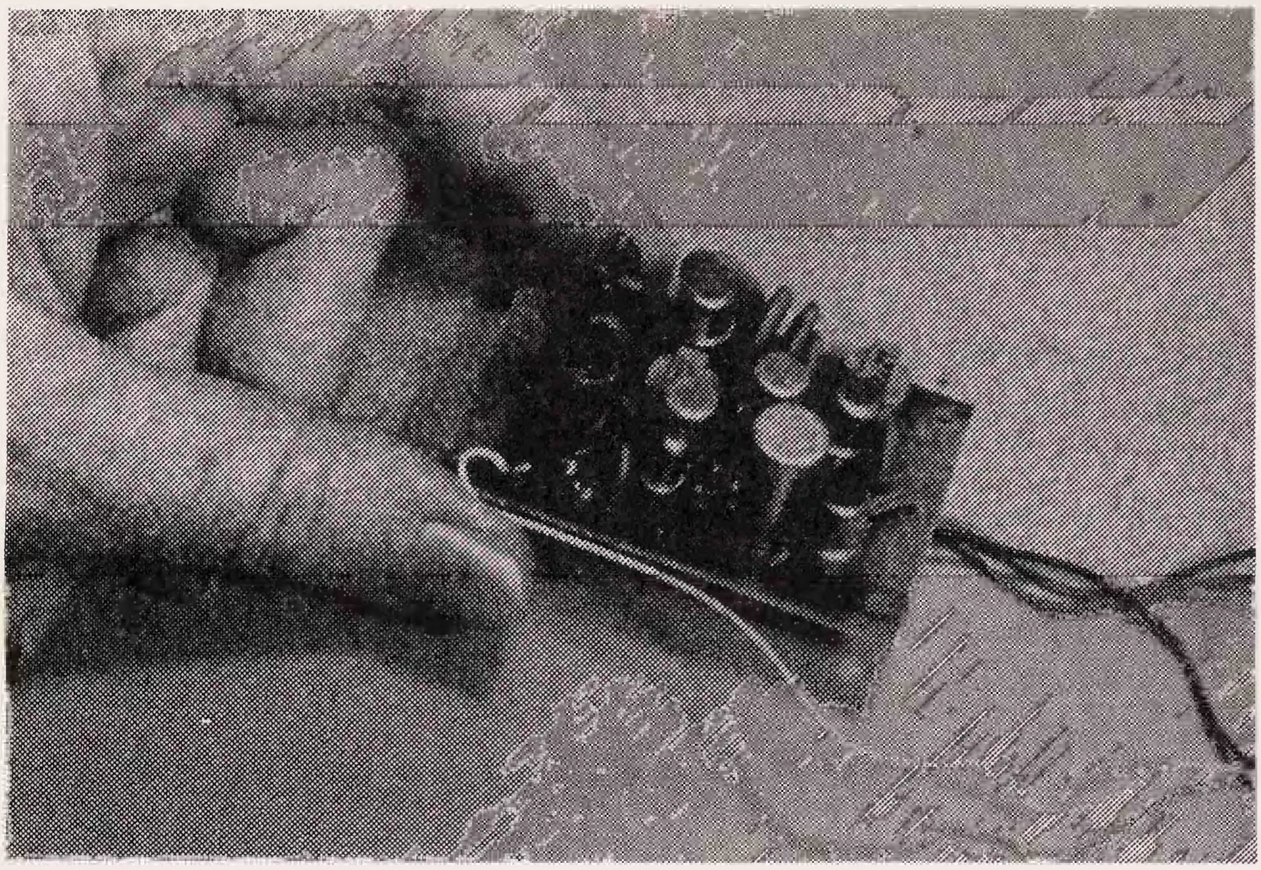


Fig. 7-1. A superregeneration receiver for radio control.

models. It has an excellent range of operation when properly adjusted and tuned.

The best evidence of proper operation of such a receiver is obtained by using earphones. The intermittent action of the detector will produce a hiss, and this should be quiet and smooth, not loud and erratic in sound. Of course this is heard through an audio amplifier of a couple of stages of transistors or an integrated circuit. When the carrier of a transmitted signal is received, the hiss vanishes, and you hear no sound at all. This is a very pronounced silence, easy to

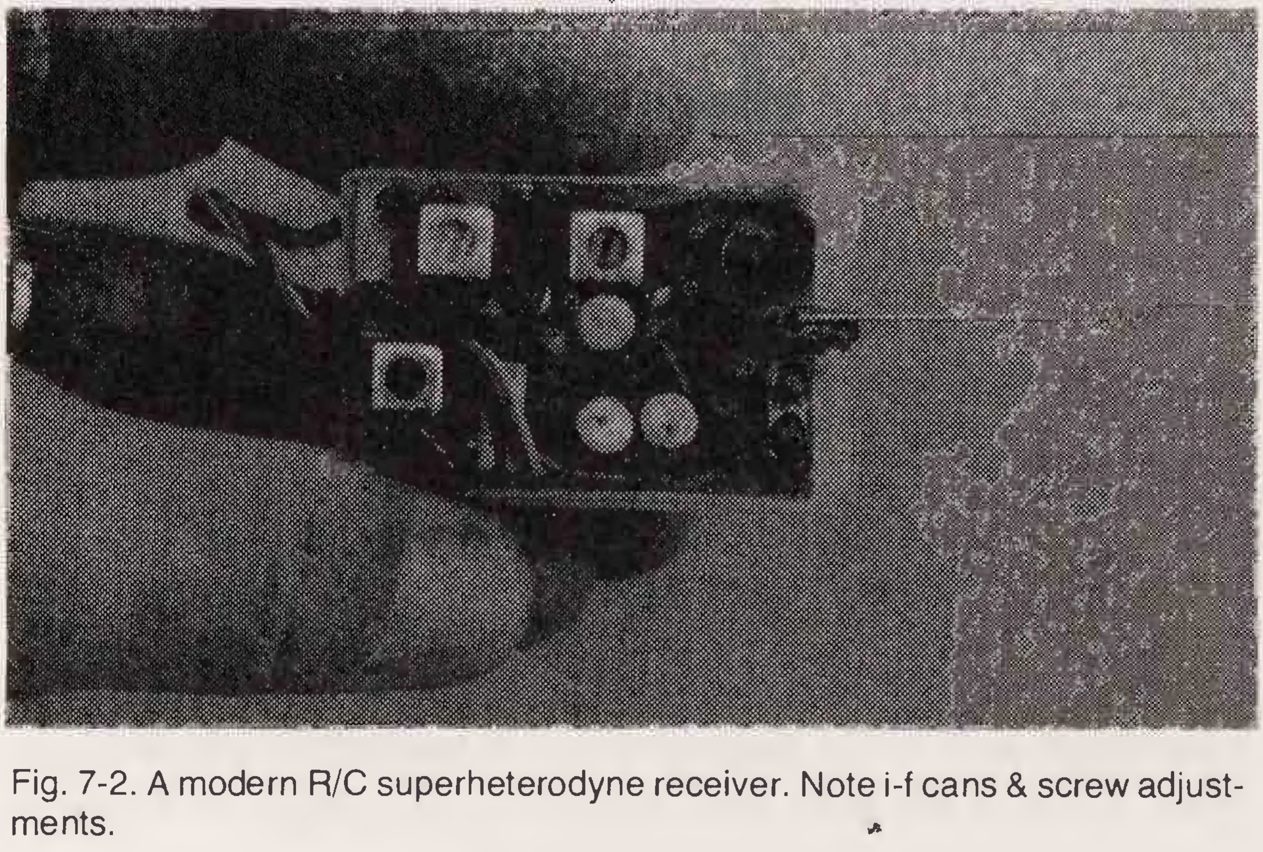


Fig. 7-2. A modern R/C superheterodyne receiver. Note i-f cans & screw adjustments.

identify. Finally, when the tone is transmitted it will come through loud and clear. It is interesting, and important, that this detector, with its AGC action, will keep the receiver from swamping at close ranges—although you can overload at very close range—and will let the sensitivity build up at distance to keep the signal received strong and active as presented to the relay stage. Some superregenerators have been used to detect pulses of rf but they have to be carefully constructed, and that is more of a problem. Tone pulses are no problem, however. The superregenerator is used currently in many toys.

THE SUPERHETERODYNE

The superheterodyne, which was once considered a problem because of size, is no longer too large or bulky or requires too much battery current. That is very evident in Fig. 7-2.

The superhet is the best kind of receiver to use, and many types are available nowadays. These can receive both tone or rf carrier pulse signals, and they are found as a part of every good digital-proportional radio-control system.

It is interesting that some of these receivers have special i-f filters which permit the removal of tuning adjustments. The Heathkit model, for example, uses a ceramic filter for this purpose which is only about ¼-inch square. This gives excellent selectivity, small size, and makes a nice small receiver possible on a small printed-circuit board.

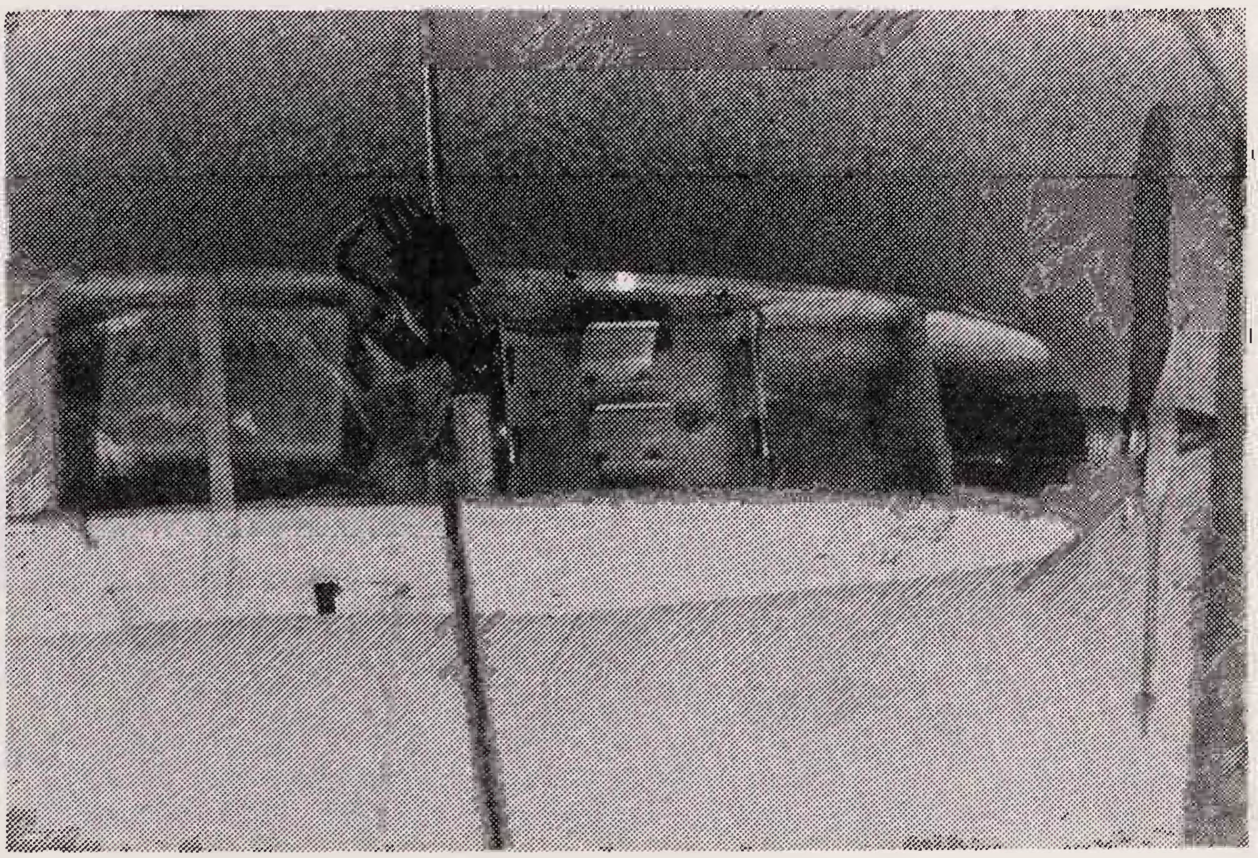


Fig. 7-3. The installation concept for a superhet receiver.

But the big advantage of the superheterodyne is its selectivity. Since it can use a crystal oscillator, tuned to a different frequency from the ones being received, and since crystals are notorious about maintaining their frequency-generation stability, you will receive only one signal—that one to which the receiver is tuned by its crystal and tuned circuits, and no other. Since the selectivity is so great, if your transmitter gets off just a small amount (which it doesn't because it also is crystal controlled) you would not receive its signal at all. This means that several such sets of equipment can operate at the same time on relative close spot frequencies.

Not only is the selectivity of primary importance for racing and rejection of interference etc., but the fact that you have i-f amplification as well as audio or pulse amplification, and ahead of the first detector you have rf amplifiers, means that this kind of receiver can operate at ranges never considered possible with a small-output transmitter and a superregenerative receiver. Yes, the modern radio-control receiver, the superheterodyne, is fantastic in operation, size, capability, selectivity battery drain, and ruggedness. The installation of a small superhet receiver package in its plastic wrapping to prevent possible oil seepage from the engine, but less its foam rubber wrapping which is always used with this kind of installation, is shown in Fig. 7-3.

Of course in this photograph the airplane was not finished but at this point in the construction of the airplane it was necessary to consider the radio-control equipment installation to check balance and space and to put in such fixed parts of the installation as were

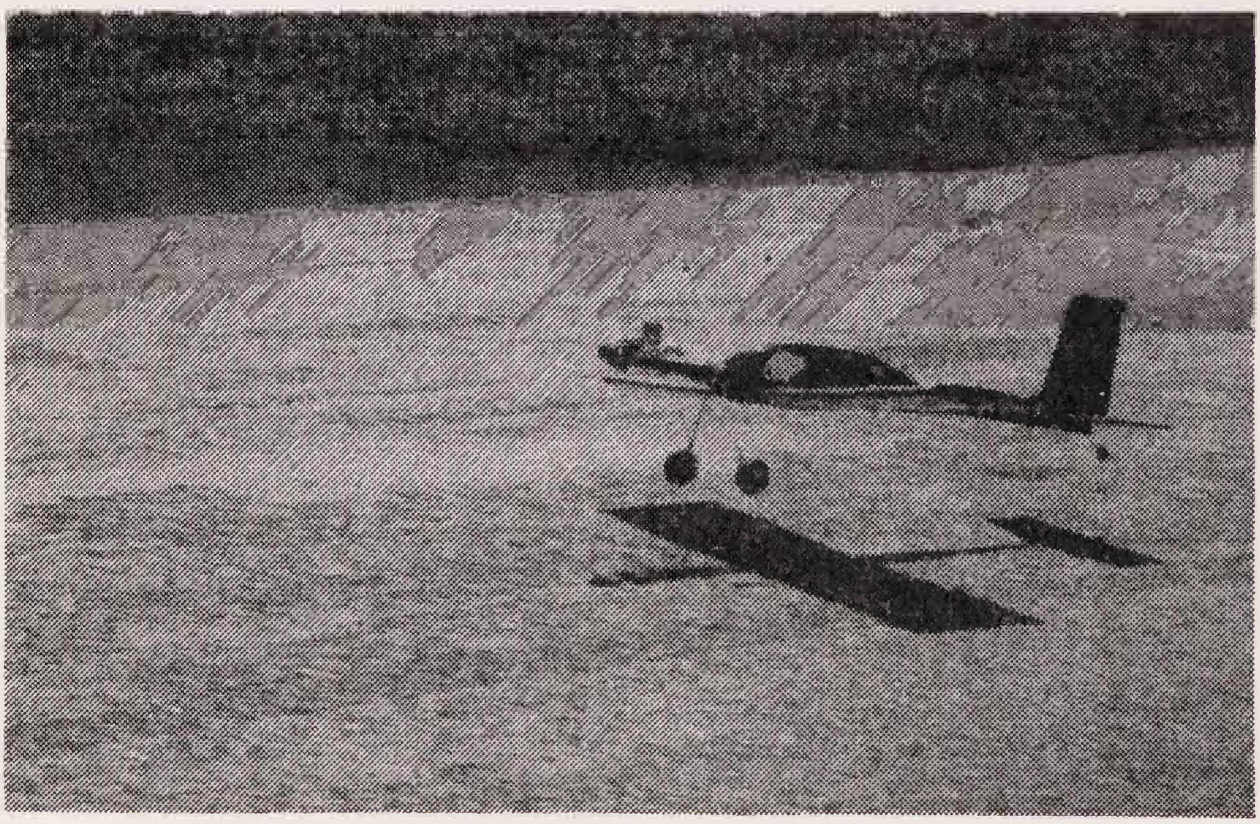


Fig. 7-4. The Bumble Bee landing perfectly.

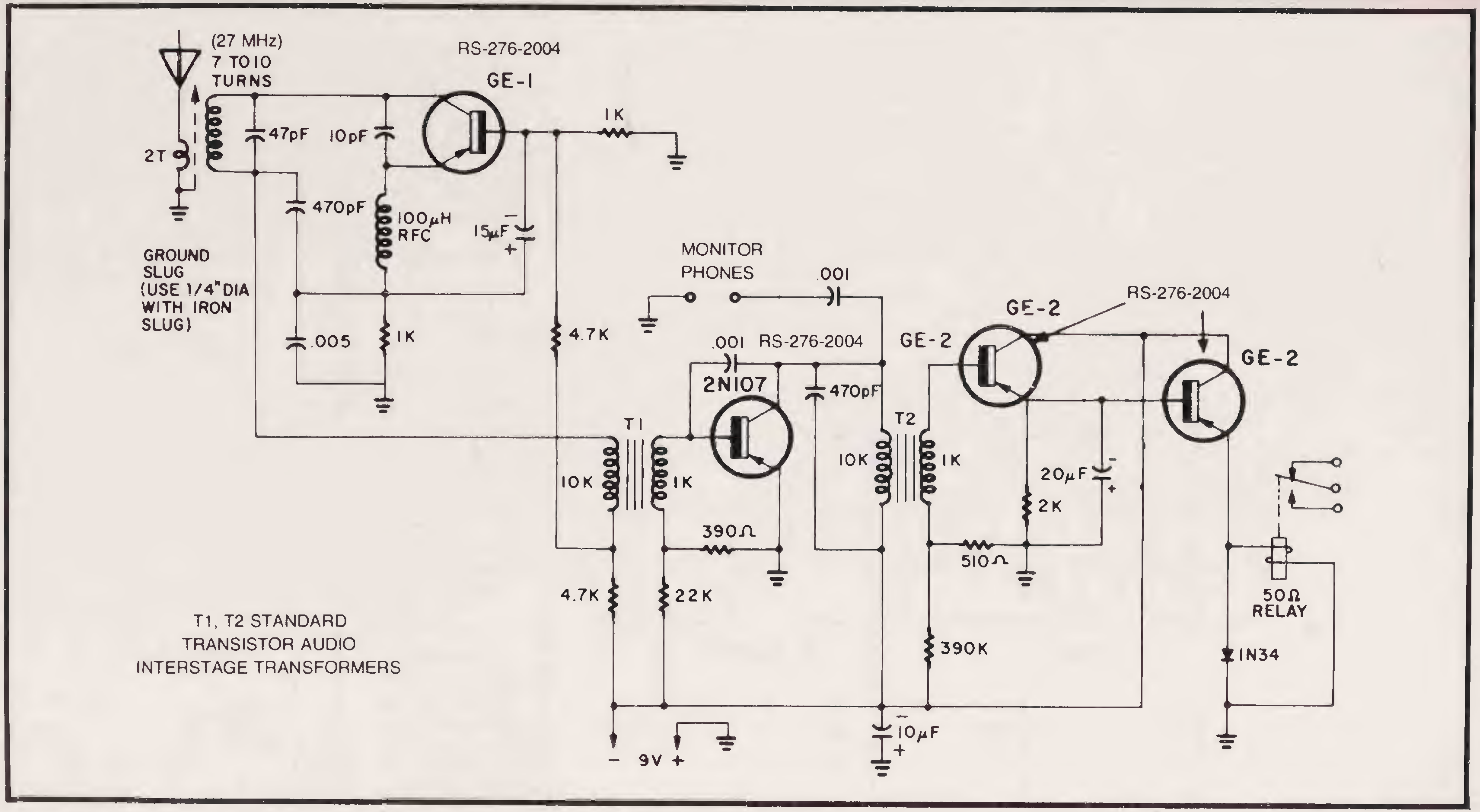
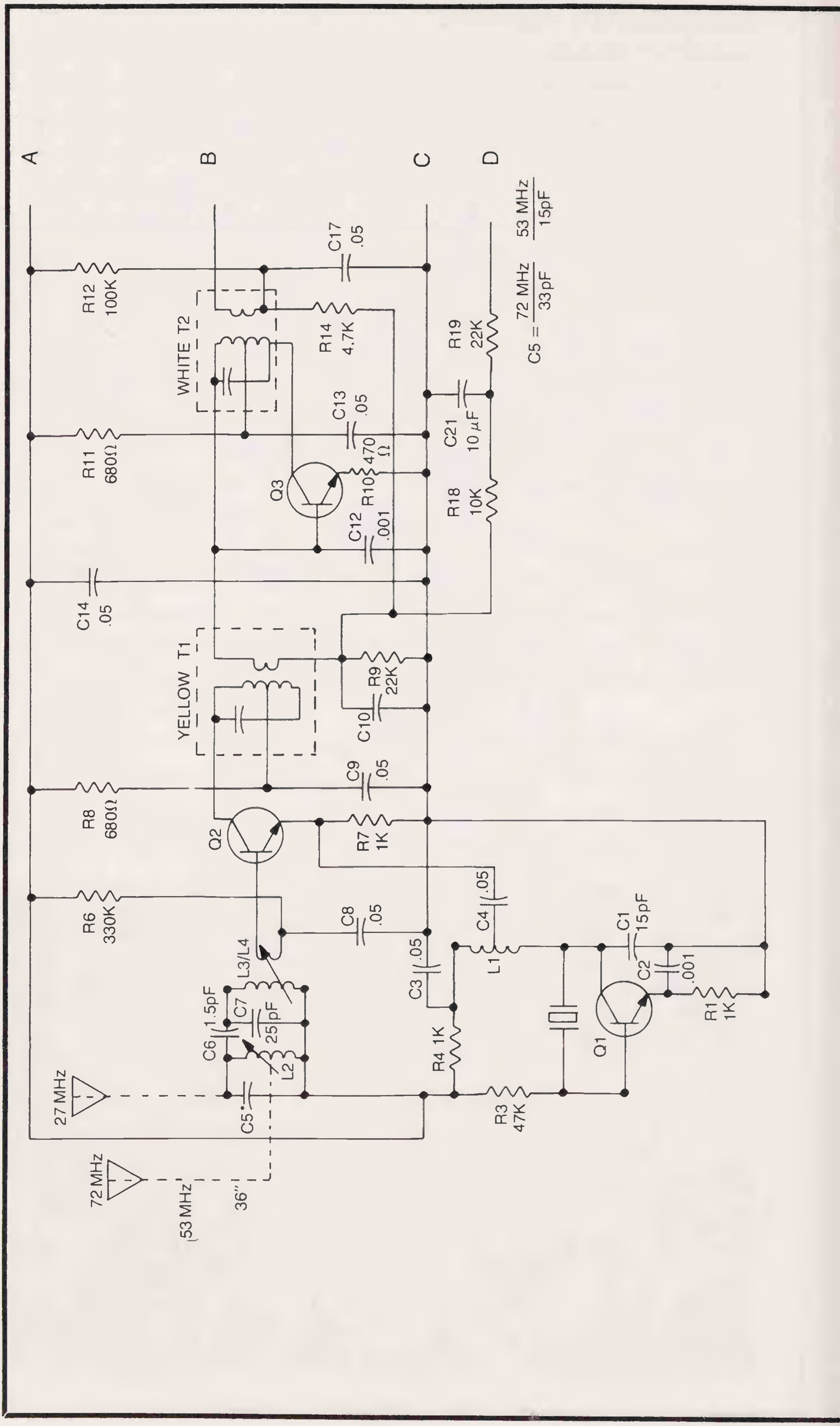
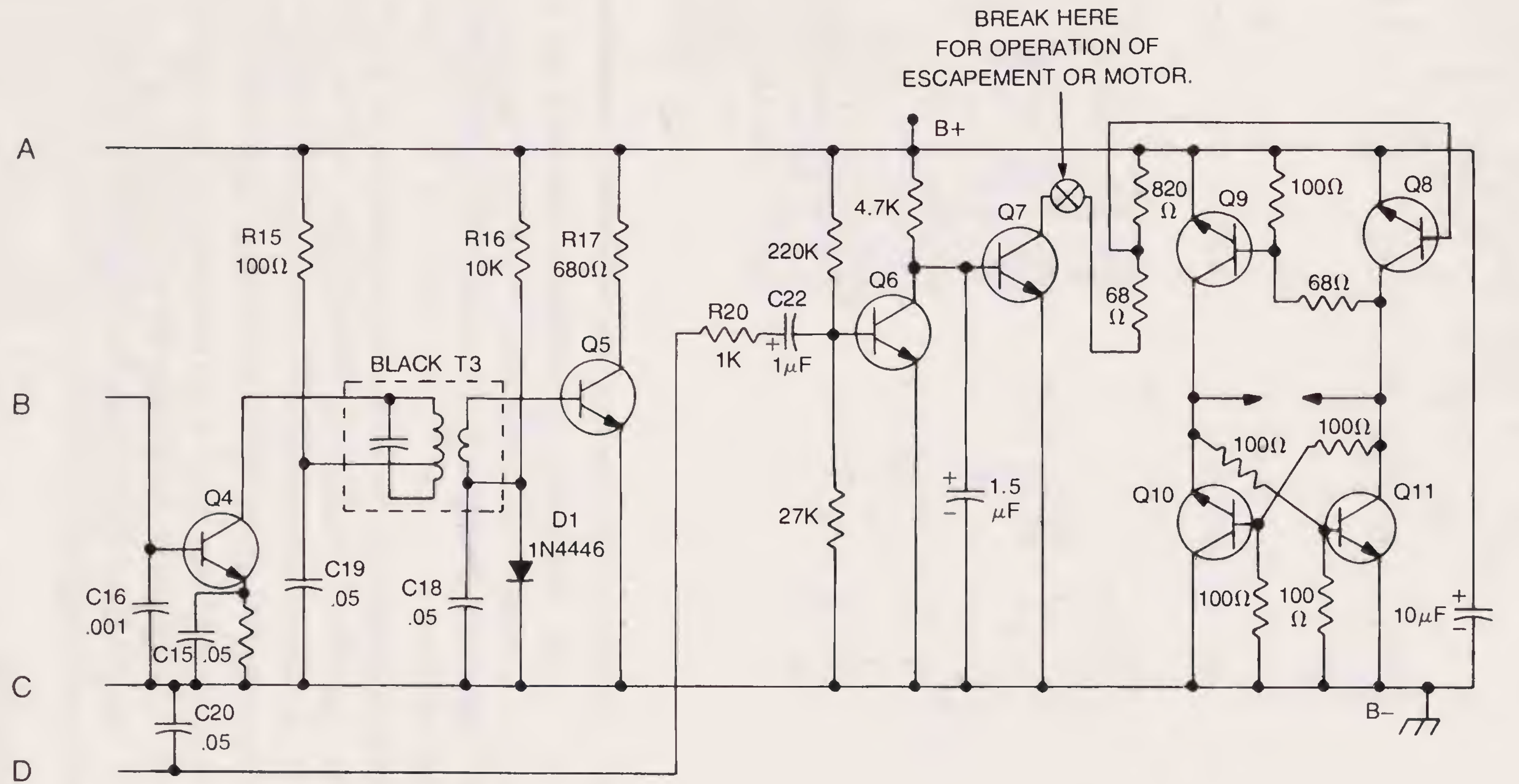


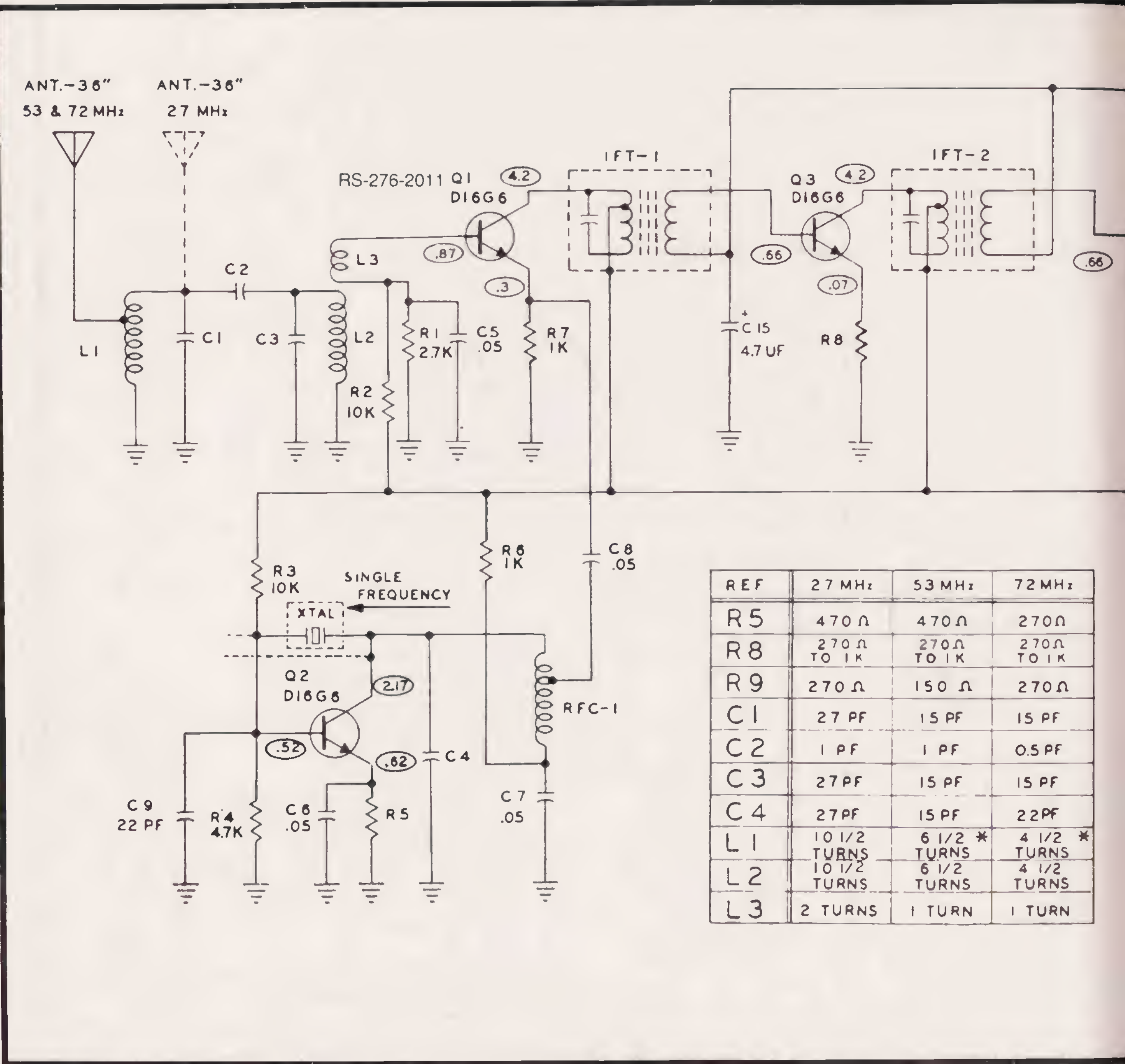
Fig. 7-5. Schematic of transistor superregenerative detector receiver.


A
B
C
D
R12 100K
C17 .05
WHITE T2
R14 4.7K
R19 22K
C5 = 72 MHz / 33pF   53 MHz / 15pF
C13 .05
R11 680Ω
Q3
R10 470 Ω
C21 10 µF
R18 10K
C12 .001
C14 .05
YELLOW T1
R9 22K
C10
C9 .05
R8 680Ω
Q2
R7 1K
R6 330K
C8 .05
C4 .05
L3/L4
C1 15pF
C3 .05
L1
C2 .001
C6 1.5pF
C7 25pF
L2
R4 1K
Q1
R1 1K
27 MHz
C5*
R3 47K
72 MHz
53 MHz
36"



Q1 = PN3646
Q2, Q3, Q4 = PN3563
Q5, Q6 = 2N2925
Q7 = 2N4400
Q8, Q9 = MPS6534
Q10, Q11 = 2N4436
IF TRANSFORMERS 465 kHz

Fig. 7-6. Ace R/C superhet.



REF	27 MHz	53 MHz	72 MHz
R5	470 Ω	470 Ω	270 Ω
R8	270 Ω TO 1K	270 Ω TO 1K	270 Ω TO 1K
R9	270 Ω	150 Ω	270 Ω
C1	27 PF	15 PF	15 PF
C2	1 PF	1 PF	0.5 PF
C3	27 PF	15 PF	15 PF
C4	27 PF	15 PF	22 PF
L1	10 1/2 TURNS	6 1/2 * TURNS	4 1/2 * TURNS
L2	10 1/2 TURNS	6 1/2 TURNS	4 1/2 TURNS
L3	2 TURNS	1 TURN	1 TURN

necessary while the airplane was being built. This also includes the servo, or escapement or actuator and push rods or torque rods and cables and switches and so on. When all this is done, then the model is covered and finished.

Well, we should not leave you with just the pie and not let you vicariously take a sample of the eating. So we include in Fig. 7-4 a photograph of a model—we considered this one because it was different from the ordinary type model—the builder called it the Bumble Bee, gave it eyes and antennas, a rod tail and long thin nose section, just to feel free to build something he found exciting to construct, and it flew like a dream. Here it is coming in for a perfect landing. The Sunday crowd loved it.

RECEIVER CONSTRUCTION

What about receiver construction? Well we have given you in a previous chapter some superregenerator detectors circuits and also audio amplifiers and relay-amplifier circuits. You simply have to

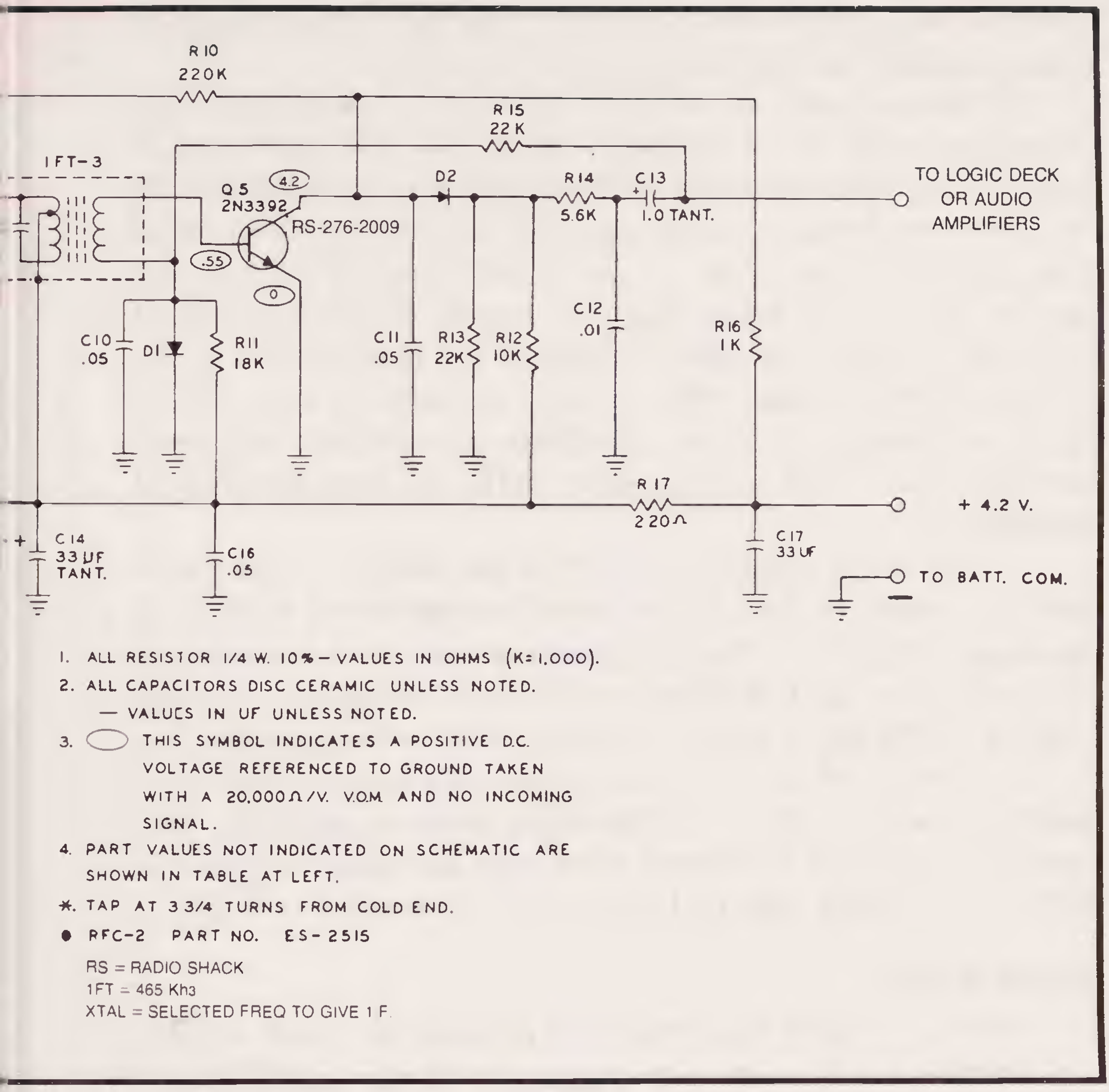


Fig. 7-7. Superhet R/C receiver.

experiment with these and put them together to get this kind of receiver and use a small transmitter for a testing device. As we have said, also, you might buy a small toy system and extract the receiver from that and use its transmitter for some kind of control system of your own imagination at short range of operation. Also, to show you how simple such a receiver might be, we call your attention to Fig. 7-5.

We also include two diagrams of superheterodyne receivers Ace R/C furnishes a kit or completed construction of the receiver, and they also have units on the 27 MHz spots. Figure 7-6 shows the general layout.

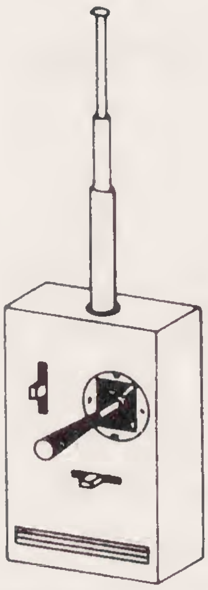
This receiver was used to drive an Adams actuator which requires a pulsing output. If you want to use this receiver with a relay, then you might omit the last four transistors and break the circuit at X and add a relay stage at this point. Ace also makes available a superhet receiver which has the relay-stage output already included, but they do not supply the relay.

A standard type of R/C receiver is the one shown in the schematic in Fig. 7-7. Courtesy of Kraft, this has improvements made yearly since this diagram and circuit were introduced. We include it here because it does represent very clearly the superhet you might be familiar with, yet one which is used in radio-control applications. It also is rather simple in concept. The primary point of focus when using this kind of receiver for radio control is the crystal-controlled local oscillator, and you must be sure that its frequency is *exactly* such that the difference between its frequency and the frequency you want to receive will be the frequency of the i-f transformers.

We do not, in general, recommend that you try to construct a superhet unless you have the necessary test equipment to check its tuning and adjustment. This is particularly true if you have tunable i-fs. As we mentioned, the Heathkit R/C receiver uses a nontunable ceramic i-f filter (three of them) which requires no tuning or checking or adjustment, and so you can construct this receiver almost as easily as you can a three- or four-stage super-regenerator. This would apply to any R/C receiver which uses that kind of nontunable filter. So you might construct one of them as easily as we did.

INSTALLATION

Although modern radio-controlled receivers are small, rugged, and reliable, you do want to use some care in the installation and maintenance of them. It is always best to wrap them in a plastic covering to keep any oil or methane fuel from getting into the parts. You do want to wrap them in three or four layers of ½-inch foam rubber to keep vibration from weakening solder joints and also to keep the units from breaking up physically if you crash an airplane. Wrap them in waterproof coverings if you use them in a boat, as the (salt) water can cause very damaging corrosion. Any kind of water and air can do that of course but salt water is the worst. Use rubber bands to mount them in model cars. You normally do not use foam rubber here in this type of model. Keep your cables from vibrating and check the plug joints often to be sure they don't expand and spread and weaken and come apart with vibration or do not make proper connections. Check often for broken cables or that some strands of the cables have broken and you are operating on a single strand the size of a thread. Keep the receiver out of extremes of temperature, such as inside cars with windows closed and sunlight on the car or model through the window. Be sure your switches are not located where they can fill with fuel and dirt. Be sure they are clean and positive acting. Keep your batteries charged, or changed if you use dry cells. Make yourself a pilot's checklist to prevent trouble; give good maintenance and installation and use it. Keep 'em flying.



8

Servos—The Muscles of the System

In this chapter we will first examine some very simple, but effective, devices which can give you steering muscle. The devices we examine here are called servos which comes from the Latin meaning slave. The only importance of this to us is that the servo responds to commands it received electrically or electronically and converts these commands into a good strong and quick mechanical motion. We need that, of course, to move rudders and steering wheels; we also need motors which can rotate for a given number of turns, stop, and then be reversed on command to wind up jibs and mainsails on model boats. When we use the rotating type of machinery we also need limit switches to keep them from rotating too much, and on some servos we also need limiting (motion) switches which cut off the drive electricity when the extreme of the mechanical movement in either direction has been reached.

SERVO OPERATION

In our book *Model Radio Control*, TAB book No. 74, we show and discuss limit switches in great detail, so we refer you to that work in case you need that kind of electronics in your particular model. But right here we also need to note that with the modern servos used in model airplanes, Fig. 8-1, there is a built-in potentiometer which gives a feedback electronically of the output-arm position so that you have constant limiting to permit exact and proportional positioning of the output arm and shaft. That, of course, is how we get proportional control, which is so necessary with our current airplane models and desirable for model race cars and boats.

Fig. 8-1. A modern radio control servo. (Courtesy Ace R/C)

These servos come as kits and are available as separate units from the various manufacturers, or you can buy them as complete units, but of course they are designed to work with a digital control system and would have to have some modification to work with any other kind of system. Figure 8-2 shows one kit package from Heathkit.

You see that an integrated circuit is used as well as separate motor-drive transistors, and the printed circuit board on which all these electronic parts are mounted. The small but powerful motor and its plastic gearing are shown on the left, and the case is at the top. The feedback potentiometer, which comes in two parts, is located just to the lower left of the printed-circuit board.

By now you might be wondering what a circuit of this unit looks like, and so on Fig. 8-3 we show you. Notice how the wiring is simplified by use of the printed-circuit located just above the printed-circuit board in Fig. 8-2.

SERVO CIRCUIT

On the schematic notice the dotted line from the motor shaft to the feedback potentiometer. This potentiometer is geared to the motor gear-train output shaft and so controls the exact position of the rudder, elevator, or whatever moving arm. A cased servo ready to use in an installation is shown in Fig. 8-4.

Then, of course you want to see how it might be installed in, say, a model airplane; well Fig. 8-5 shows you this arrangement using separate servos. Remember, though, that some control systems have the servos built in as part of the receiver package, and this cuts down on cables and makes a nifty installation in one, two, or three pieces. Usually the motor control and aileron servos are separate with these brick packages. EK-Logictrol and Kraft have such units and other manufacturers do also.

Of course we always like to see just exactly how the final installation might look, and so in Fig. 8-6 we show you one example. The receiver and battery pack, in form rubber, are located to the rear of the servos. This helps to give proper balance to the aircraft. That, incidentally, is one advantage of having the servos and battery and receiver all separate. When testing the system a separate battery pack is connected through cables, and, if you look sharply just below the wheel, you will see such a testing package.

Notice the wing servo behind the hand. It is just visible. This servo controls the ailerons and thus must give a push-pull motion from its linkage so that as one aileron goes up the other goes down. That is easy to accomplish using the two-sided arm furnished with these servos.

Well, as a final current example of how servos are used, look at Fig. 8-7, where we have a model race car and its two servos which control steering and accelerator and brakes. The accelerator and braking operation are combined so that as you advance the accelerator servo the brakes release, and as you slow down the brakes are applied. Again a nifty arrangement which makes for fast and accurate control of the car in races.

It is easy to see the linkage which connects the front servo to the steering-arms linkage. Notice also the packaging of the receiver (on left) and battery package (on right) of body frame. These are wrapped in plastic and foam rubber to prevent oil or fuel from getting into them, and they are suspended in slots provided with heavy rubber bands. That keeps the vibrations from affecting them. In our book *Model Radio-Control*, we have a full chapter on model cars using electric power and a later chapter on this kind of automobile model. You might want to examine that work.

In Fig. 8-7 we can also learn something else. If you will examine the steering linkage you will see how you might arrange such to work with the simpler servos which we now show you how to construct. We do not recommend these following simple servos for use in model airplanes unless they are very stable and fly very slowly, but they may have other uses in cars and boats and other devices such as, perhaps, robots. Now let use examine these small devices and learn about them.

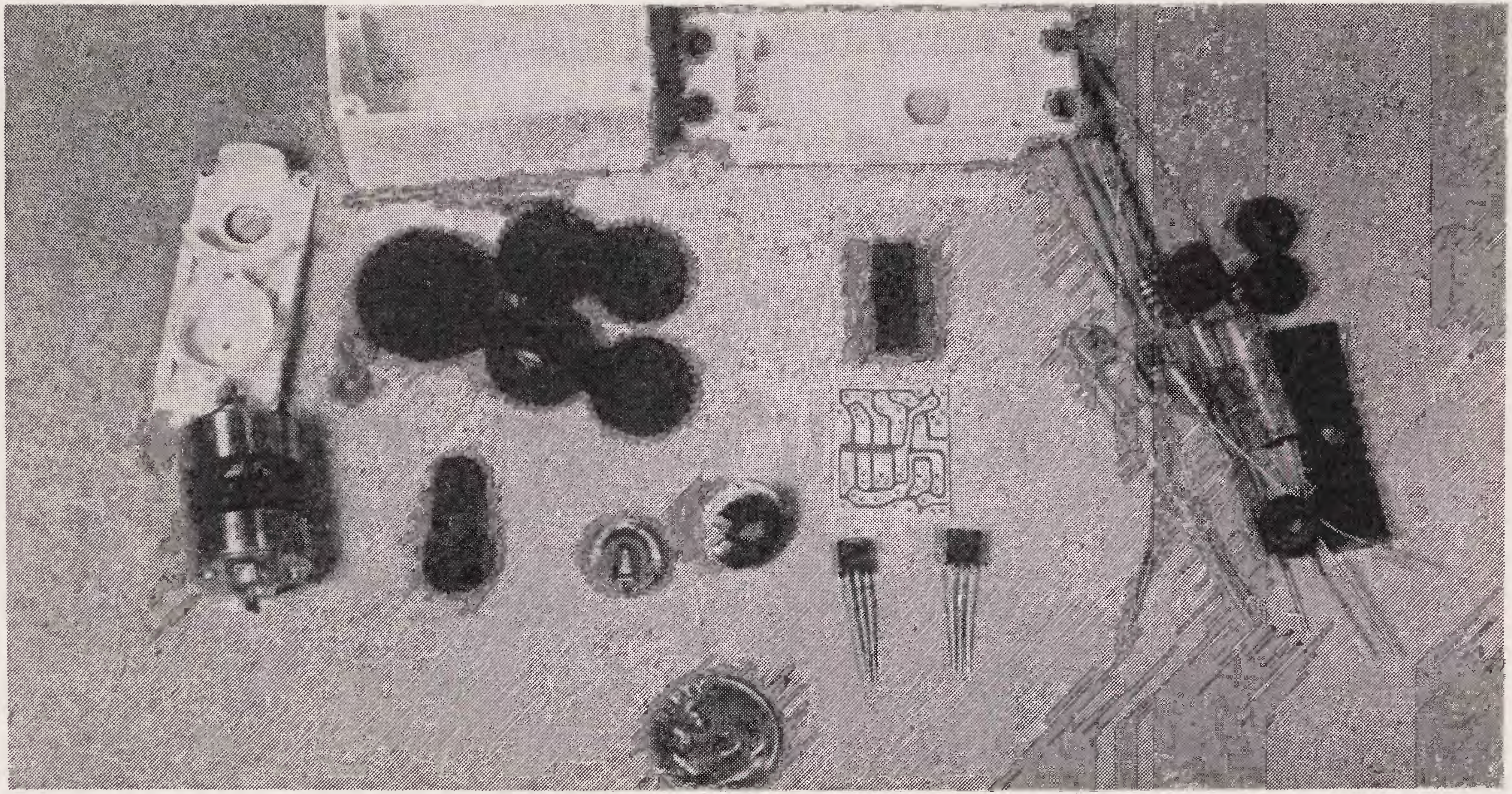


Fig. 8-2. The servo package components from Heathkit. Note dime for relative sizes of parts. (Courtesy Heath Company)

In the previous chapter, you connected your receiver to a small motor and started and stopped it at will by sending a command or not sending a command. To make this motor turn to any one of three given positions and stop, which is our requirement for steering, cams must be added and we must also learn something of a new method of sending commands by pulses.

Perhaps you are wondering about the name *servo*. In radio-control applications, this word is applied to any device that produces mechanical motion on command and has (generally) a small electric motor as a prime source of power.

So we may understand what we want it to do and, thus, why it is built the way it is, let's consider the problem at hand before we construct the device.

The first and most important control is steering. This means we want at least three positions of the steering wheels or rudder and be able to send a particular command for each one. The three positions are, of course, left, right, and neutral.

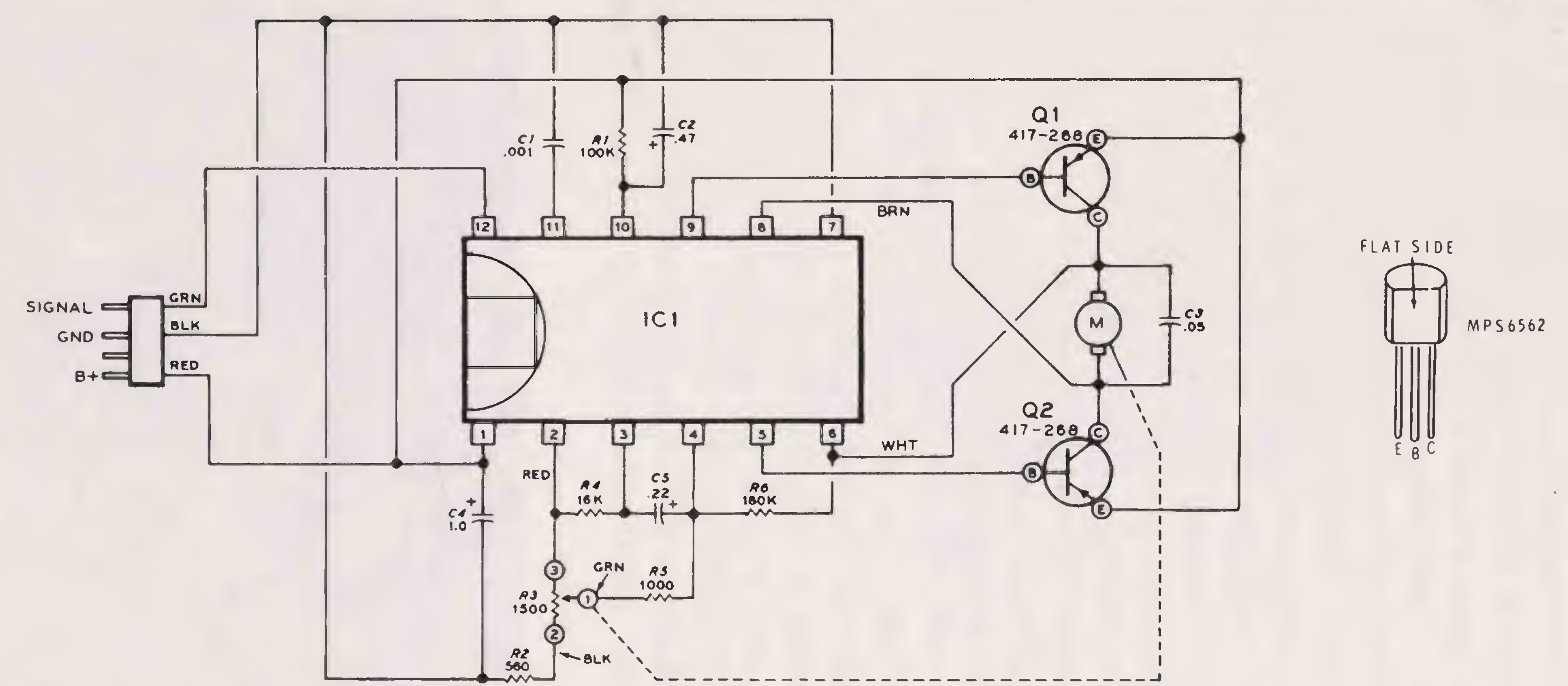
The second most important control is the ability to start and stop the model at will, which represents two more commands.

It's possible, however, to simplify this system. If we construct our servo so that, in the absence of signal, it will always return to neutral automatically, we have, as far as remembering the command goes, eliminated it. It is *sent* (in this case the absence of a signal represents a command), but we just don't worry about it. Whenever we release the button switch, the model goes straight.

For the left and right commands, we use pulses. If we depress the keying switch and hold it down, the model will go, say, left. If we release the keying switch, the model goes straight. Now to make the model go right, we press the keying switch, release it, then depress it again and hold it down. Try this code with a light connected to the relay of your receiver. One flash is left, a flash off and then a flash on is right. The final command is a modification of the first—a very quick press and release—a short of "blip." This last command stops the drive motor.

How to we *start* the drive motor? That command is just like a signal for left. A press and release at about the same speed as the command used for left, but not a "blip." It may seem confusing, so let's build the unit now and, as we operate it, it will become much clearer.

The parts we need are a small motor (the 3- to 6-volt-type found in any hobby shop), a worm gear and a pinion gear. These can generally be found at a shop selling model trains. Just make certain the worm gear will fit the shaft of the motor as indicated in Fig. 8-8.



NOTES

1. ALL RESISTORS ARE 1/4 WATT. RESISTOR VALUES ARE IN OHMS (K=1000).

2. ALL CAPACITOR VALUES ARE IN µF UNLESS OTHERWISE MARKED.

3. ◯ THIS SYMBOL INDICATES A POSITIVE DC VOLTAGE MEASUREMENT.

4. ▭ THIS SYMBOL INDICATES THE NORMAL OPERATING VOLTAGE RANGE.

5. VOLTAGE ON PIN 2 OF THE IC IS VARIABLE FROM 0.2 TO 0.4, DEPENDING ON THE INPUT PULSE. VOLTAGE SHOWN IS WITH THE SERVO IN THE CENTER OF TRAVEL.

6. VOLTAGE ON PIN 6 OF THE IC IS VARIABLE FROM 1.5 TO 2.7, DEPENDING ON THE INPUT PULSE. VOLTAGE SHOWN IS WITH THE SERVO IN THE CENTER OF TRAVEL.

7. ALL VOLTAGES ARE MEASURED WITH A HIGH IMPEDANCE VOLTMETER FROM THE POINT INDICATED TO COMMON GROUND. VOLTAGES MAY VARY ±20%.

8. REFER TO THE SERVO PHOTOGRAPH AND CIRCUIT BOARD X-RAY VIEW FOR THE PHYSICAL LOCATION OF PARTS.

Fig. 8-3. Heathkit servo schematic.

We also need a piece of light tin (in the model shown, a coffee can was used) and a small piece of ⅛-inch plywood for a base.

The first step is to mount the motor, worm gear and pinion gear as shown in Fig. 8-8. The two angle brackets holding the shaft of the pinion gear should be made of heavier material than the coffee-can tin— we do not want them to bend in operation. After mounting, make sure that the motor turns the gears easily and without binding. The spur gear is fastened tightly to its shaft. (Only one angle bracket is shown in Fig. 8-1 since the photo was taken during assembly).

The next step is to construct the three cams and the contact fingers according to the template of Fig. 8-9 and, finally, mount them on the base and shaft as shown in Figs. 8-10 and 8-11 Note in Fig. 8-11 that the shaft wiper contact and the crank (which actually moves the steering element) are shown. In this figure you can also see the spacing between the cams. This is not critical so long as the three cam wipers do not touch each other.

The cams must be positioned as shown in Fig. 8-9, and, as we discuss the wiring, we will refer to them as: A, the neutralizing cam; B, the left-right cam; and C, the drive-motor control cam.

The wiring is quite simple. One lead from the motor (on the right in Fig. 8-9) connects directly to the shaft wiper. To this same motor terminal we connect one side of a .01μF capacitor. The other motor terminal connects directly to the battery's plus terminal and the other lead from this capacitor. The battery to be used will depend on the size of the motor. Check your dealer or parts house for the battery you need.

Fig. 8-4. A servo ready to install. (Courtesy Ace R/C)

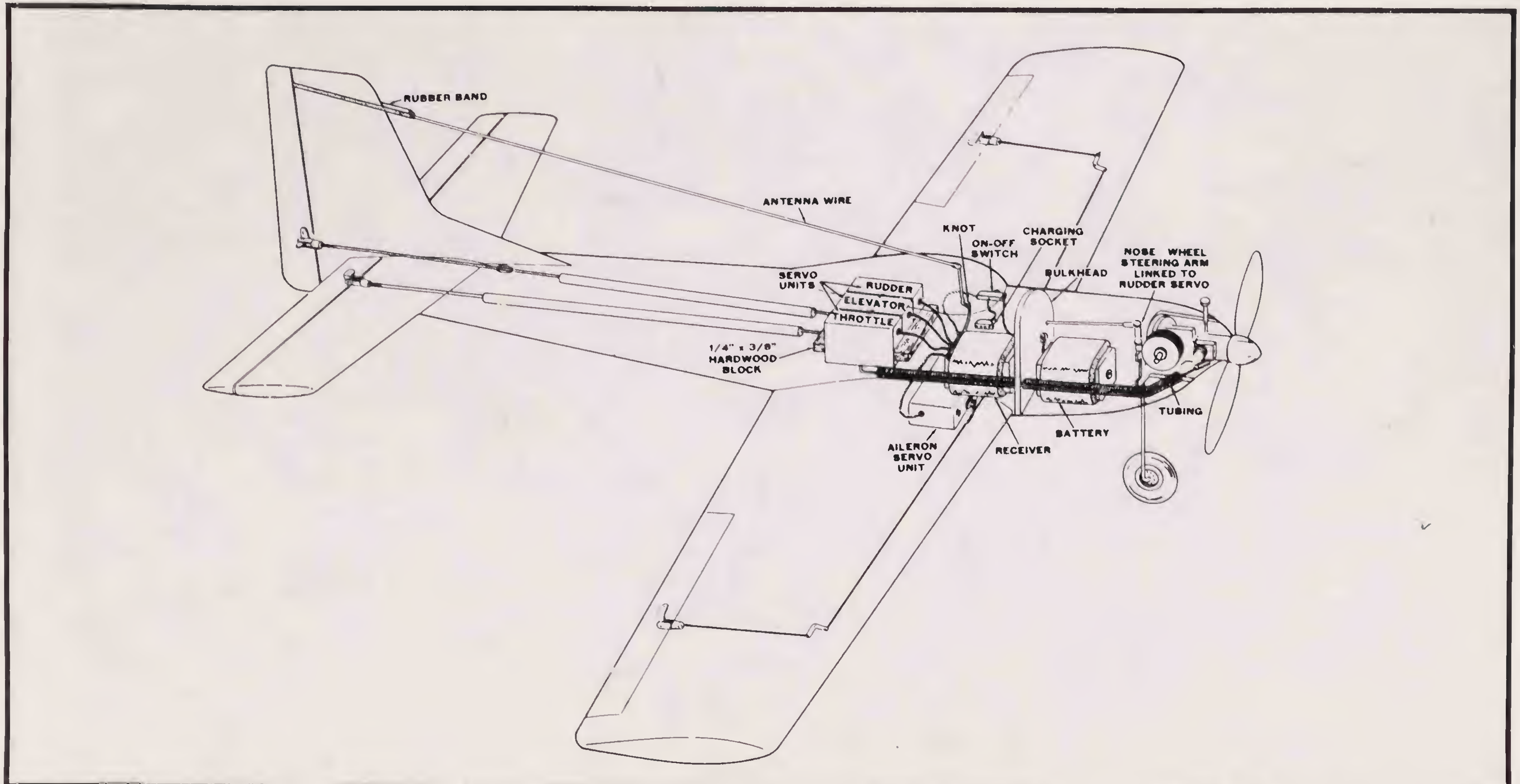


Fig. 8-5. Servos in an airplane model.

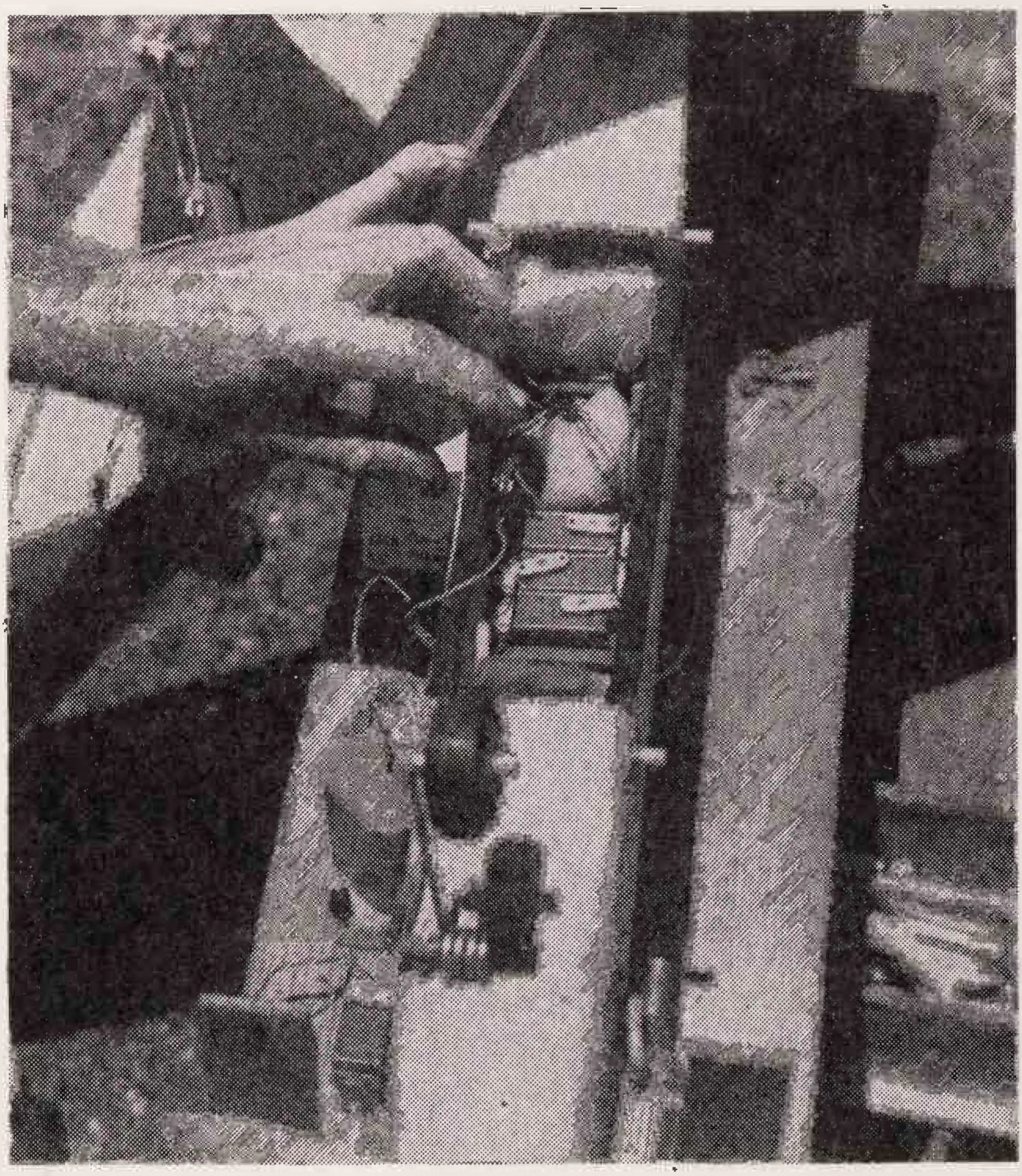


Fig. 8-6. Servos installed in model airplane.

The minus terminal of the battery connects directly to the frame lug of the receiver relay. The normally open contact of the relay connects to cam wiper 2; the normally closed contact connects to cam wiper 1. (Note that each cam wiper also has one lead from a $.25\mu F$ capacitor connected to it). The other lead from each of these capacitors is connected to shaft wiper 4. These capacitors prevent sparking, which could be picked up by the receiver and cause erratic operation.

From shaft wiper 4, a length of insulated wire is connected directly to one terminal of a drive motor. (The drive motor is the motor which causes a propeller or the rear wheels of a car to turn—it makes the model move). A second insulated lead is connected to cam wiper 3 and this goes to one side of the drive-motor battery as shown in Fig. 8-2. The other terminal of the drive-motor battery is then connected to the second terminal (or lead) of the drive motor.

Now let's see how the basic servo operates. If the cams are correctly positioned on the shaft (they are soldered to it so they turn when the shaft turns) and the relay is not energized, the electrons will want to go from the minus terminal of the batteries to the plus terminal. So, starting at the minus termial (battery No. 1) the electrons can go to the relay armature and through the normally closed (NC) contact of the armature to cam wiper 1. Since this is a battery (direct current, that is), the electrons cannot go throgh the capacitor and they stop. The circuit is incomplete and nothing happens.

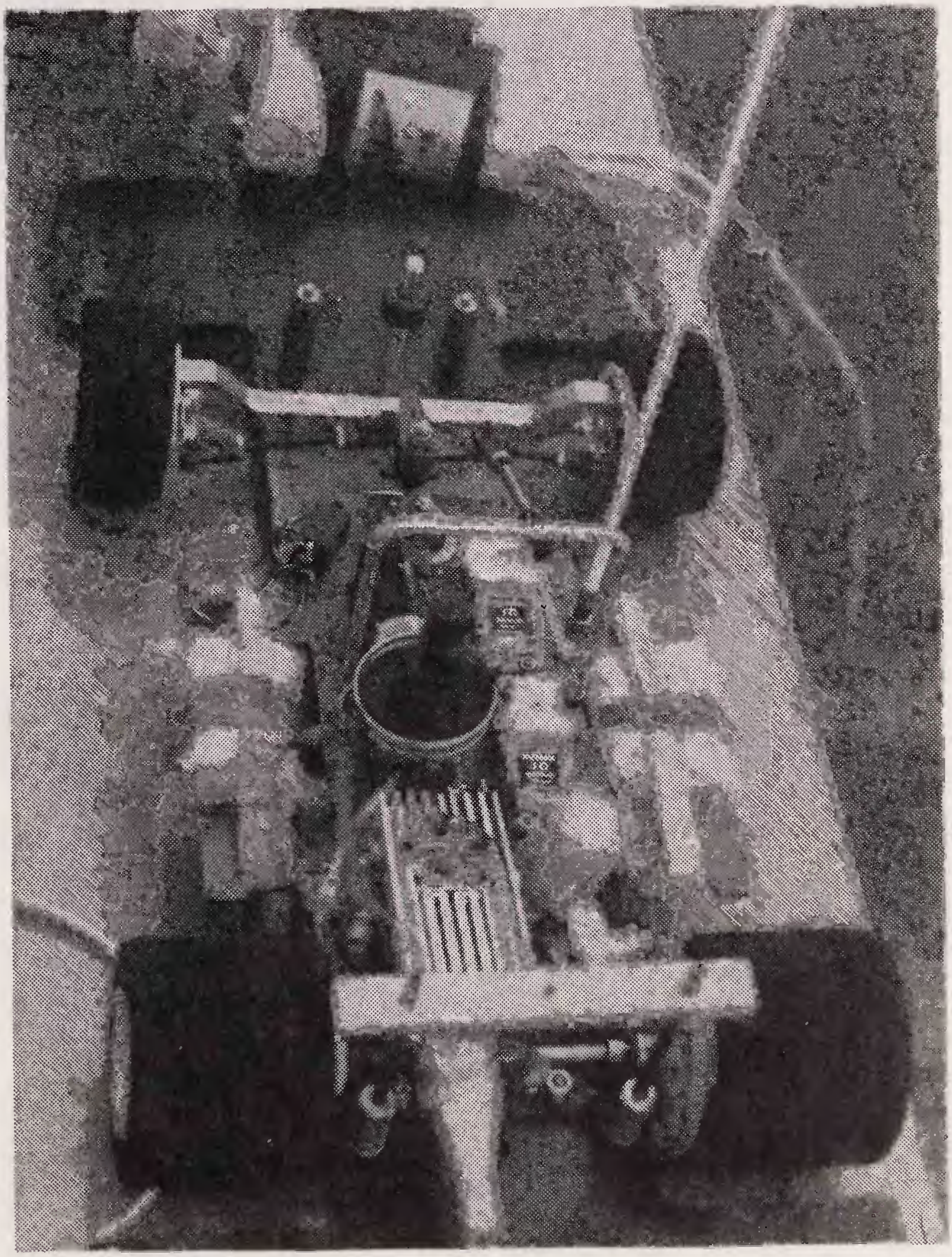


Fig. 8-7. A model race car with two servos, receiver, and batteries.

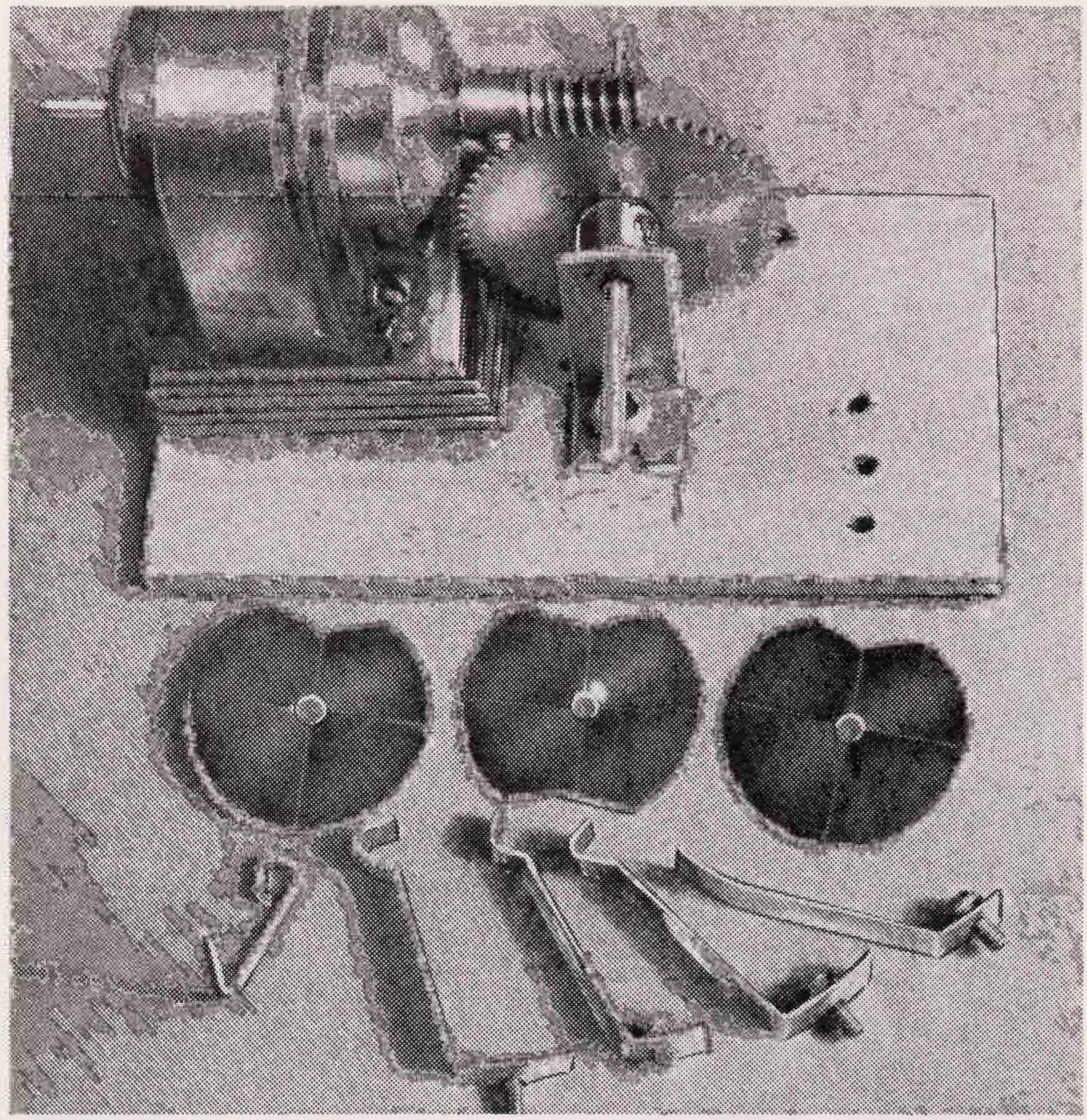


Fig. 8-8. Mounting the motor, worm gear and pinion gear is the first step in servo construction.

Now let's send that first command—press and hold. When we do, the receiver relay armature moves from the NC to the NO contact. The electrons (or current of electricity) can now go from the NO contact to cam wiper 2. Since it is resting against cam B, they flow through this cam to the shaft, down the shaft to shaft wiper 4, down shaft wiper 4 to the second motor terminal, through the motor (motor No. 1) and back to the plus terminal of the battery.

The circuit is now complete, the motor turns and keeps turning until the indentation in cam B breaks the connection to cam wiper 2. To do this, the shaft has to rotate 90°. The little crank on the end, instead of being down, is now to the right and stays there as long as we hold the keying switch down.

Releasing the keying switch causes the relay armature to move back to the NC contact, but now, since the shaft has turned, the electrons can flow through cam wiper 1, cam A, the shaft, wiper 4 and the motor to cause the motor to run again. This time it runs until

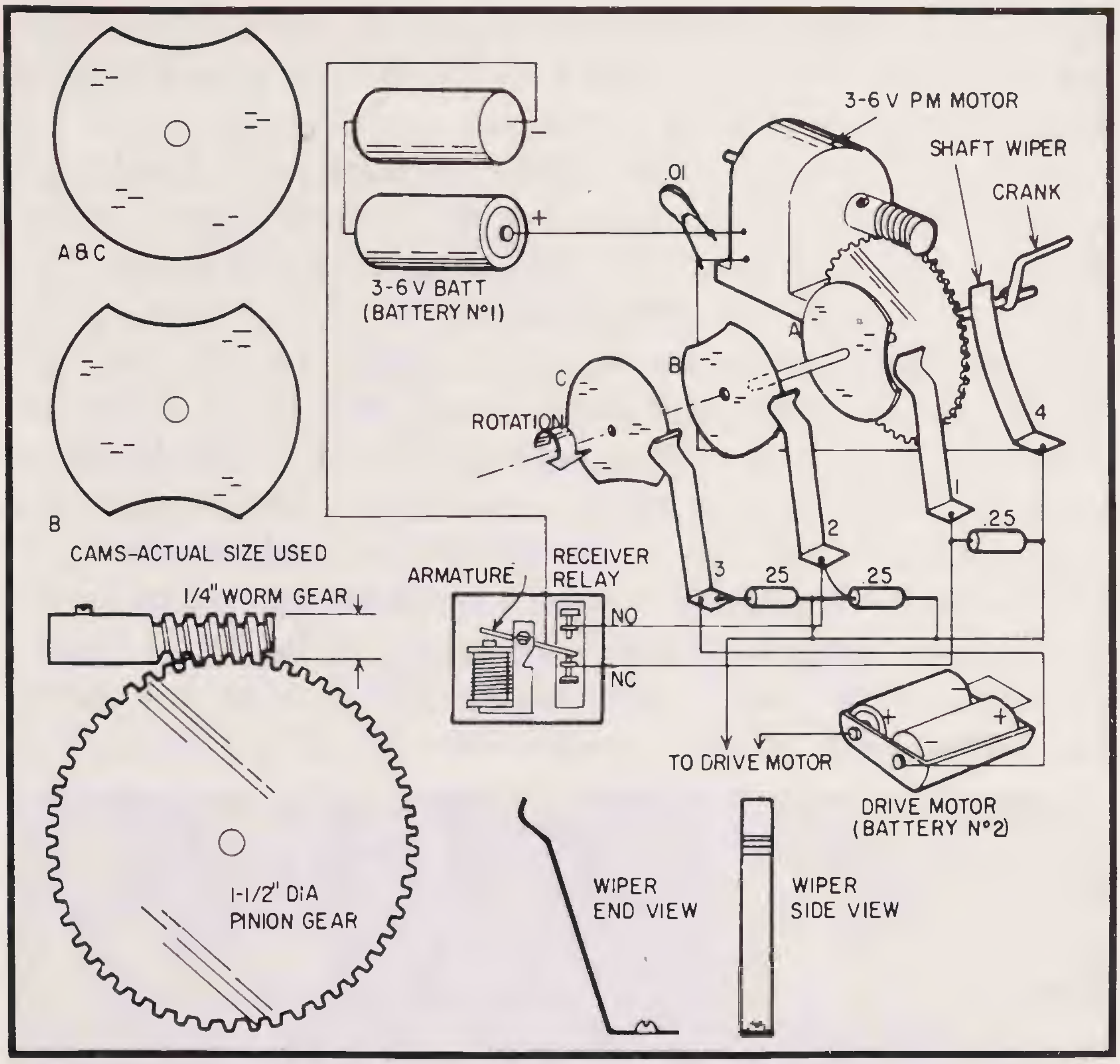


Fig. 8-9. Template for constructing the three cams and four contact fingers shown in Fig. 8-1.

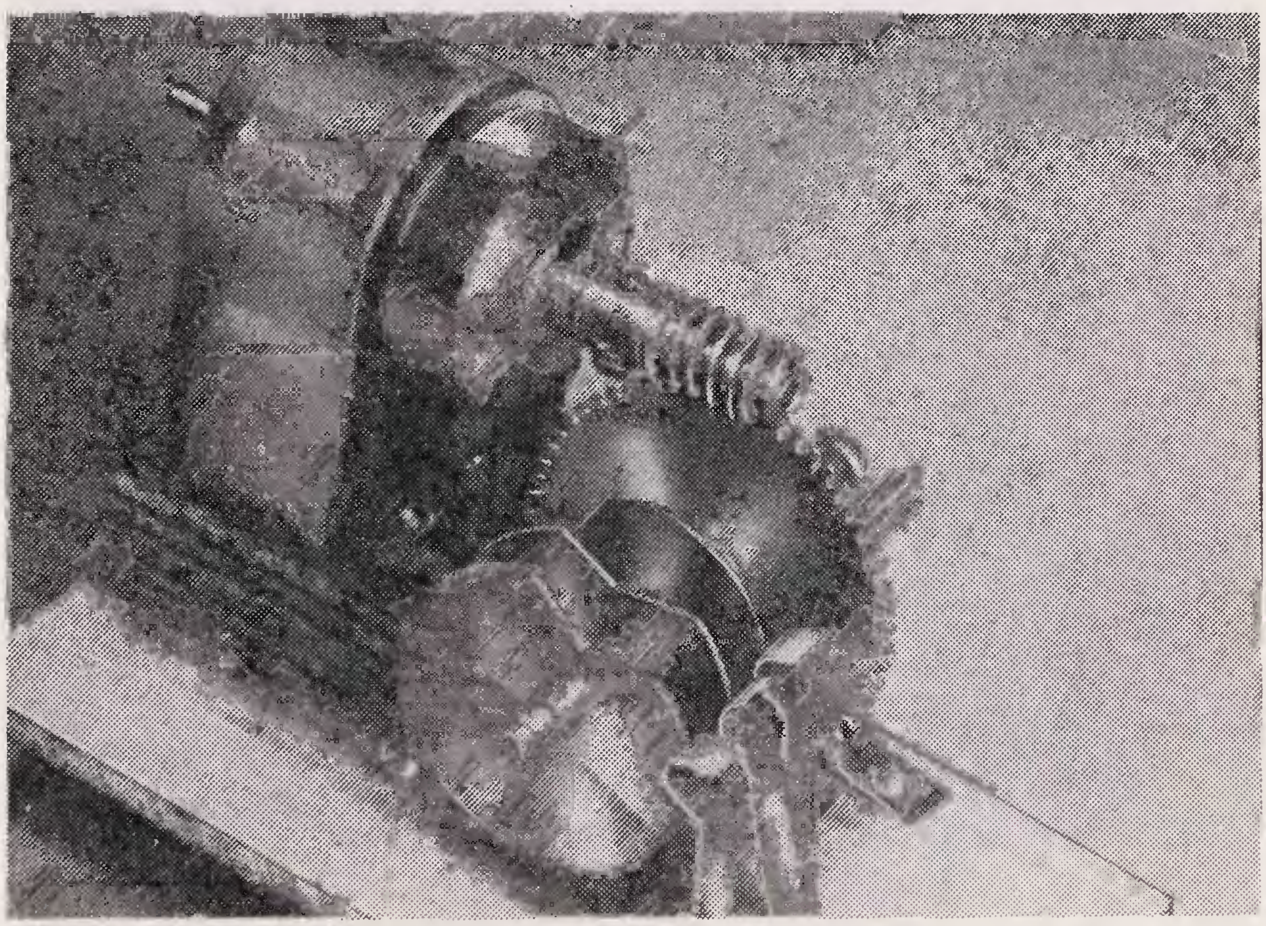


Fig. 8-10. Cams and contact fingers mounted on shaft and base.

the cam-A indentation breaks the circuit to cam wiper 1. The crank has turned a full 270° more and is now back to its original starting place—the neutral steering position.

To turn the crank 270° from this neutral position and stop, giving us the "right" steering position, use the code given previously: Press, release and press, and hold the keying switch closed. This has to be done with the right rhythm because this is what should happen: When we press the first time, the electrons flow through the relay (as previously described), wiper 2 and cam B. The motor starts turning. When the first indentation of cam B breaks the circuit to wiper 2, if our rhythm is correct, we will have released the keying switch so the electron flow is transferred to Cam A through wiper 1 to keep the motor going. Now as soon as the first indentation of cam B has passed wiper 2, we have again depressed the keying switch, once more transferring the electron flow to wiper 2 and so, as the second indentation breaks the circuit here, the motor will stop. The

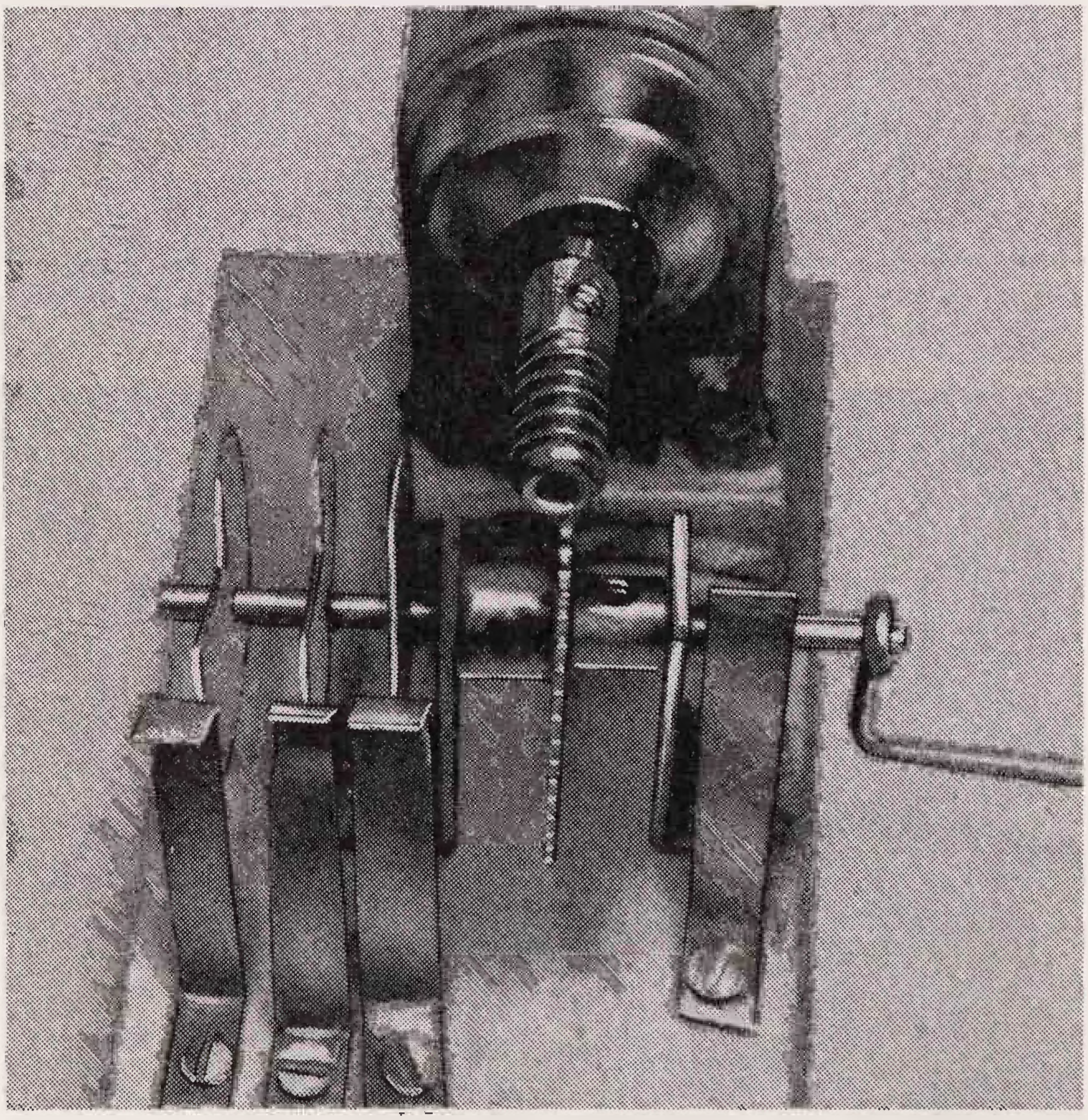


Fig. 8-11. Closeup of cams and contact fingers mounted on base shows spacing between cams. Note the little crank on the right side, used to move the steering element.

shaft will have rotated a full 270°, and the little crank will be to the right.

This will take a little practice and you may have to readjust the positions of the cams to have the motor stop with the crank in the positions specified. You may have to add a small drag or friction wire pressing against the motor shaft (as described in the next chapter) to prevent the motor from coasting past the broken-circuit positions. You may also have to reduce the battery voltage applied to the motor to prevent continuous rotation. These are adjustments best done by experimentation so we leave those details to you.

Assuming now that you have the steering part working as it should, examine the motor start-stop action. This involves cam C. As shown in Fig. 8-9, cam wiper 3 rests against cam C. The electrons from the drive-motor battery (battery No. 2) can go through the wiper, the cam, down the shaft, out wiper 4 and the line to one side of the drive motor. They won't go anywhere else because they want to get back to their own battery. They go through the drive motor and back to the plus side of their battery (battery No. 2) and so the drive motor runs.

Now, if we send the "blip" mentioned earlier, the *steering-motor* circuit is momentarily completed through wiper 2, but only momentarily—just long enough for the shaft to rotate a very small amount, causing the indentation of cam C to break the circuit to the drive motor. At this time, the receiver relay armature is back against the NC contact but the shaft of the motor didn't move far enough to close the circuit between cam A and cam wiper 1. What happens? The drive motor stops, the steering motor stops and the model stops.

To start the drive motor, use the code given previously: Depress the keying switch for a longer time and release. The cam shaft will make a complete revolution, stopping when the circuit to cam A is broken—but, at this stopped position, cam C does make contact to power 3 and the drive motor runs. Try it. Adjust the cam if necessary so this does happen. It will take a little practice to get the rhythm, but once you do, you have mastered the basic method of radio-controlling a model car or boat. I do not recommend this servo for model aircraft.

CONSTRUCTING A MORE ELABORATE SERVO

Our first servo was the simplest possible and somewhat limited in power. We will construct a more elaborate single or dual type which has had application in a model aircraft for rudder and motor-speed control.

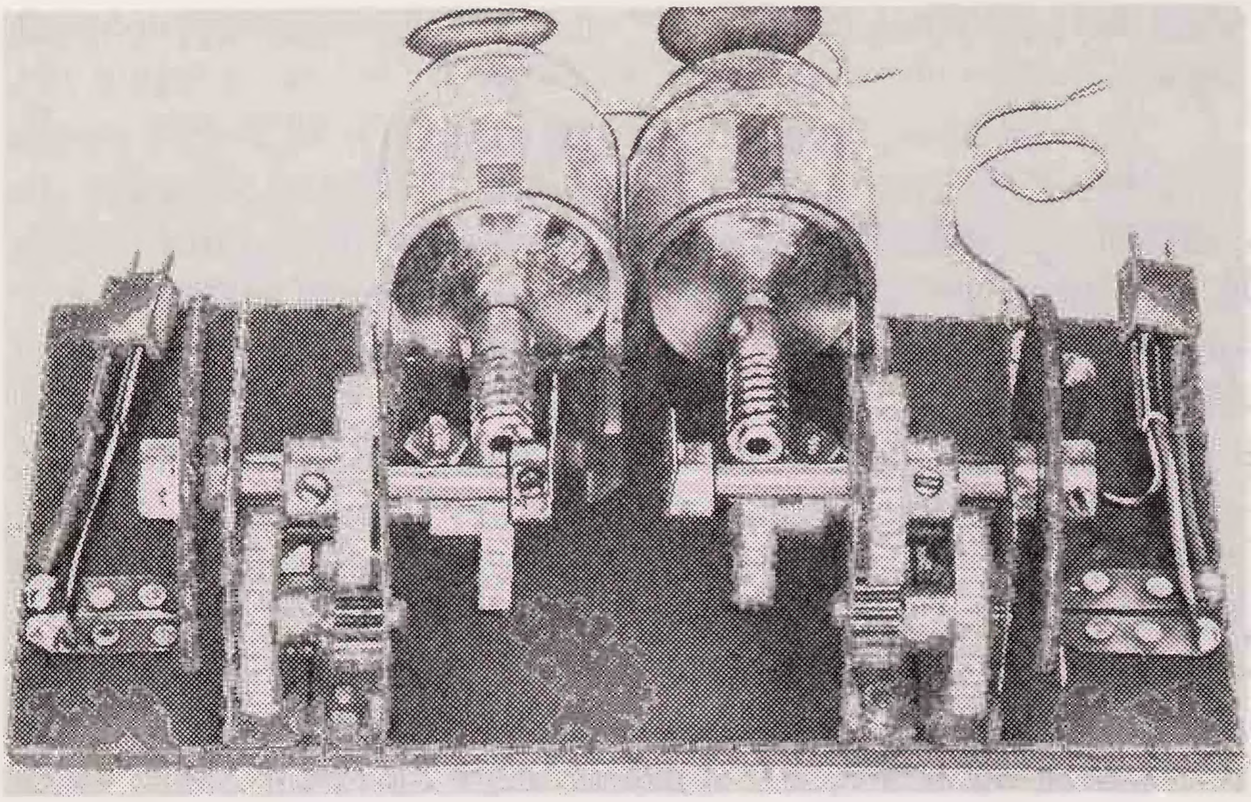


Fig. 8-12. Front view of dual-unit servo with elaborate pinion-gear train added.

Figures 8-12 and 8-13 show the front and rear views of the dual unit. Note that the basic worm gear is used but, in addition, a more elaborate pinion gear train has been added. While the method of breaking the circuit to the motors is similar to that of the simple servo, the method of making the cams is different. Instead of individual cams, this unit uses a single plate with cutouts positioned as shown in Fig. 8-14. This type of cam is referred to as a *commutator.* Note the capacitors for arc suppression mounted directly across the motor terminals in Fig. 8-13 and, in all three figures, note

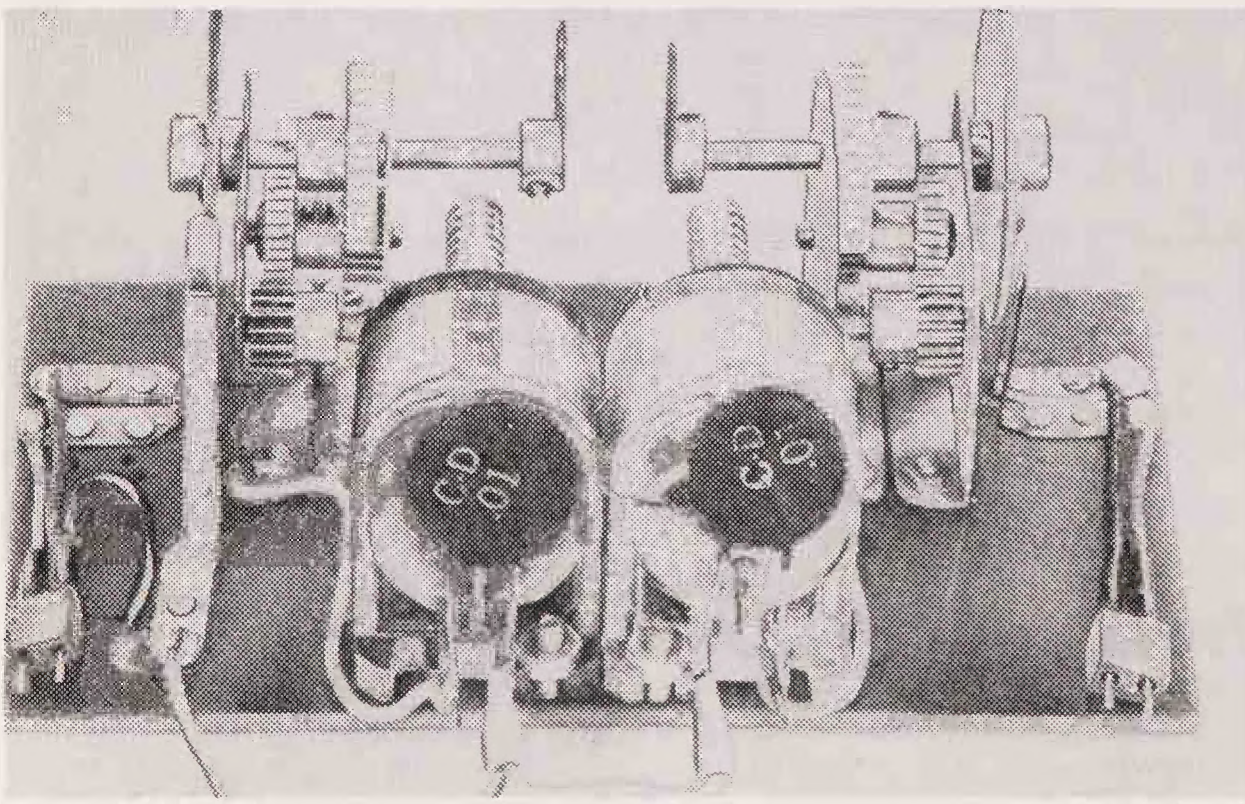


Fig. 8-13. Rear view of dual-unit servo, showing arc-suppression capacitors mounted directly across the motor terminals.

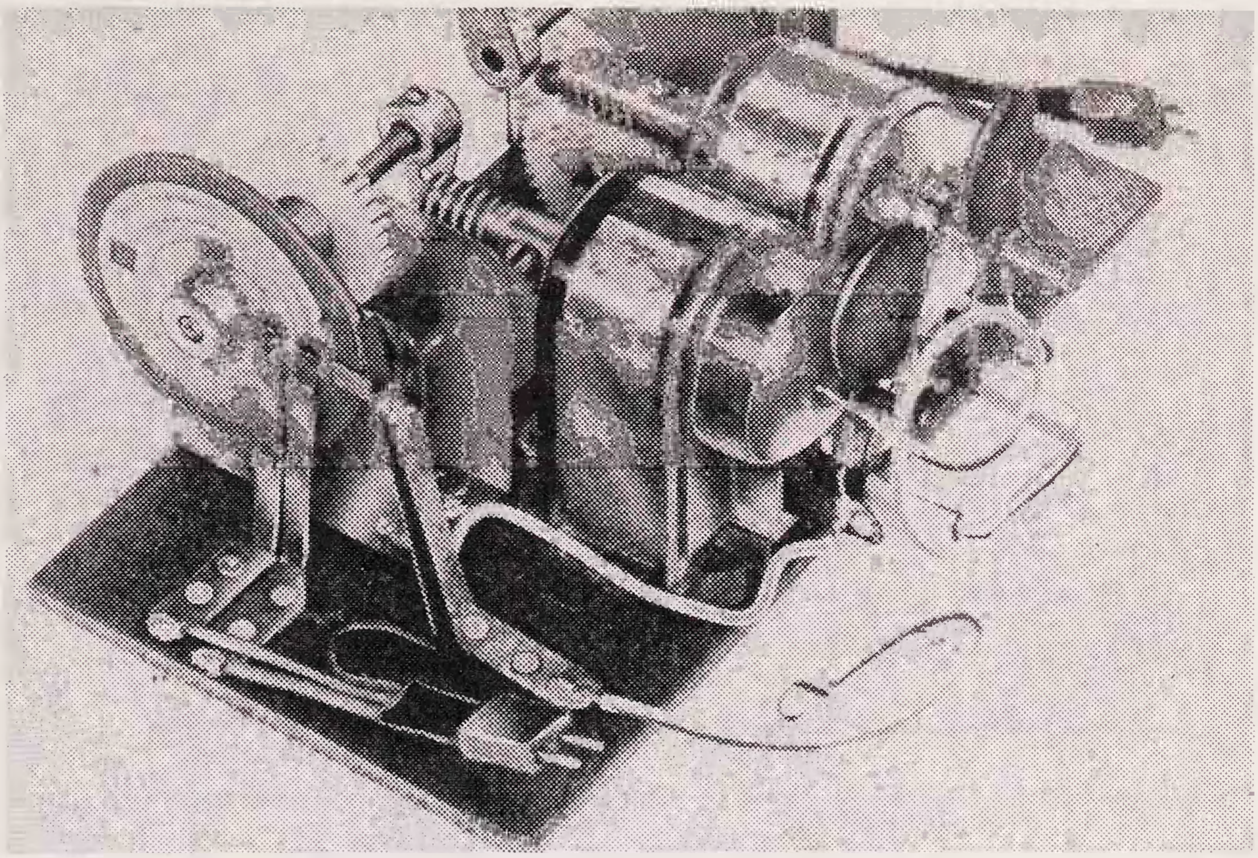


Fig. 8-14. Dual-unit servo uses a single plate with cutouts instead of individual cams. Note the positioning of this type of cam, known as a commutator.

the neat method of using small plugs to connect the unit into the battery and receiver circuitry. This is an excellent idea and should be used with all radio-control components (receivers, etc.), so each is readily removed for inspection, servicing, testing or use in other models.

Refer to Fig. 8-15 for templates and details of mounting. The components are mounted on the 1/16-inch base plate as shown. The gears (a Pittman reduction unit available at most hobby shops) come with shafts that are easily cut to the proper length. Mount the gear train first and make certain that all gears turn easily by hand. Now mount the motor, and again make certain there is no binding. Connect a battery to the motor and run it, checking to see that all gears move freely and easily after being firmly anchored to the base plate.

To make the commutator, cut a metal disc from tin or brass stock and cement it firmly to the face of a fiberboard disc as shown in Fig. 8-14. Don't worry about alignment at this time. We can adjust the little cranks (center of Fig. 8-14) after everything else has been constructed and adjusted. These cranks are made from tin drilled and soldered to small collars which can be screwed tightly to the shafts. The three holes in the cranks allow a variable amount of movement of the steering element. The hole farthest from the shaft will give the greatest amount.

The commutator is mounted either by soldering the metal disc to the shaft or by soldering it to a collar and then tightening the screw to hold it fast to the shaft. The contact arm (or wipers) can be made

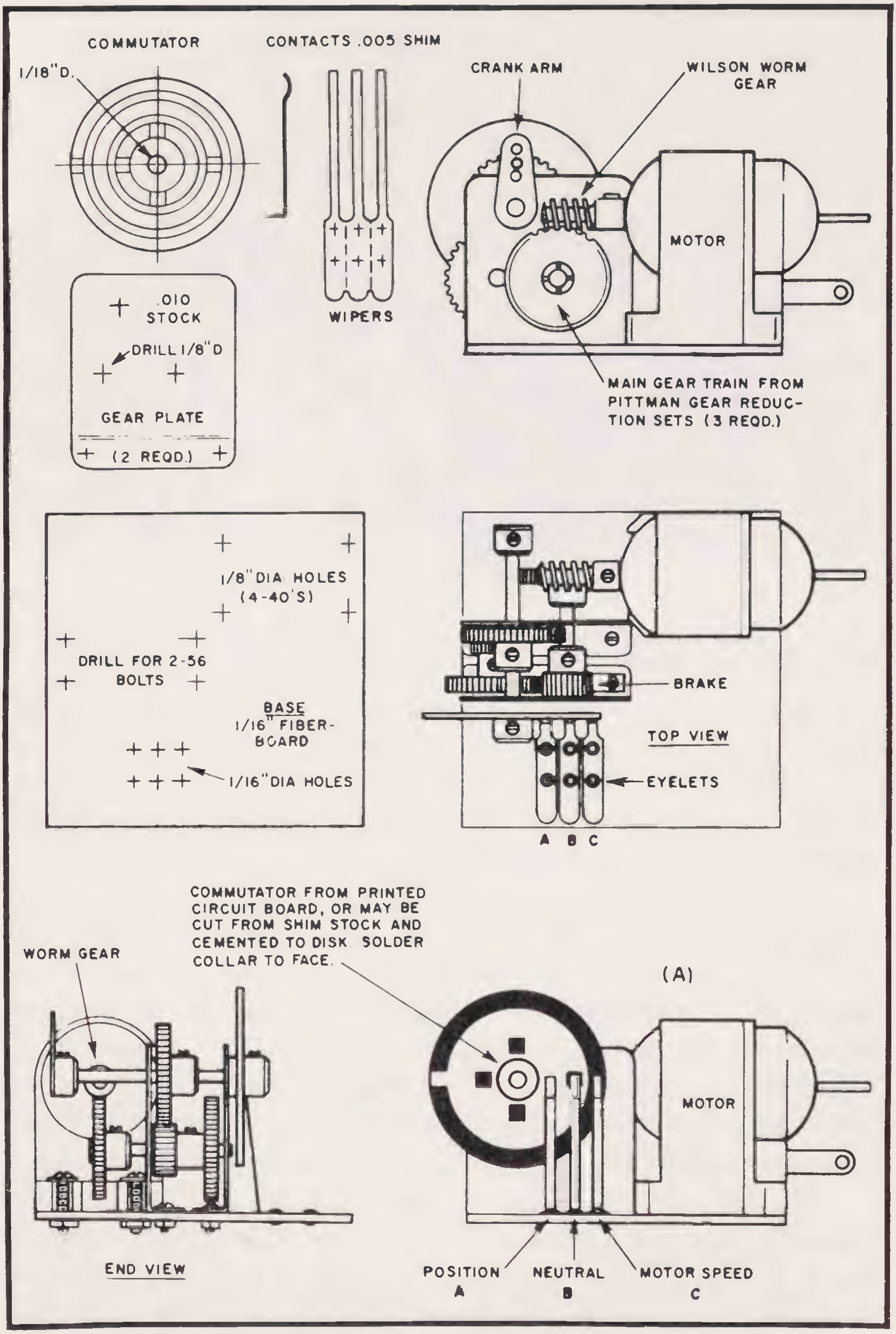


Fig. 8-15. Template (not to scale) and details of the dual-type servo. The Pittman gear train is a reduction unit obtainable at most hobby shops. Check the gears through a complete revolution to make sure they do not bind at any point. (Courtesy Flying Models Magazine)

by tracing the pattern in Fig. 8-15 onto a sheet of beryllium copper .005-inch thick. Bend these wipers and also the base mounting tab so the arm leans down 30° from the vertical. Clamp these contacts in place on the baseboard so they connect to the commutator. Drill

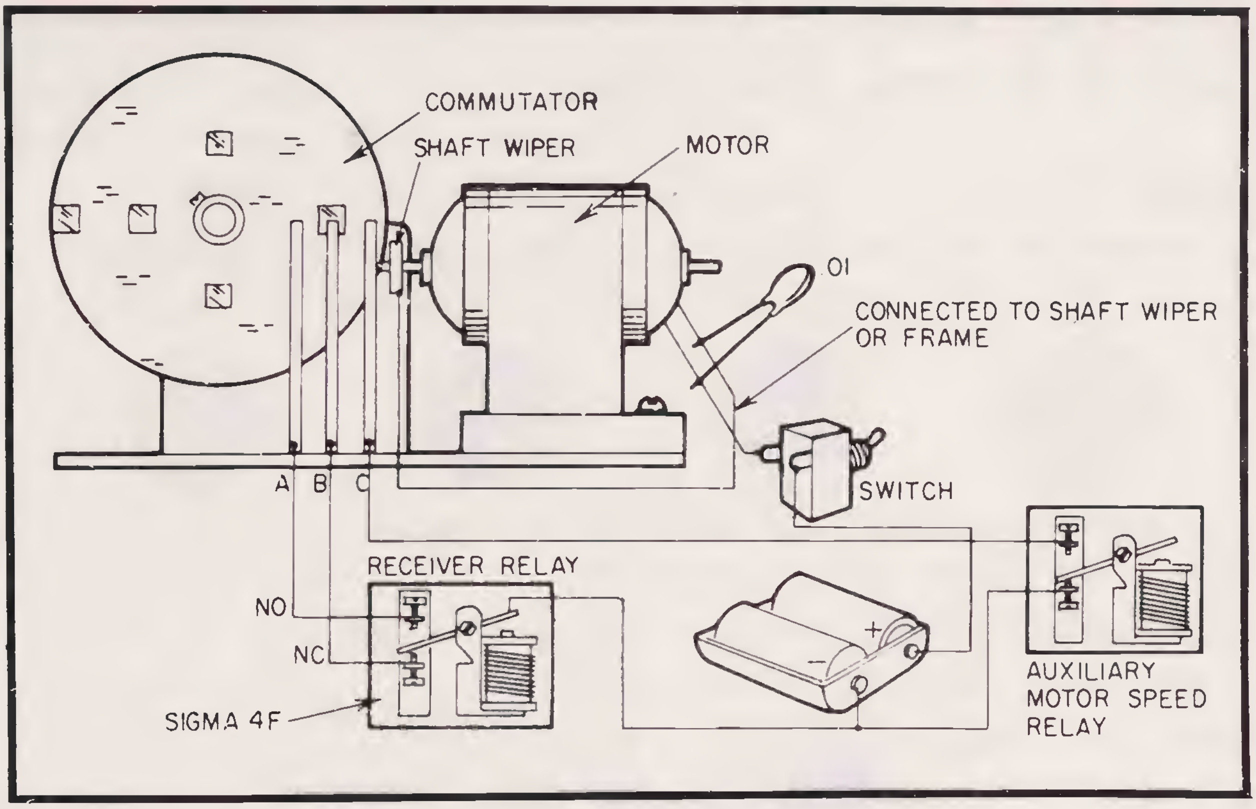


Fig. 8-16. Pictorial wiring diagram of dual-type servo.

through their bases and the base plate simultaneously. Make certain these wipers do not touch each other. Mount them with small screws and check the tension against the commutator disc. They should be firm and tight, making a good wiping contact.

If the wipers are mounted as a single unit, you can separate them by sawing through the mountings with a fine-toothed metal saw.

Here is how the command code works: one pulse and hold (depress and hold)—the shaft turns 90°. Release, and the shaft returns to neutral. Two pulses and hold (with the correct rhythm)—the shaft moves to 180° and stops. Release, and it returns to neutral. Three pulses and hold—the shaft turns 270° and stops. Release, and it returns to neutral. This is the same as for Fig. 1-6.

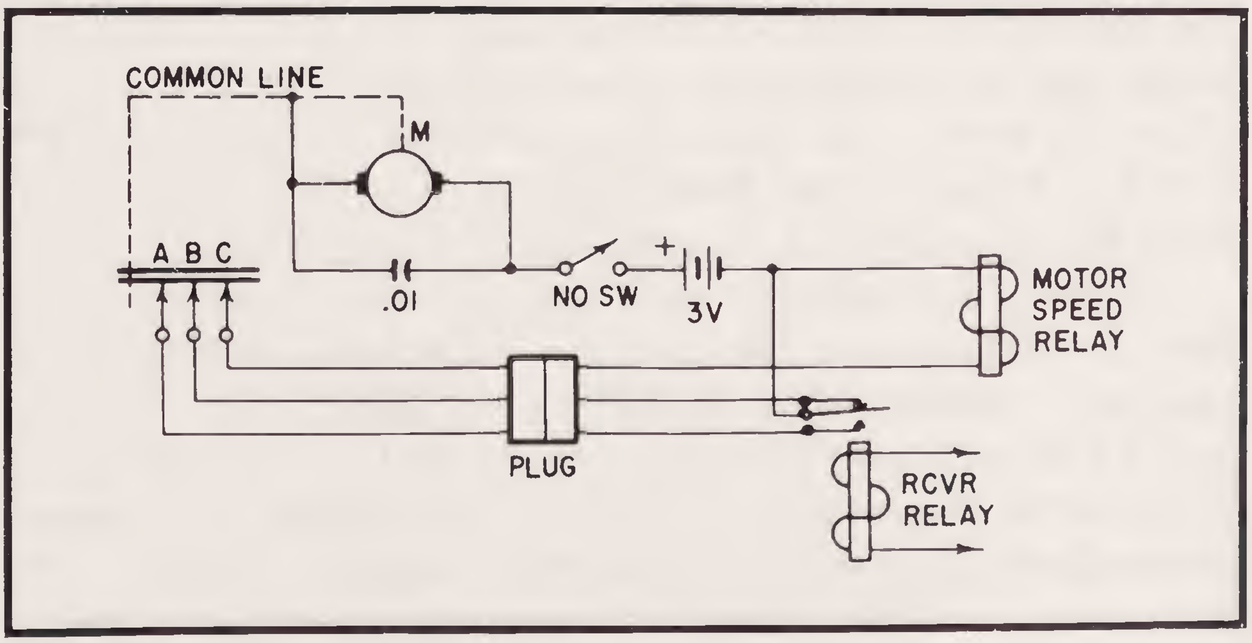


Fig. 8-17. Schematic diagram of dual type servo.

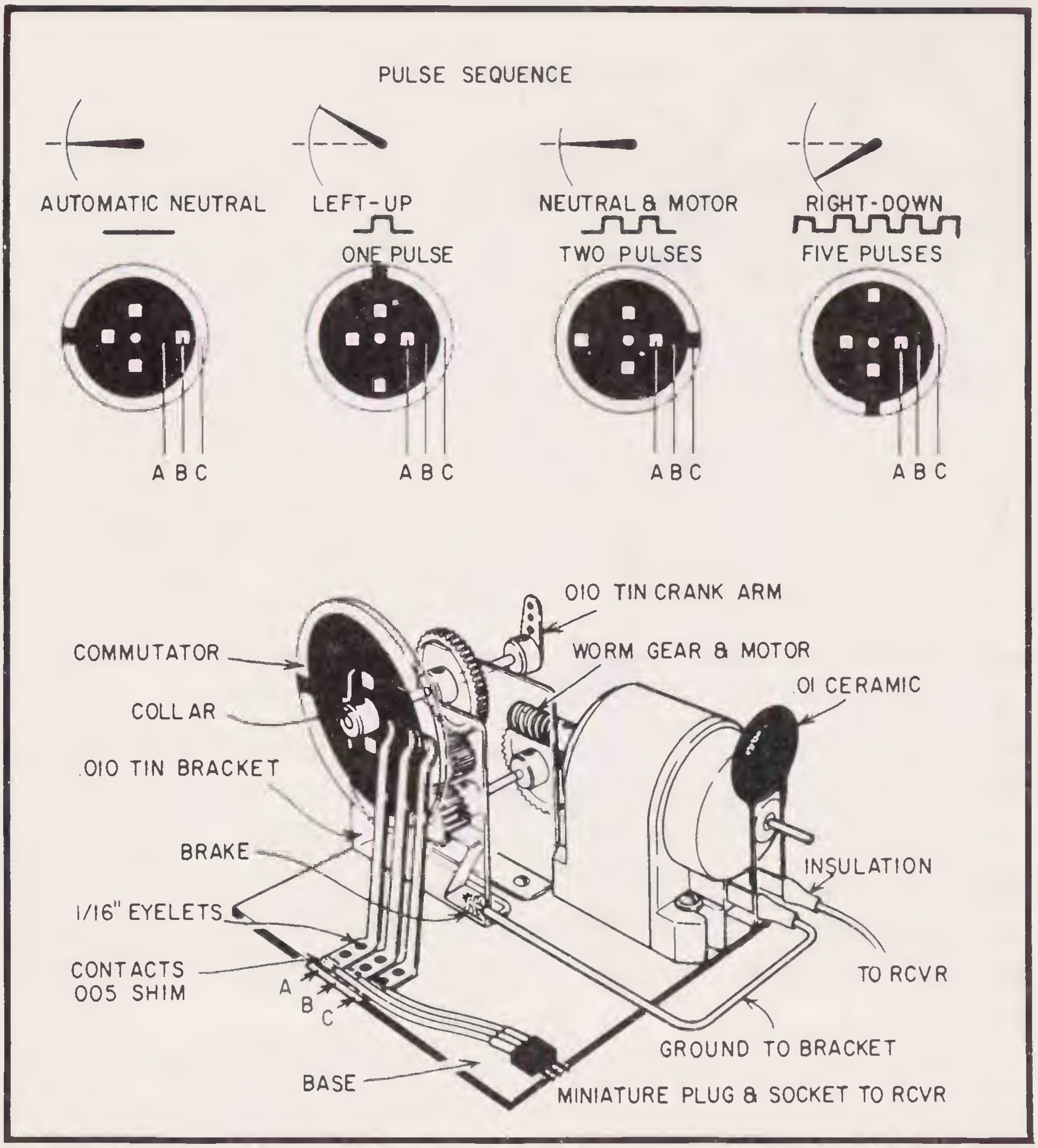


Fig. 8-18. General sequence of operation, showing commutator cam in its various positions.

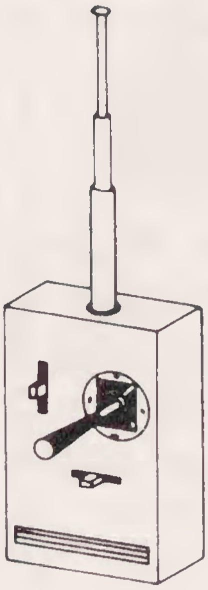
A small spur on the commutator will be under motor-speed wiper C when the commutator has turned 180°. Refer to Fig. 8-14 and note that this little projection is closing the switch mounted just in line with the commutator. (The motor-speed wiper C can be mounted in line with the other wipers, as in Fig. 8-15, or to one side as in Figs. 8-13 and 8-14). Wiring diagrams are shown in Figs. 8-10 and 8-16. Figure 8-9 is a pictorial; Fig. 8-17 is a schematic.

Either of two methods can be used: closing an auxiliary circuit when the code (press, release, press and hold) is transmitted, or keeping this auxiliary circuit energized. The latter method might be used if a second motor with a large gear train controlled the drive-motor speed. However, you must realize this auxiliary circuit would be energized each time the steering servo completes a cycle. There are ways to avoid that, and we will leave the contact in place although we may not use it now. Later on, when we talk about full- and half-speeds and reversing the drive motor, we will show how such an auxiliary contact can be used so this auxiliary circuit will not operate unless we specifically command it.

Figure 8-18 shows how a small brake can be made to ride on one of the pinion gears to prevent overtravel. It also shows the general sequence of operation related to the positions of the commutator cam.

RELAYS

It may be of interest to know that Allied Electronics (401 East 8th St., Fort Worth, Texas 76102) stocks a wide variety of relays for control. In fact they include some integrated-circuit relays using a magnetic reed which are small and self contained. So, if you want to find a relay for use in any of our circuits, we suggest you contact them.



9
Model Aircraft

We have already learned that nowadays the common radio-control equipment for model aircraft is the digital simultaneous-proportional multichannel type exemplified by that shown in Fig. 9-1.

There are many types of this equipment and most of it is good and does what it is supposed to do if you have done your part keeping it clean, the batteries charged, within temperature tolerances, etc. So, with this in mind, let us now examine some airplane models which we find at the flying fields and think about them and the installation of radio-control equipment in them. Figure 9-2 shows a relaxed picture of a Sunday fly-in at a local field, and, believe me, it's a fun place to be.

Meantime, of course, where are the airplanes? They are on the sideline waiting their turn to take to the air. A few of them, in one grouping—not all pilots want to be in the same place at the same time—are shown in Fig. 9-3.

What is interesting about this picture is the type of aircraft shown. These are essentially the flying models of model airplanes. They are not scale but are primarily designed for just the purpose for which they are used—to fly with radio control. They are rugged and strong and usually always come from kits.

Speaking of kits, we were interested in where kits come from and so contacted Sig Manufacturing Company to ask about this. We obtained Fig. 9-4, which shows the endless bins of balsa parts used to make up the kits and one lady in the process of assembling these pieces in one of the packing boxes. Yes, most airplanes nowadays

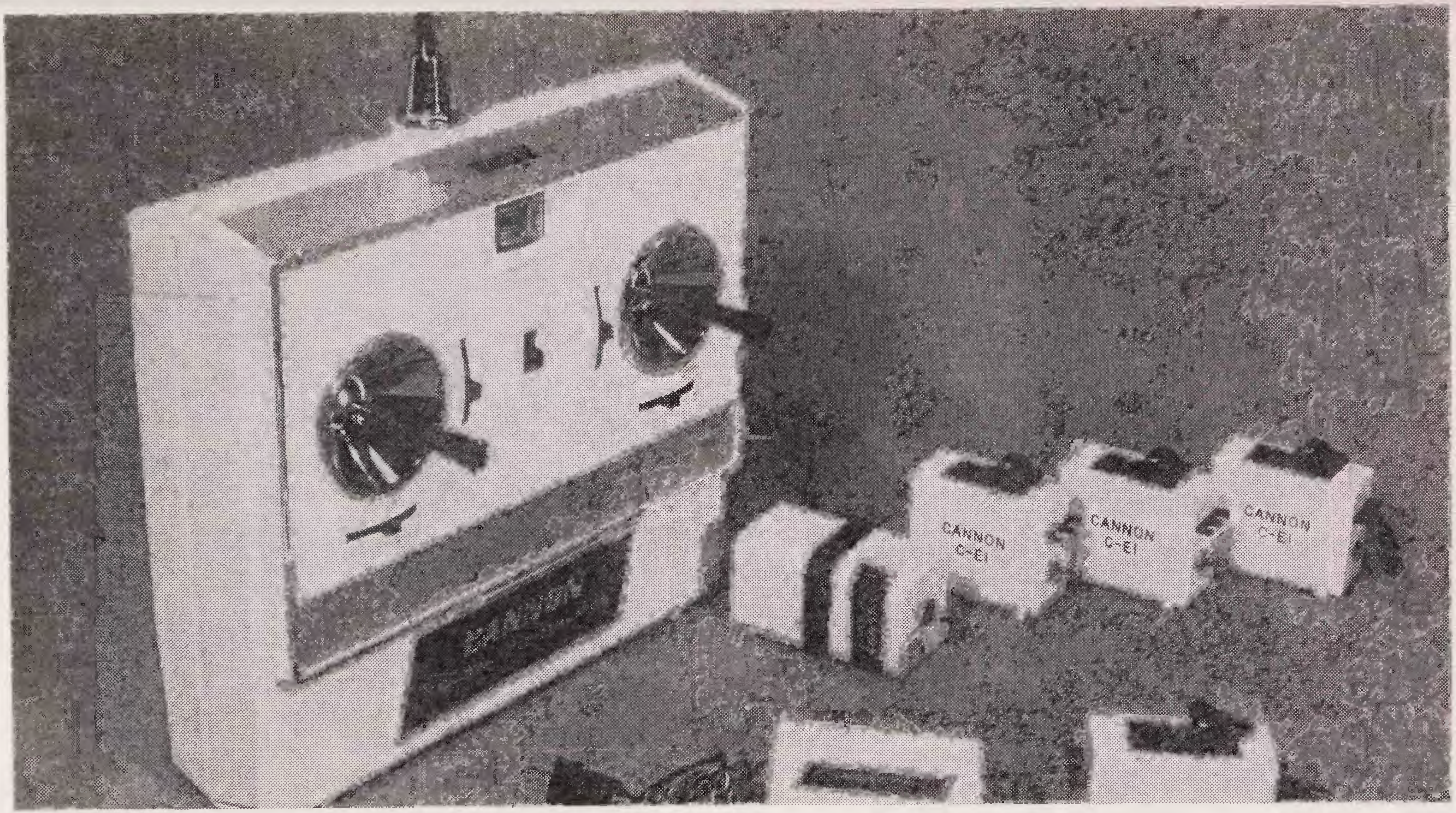


Fig. 9-1. Cannon multichannel digital radio control system.

Fig. 9-2. A relaxed Sunday fly-in at a local field.

come from kits, and you have a wide choice of style and type and size and color and method of fabrication. You can even get prefabbed airplanes so that all you have to do is go to the field and fly them.

RULES OF THUMB ABOUT AIRCRAFT

Let's examine some aircraft seen at model flying fields. First there are the trainers. These are exemplified by the aircraft shown in Figs. 9-5 and 9-6.

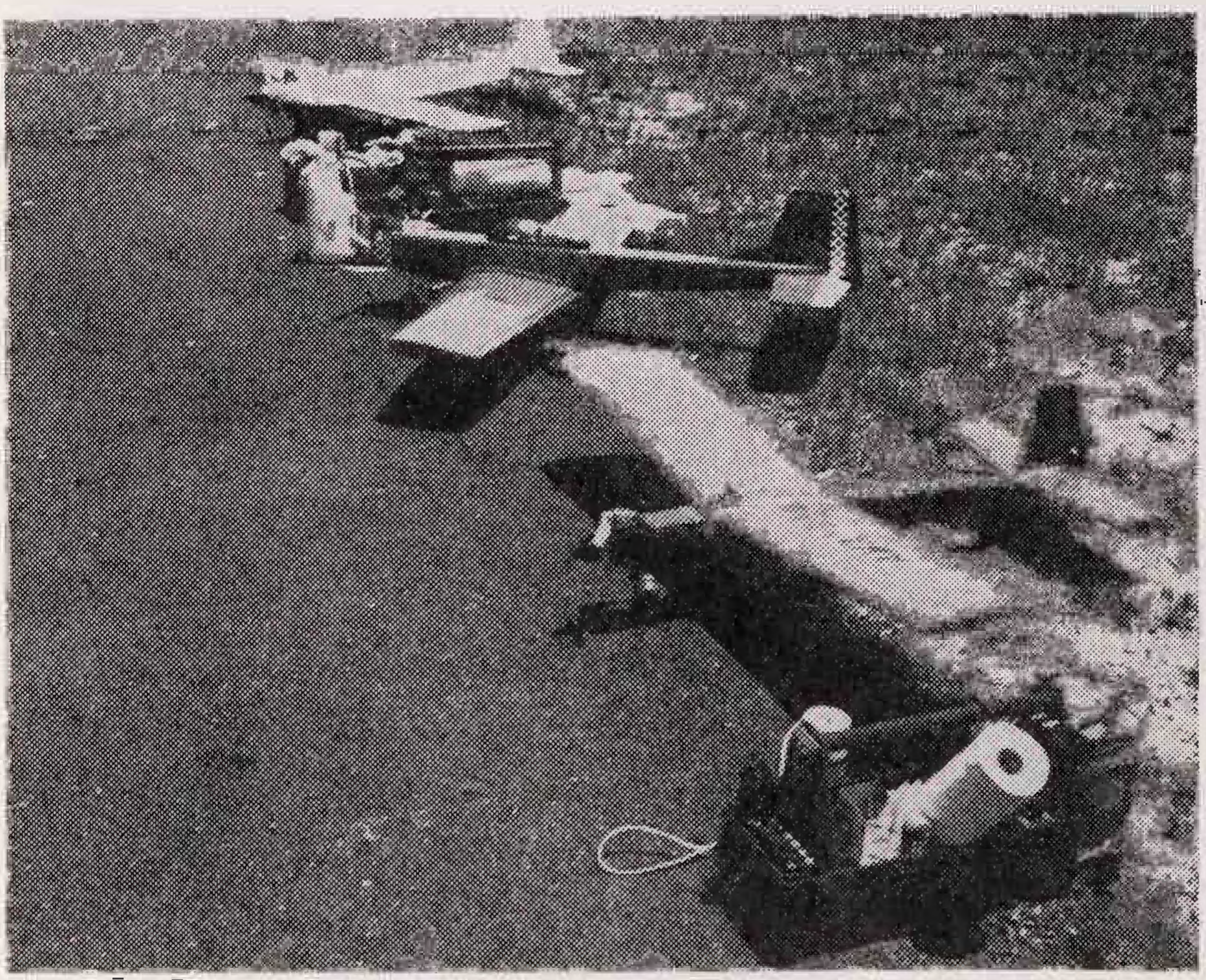


Fig. 9-3. Model planes on side line at local fly-in.

Fig. 9-4. Packing balsa parts in kits. Note bins in background.

Notice that the Colt is more an approximation of the real airplane than the Kadet, which is a slow-flying, very-stable, easy-to-construct model. The Kadet does not have ailerons, and this simplifies the radio-equipment installation. The Colt does have ailerons and is slightly more advanced, but is easy to fly. Another, more-advanced plane is the Kavalier shown in Fig. 9-7.

While we have chosen these three examples to show you, please realize there there are many other manufacturers who also produce fine kits, and so the ultimate choice will be yours, and you will make that choice depending upon what you like to see as a model, the type construction used, the recommendations of other fliers at the hobby field, and you own past experience.

If we were to move to another aircraft seen at times at model flying fields, we might categorize these as Sunday Fliers. These are the funny models which do fly and perform quite well in the air, but are often the subject of amusement or incredulity when seen on the ground. Some such aircraft may be just a small box to mount the radio, servos, and motor, and a single- or dual-spar boom to keep the tail section in place. Sometimes they have names like Ugly Stick etc. You get the idea? But they do fly, are considered "quickies" to assemble, and pose no great loss if they crack up. Sometimes they are the beginning point in this hobby, and there is much to be learned from flying them.

Then there are the beautiful scale-model airplanes, usually the envy of everyone around, models such as in Figs. 9-8 and 9-9. They can be duplicates of almost any big aircraft, even the multiengine 747s or bombers.

Yes, these are more difficult to fly and are not recommended for a beginner unless he has an experienced flier to start him off properly. As you know, modern digital equipment can have a buddy box which permits the learner to fly while the instructor holds the master box. He can take over anytime the student is in trouble. Usually, however, the pilot takes off and flies the airplane to altitude and makes sure it will fly and tries to get the bugs out of trim and control and so on and then the student may take over and fly while the plane is upstairs. When sufficiently proficient, the student may try landings and finally takeoff maneuvers, and so the probability of a crash is drastically decreased. Much time, care, and patience goes into the beautiful results we have shown. Much care and precaution in flying these is usually evident.

The satisfaction of creating and building such scale aircraft is its own reward. It is a pleasure to show them to friends and guests and to relate the flying capabilities and experiences. Try it.

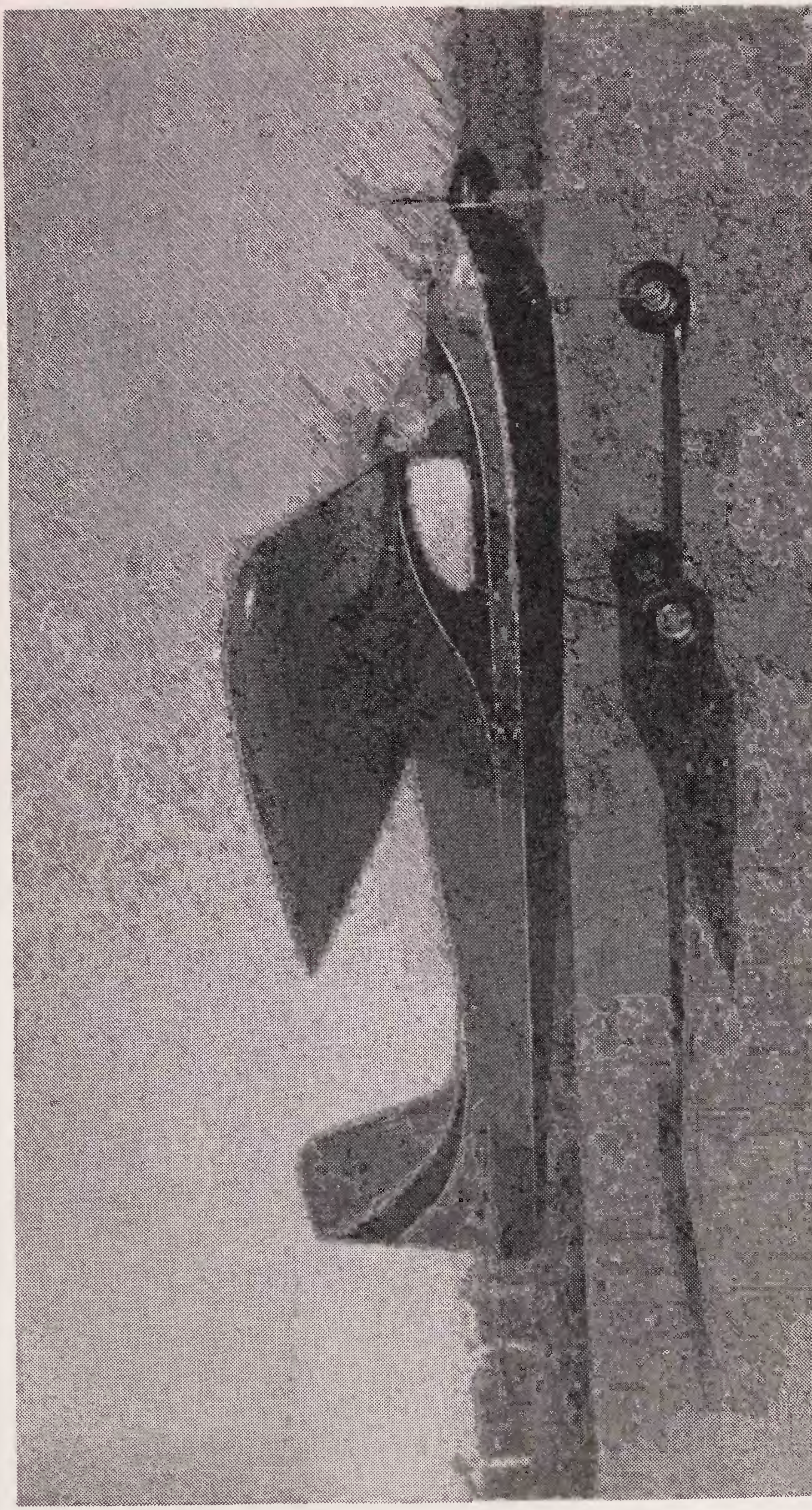


Fig. 9-5. The Sig Kadet Trainer.

Now the next category probably is the pylon racer. These are ultraspecial aircraft flown only by the most daring, quick-reacting, and far-sighted modelers. This group of pilots is a special breed who knows engines, fuel, airplanes, and equipment better than most anyone else. They fly their fast (up to 175 mph) models around spaced pylon towers in racing events sure to cause gasps of amazement (and worry).

We show some pylon racers and discuss them in our book *Advanced Radio Control,* TAB book No. 122. If you are interested in this aspect of model flying we invite your attention to that work.

Finally we might say that the last group is model aircraft already put together, or most all put together; and so you have little to do to make them fly. Some of these come complete with radios in them. Others require that you make the installation. This might be a way to try the hobby if pressed for time or you don't like to fabricate models. You can just fly and have fun.

So you see there is a model aircraft for everyone, and even with the kits, some modelers like to add a little here and a little there, to adjust and change, making the design his own. That, too, is fun, and you learn a lot about aeronautics when you do this, and you can't get far off because you probably have started with a flying airplane to begin with. When you have been in the fun contests (see *Flying Model Airplanes and Helicopters by Radio,* TAB book No. 825) you will imagine some changes to make in your own model to make it do better what the judges have decided you must do during the contest. Try it, you'll like it.

Some good rules-of-thumb in selecting a model are: Weigh the equipment you plan to install in the model, including the batteries. Note how much this is in ounces. Look over the models, select one and note its weight in ounces (usually specified on the box). Add the two weights. Now determine the wing area (width times length) in square inches divide this by 144 to convert to square feet. Divide the total ounces by the number of square feet. If this figure is less than 14, the model will be suitable; if the figure is over 14, then don't try it if you are a beginner. Choose another model.

This 14 means that the wing loading is 14 ounces per square foot of wing area. A loading of 12 ounces is better if you live at high altitudes, say 7,000 feet, or you might use 17 ounces at sea level.

Now for the motor size. This is recommended by the manufacturer of the model or kit, but we also have a rule-of-thumb that works quite well: 1 cubic inch displacement for each 200 ounces of model weight. Thus, for a 4-pound airplane (model plus equipment):

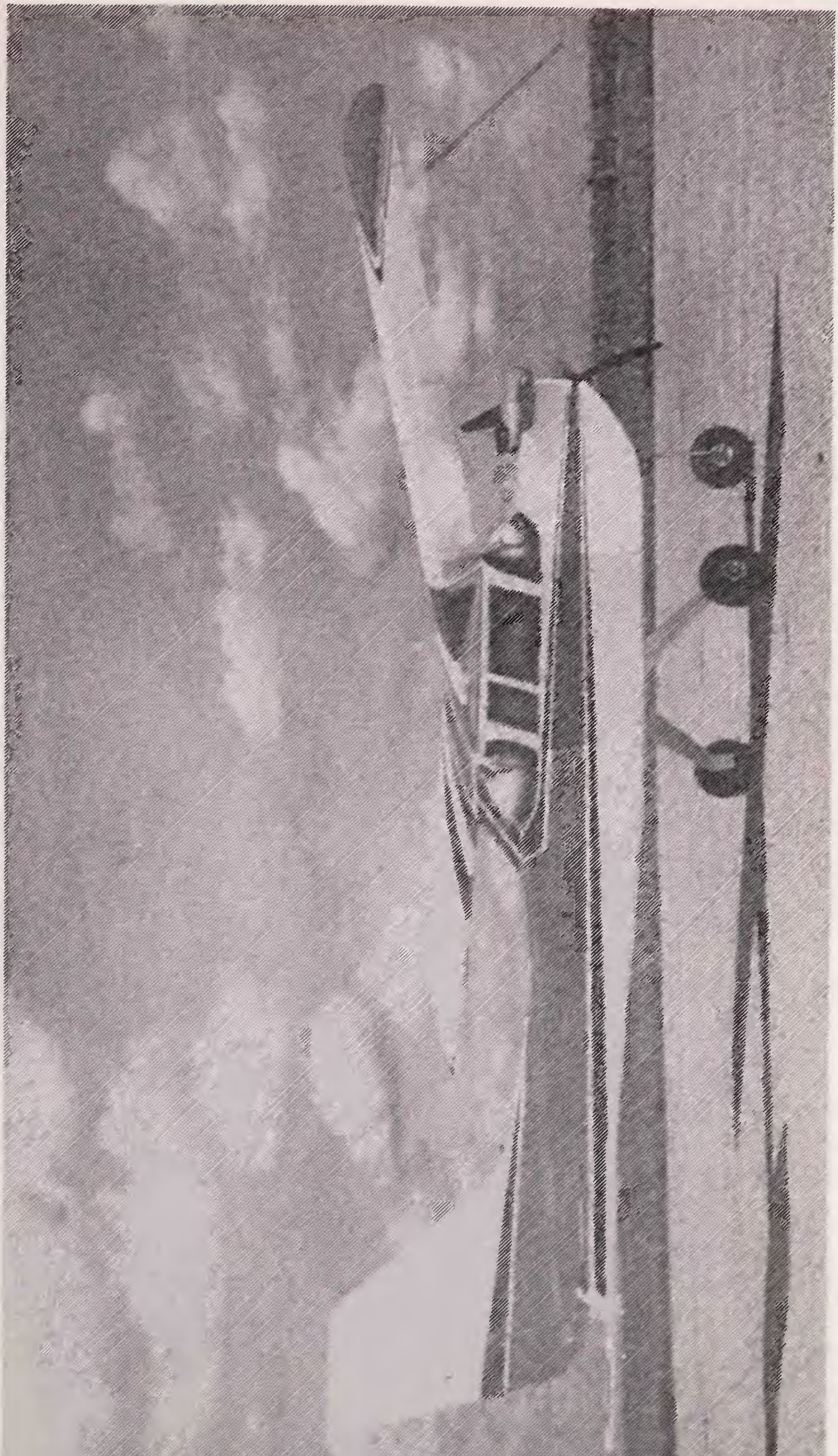


Fig. 9-6. The Sig Colt Trainer.

$4 \times 16 = 64$ ounces and 64/200 times 1 gives a .32 engine. You could use a so-called 29 or 35 motor.

The propellers should be large and of low pitch; lengths of 10, 11 or 12 inches are common. The pitch may vary from 3 to 5 inches. Pitch means how far the propeller would go per revolution if it were screwed into a solid substance.

We might generally list the features we would want as:

1. Large enough cabin space to accommodate our equipment (Fig. 9-1) and easy access to this equipment once installed.
2. A wing large enough that the wing loading is 14 ounces per square foot of wing area (or very close to that figure).
3. Good dihedral (the V bend to the wing) and a high-wing type—these contribute to the model's flight stability.
4. A strong tail wheel high enough off the ground that the tail surfaces won't be damaged on normal "one-wheel" landings.
5. A strongly-constructed wing that withstands warping and the strain of violent maneuvers. (We may not command these, but sometimes the model gets into them on its own!)
6. A good strong nose section that can withstand "noseover" landings.
7. A landing gear strong enough to withstand landings without damage to itself or the model.
8. Large enough wheels that they won't dig in on ground takeoffs or landings.

BUILDING THE MODEL

Examine Figs. 9-10, 9-11.

Follow the plans. Use silk, nylon, or monocote for the covering. Use a good strong glue. The ultra-quick-drying kind usually results in a model that won't last. Use a glue that penetrates the wood before it dries, making a very strong bond. Use the recommended type.

Make absolutely certain there are no warps in the wing or tail structures before you cover them. Lay the wing on a flat board, holding one end up slightly, and see if it's warped. If necessary, break the glue joints and do it over. Don't try to fly a model with warped wings.

In covering, keep the grain of the cloth parallel to the leading edge of the wing. If you cross-grain, warping will result as the dope dries.

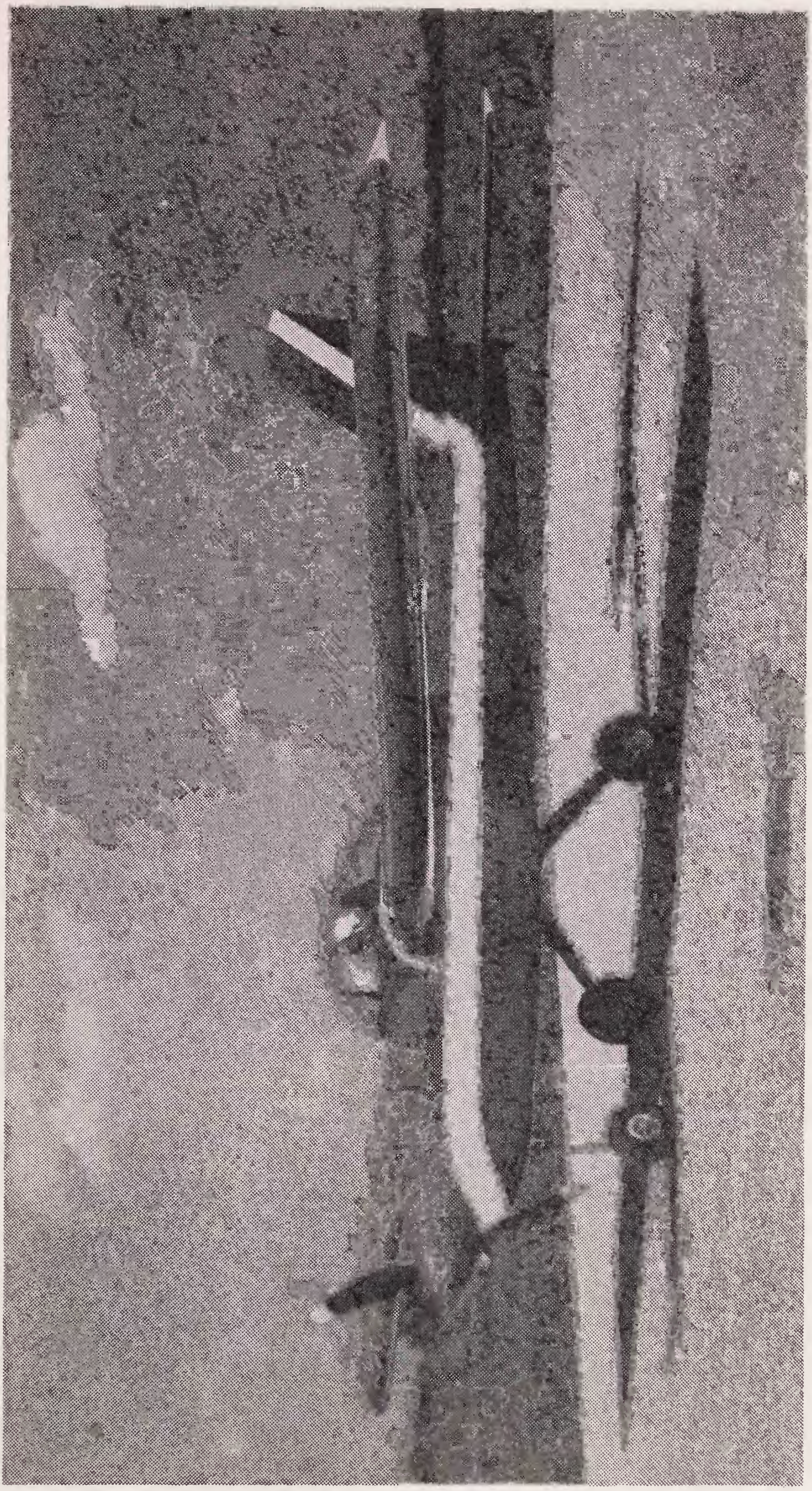


Fig. 9-7. The SIG Kavalier.

After constructing the wing, balance it. This is done by setting it on a straightedge running crosswise to its center and adding weights to the tips (if necessary) to get as perfect a static balance as possible.

RADIO INSTALLATION

With modern equipment the receiver has its antenna already attached. It is usually a flexible strand of wire, but sometimes a rigid piece like piano wire. In any event, do not shorten or lengthen this antenna. It is very critical in length and must not be changed. Do not double it back on itself in the body, and keep it away as far as possible from all rods, machinery, radio gear, etc. as possible. It is common to run it out of the cabin and back to the top of the tail, allowing any excess to trail loosely back out in space behind the rudder. Make sure it won't tangle in the rudder, however.

There are many ways in which the radio equipment can be placed in the model. Most kits show a recommended installation right on the plans. One installation we made using the Logictrol equipment is shown in Figs. 9-12 and 9-13.

In models in which the appearance of the antenna may mar the beauty of the aircraft, the antenna is kept inside the body or run along one corner under the silk, nylon, or monocoat covering. It can be hidden just so long as you keep it straight and do not change its length. It might even be placed in a wing. Use a tiny, but positive connector to connect it to the radio. But do not corner under the silk, nylon, or monocoat covering. It can be hidden just so long as you keep it straight and do not change its length. It might even be placed in a wing. Use a tiny, but positive connector to connect it to the radio. But do not cable it into the aileron servo cables or any other cables in the installation. Keep it separated.

ADJUSTMENT AND TESTING

Of course your kit instructions generally give you this kind of information. Check them out and be sure they do include this. But in general here is what goes on after the model is built and the radio installed.

You have now covered the fuselage with silk or nylon or monocoat, and you have installed the linkages as well as the escapement. We can now begin preliminary tests and make initial adjustments, so that when we install our radio-control equipment and make that first flight (that's the one we sweat out!), the chances of success will far outweigh those of failure.

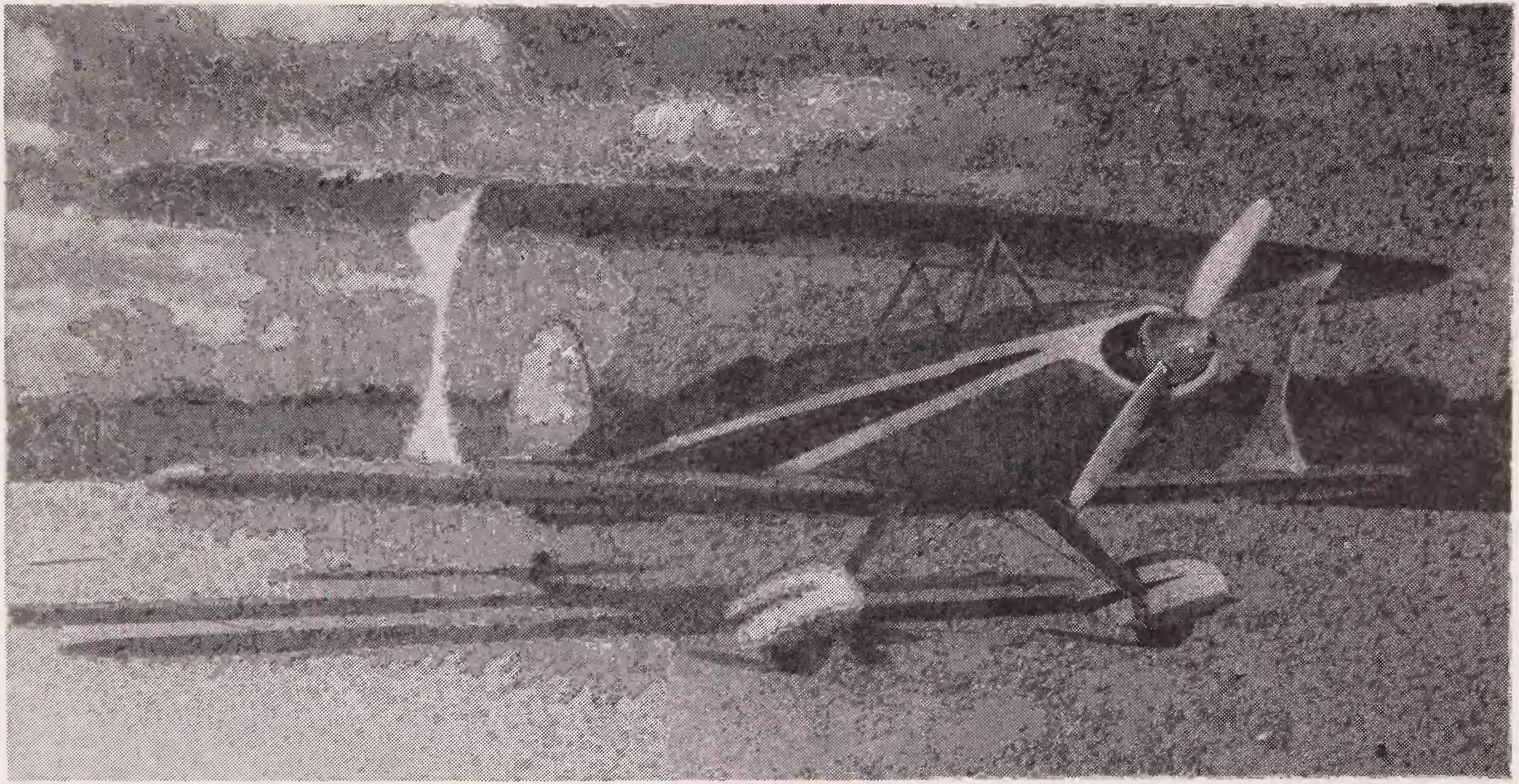


Fig. 9-8. Sig Steen Skybolt. Sport Design by Claude McCullough.

Since we have chosen a model capable of carrying a reasonable payload, if we glide-test it without the payload it should just about float through the air. We plan to do this and expect no damage, even if the first few glides are not perfect. However, the first step is to locate the center of balance.

Fasten the wings and tail surfaces in place according to the plans furnished with the kit. Mount the motor and wrap it with a piece of cloth or plastic to keep our dirt. Do *not* put on the propeller. Now locate the center of balance. For this, ask a friend to help. Each of you will take a wing tip. Hold the model with one finger and move it along the end of the wing until the body of the plane is horizontal. Make certain that the wing is not on crooked. Check by measuring with a string from the tip of the tail to the rear corner of each wing tip. The distance should be the same. The model should balance at about one-fourth to one-third of the wing width back from the front (leading) edge. If it doesn't, add weight in the payload compartment until it does. Mark this line of balance across the top of the fuselage with a pencil.

Now take a 12-inch length of good heavy twine. Tie one end to a hook set into the body exactly in the center of the width of the fuselage at the point where the leading edge of the wing crosses the fuselage. Make a second fastening just behind the wing, also in the center of the width of the fuselage. You will now be able to raise the model by this string and, using a hook placed just above the front-rear balance line, adjust its position until the model is level. Note the side balance. Does one wing end to drop? If so, add weights to the high wing until the model is balanced on its longitudinal axis. The model is now ready for the test glide.

Pin the movable surfaces so they are exactly in line with the fixed portion. Select a day when there is as little wind as possible. Grasp the model just behind the balance point underneath the cabin. Hold it up just higher than your head. As you run forward, you'll feel it begin to lift in your hand. Now, *push it forward toward a point on the ground about 50 feet ahead and let it go.*

The airplane should glide down toward this point in a smooth, flat glide. If it doesn't, it may try to climb and then suddenly drop; it may veer sharply or graudally to the right or left; or it could drop very sharply with no glide.

If it tends to rise and then drop, raise the rear edge of the wing and place about a 1/16-inch piece of balsa underneath it. Try it again. If it still "balloons," use another strip.

If it tends to drop sharply, raise the leading edge, using the same procedure. If it should veer somewhat sharply to either side,

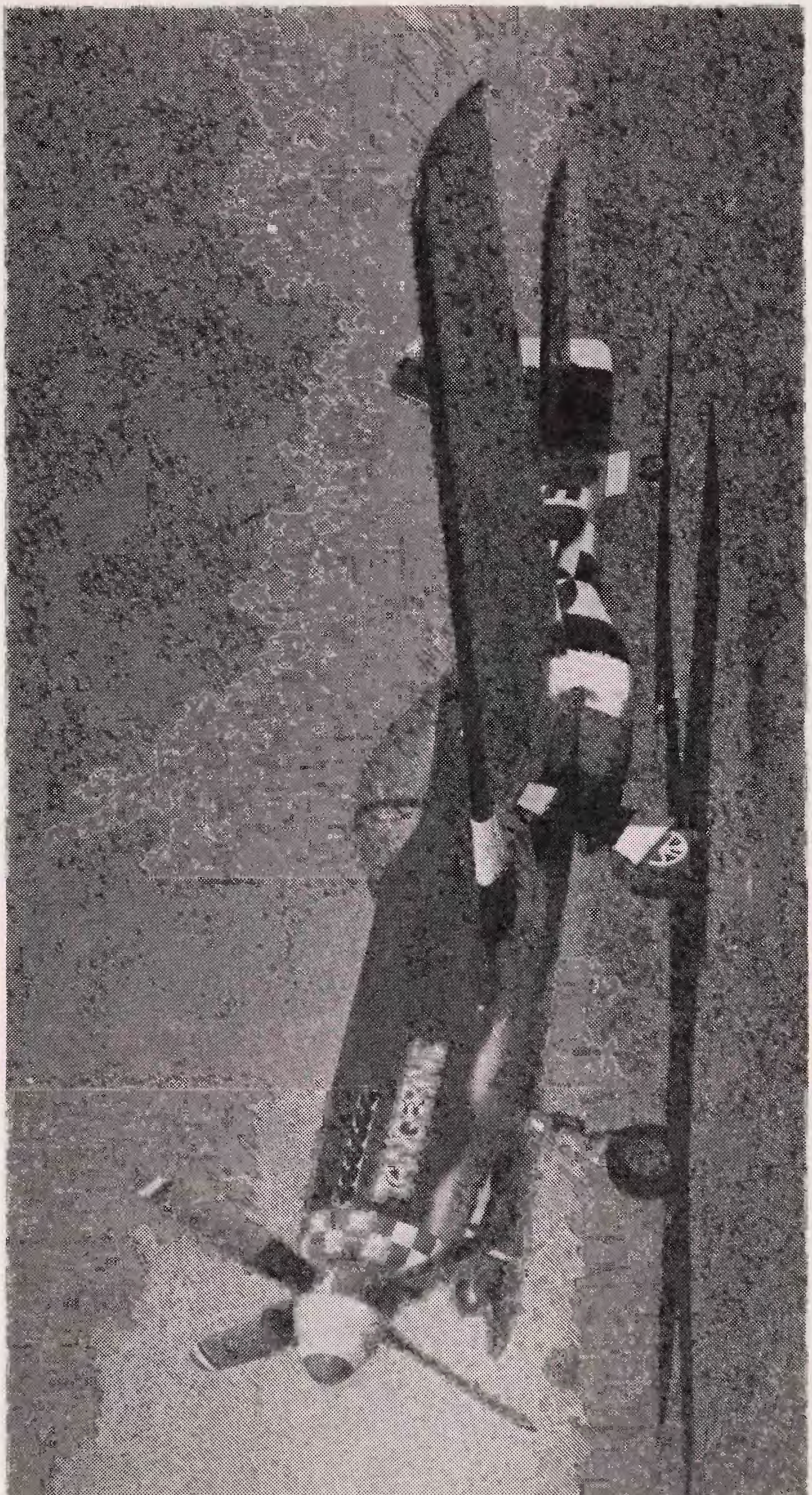


Fig. 9-9. Sig. P-51 Mustang: Tangerine.

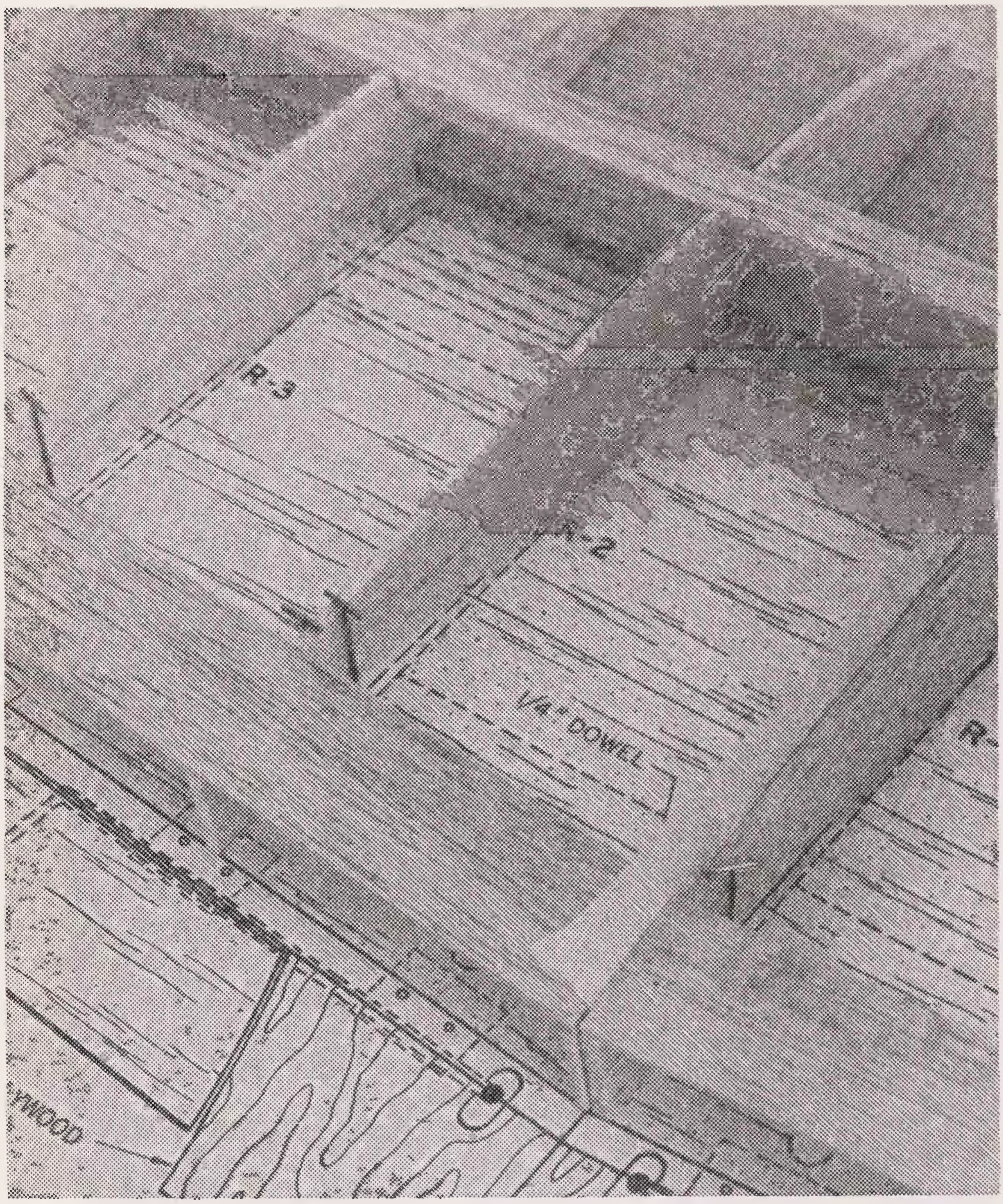


Fig. 9-10. Position the model pieces directly onto the plans.

check the position of the wing to make certain it is on straight. Check the horizontal part of the tail assembly to make certain it is level. If these are okay then remove the pin holding the rudder in place. Repin it so the rudder has an angle of about 10° from the fixed part, and is turned in the opposite direction the model turned. Test again and adjust the rudder until the model glides straight.

If you find this takes an excessive amount of rudder, say 30° or so, check the wing for warps and the vertical tail surface for misalignment with the center fuselage line. *Do not try to fly your model under power until you get a good straight glide.* The model may not float in the glide, but this is all right as long as the glide is straight and reasonably flat (on a flat glide, the model would go straight down the line from your eye to that point 50 feet ahead on the ground). *Never* try to *throw* the model either up or straight ahead. *Push* it, and always toward that same point on the ground.

There are two schools of thought on this phase of testing a model. One says "fly it, the control will take care of possible trouble." The other says, "test glide it, there's enough to do to fly it without asking for trouble." I agree with this second point of view.

Even if the model is damaged in the test-gliding phase, damage will always be slight compared to a full-powered crash.

Now that the model has been checked without the radio receiver and batteries, install them and maintain the same balance. Put heavy sponge-rubber cushion around the receiver or foam in some installations. This not only prevents damage to the radio equipment, but also protects it from trouble due to motor vibration. If you test-glide the model now, the glide will be steeper and faster due to the increased weight. That's all right so long as it is straight. After you complete the first test-glide phase, run the motor and send signals to make certain the equipment operates satisfactorily with the motor running. In case of vibration trouble, check all connections. If you have a bad cable joint, it will come apart during this phase of testing.

The best method of connecting the batteries to the switch and the receiver is by soldering all wires.

Now we're ready to fly! Choose a low-pitched propeller (3-to-4-inch pitch) 10 to 12 inches in diameter (the kit will recommend one). Make certain that the motor has some "down thrust" ... that is, the line of the motor shaft should run back to a point as high as the tail surface and about three inches to the right, as we look at the model from the nose. This offset to the right is called side thrust. Now rev up the motor, making sure it's running smoothly and steadily. Put

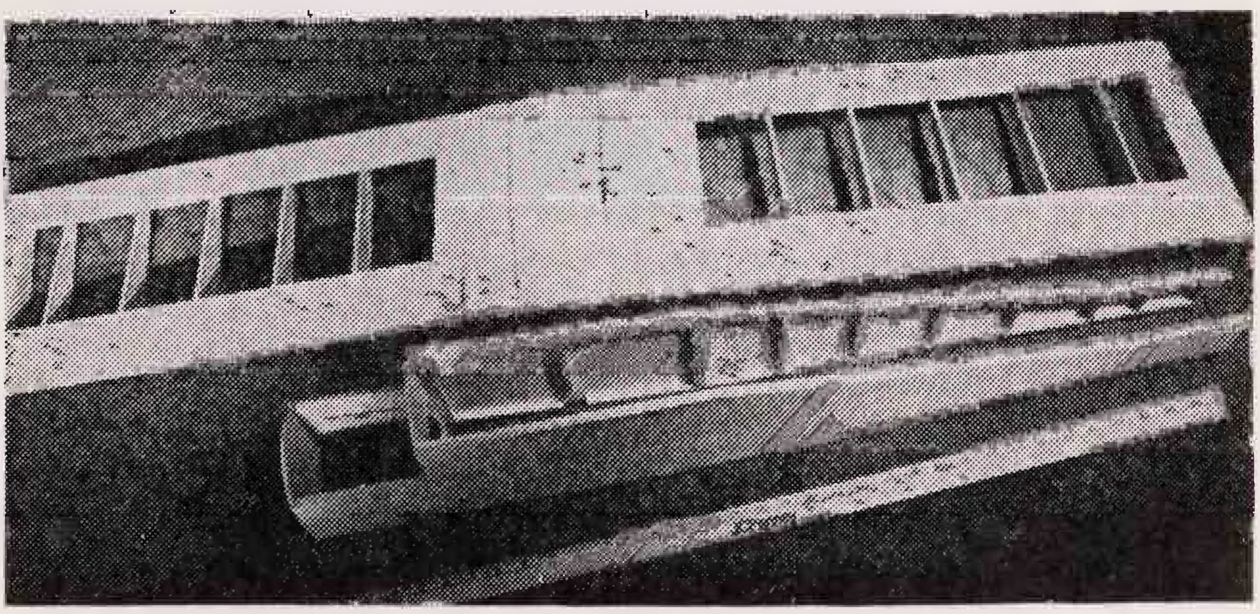


Fig. 9-11. Make wiring strong and eliminate warps. This SIG Kadet has an easy to assemble fuselage.

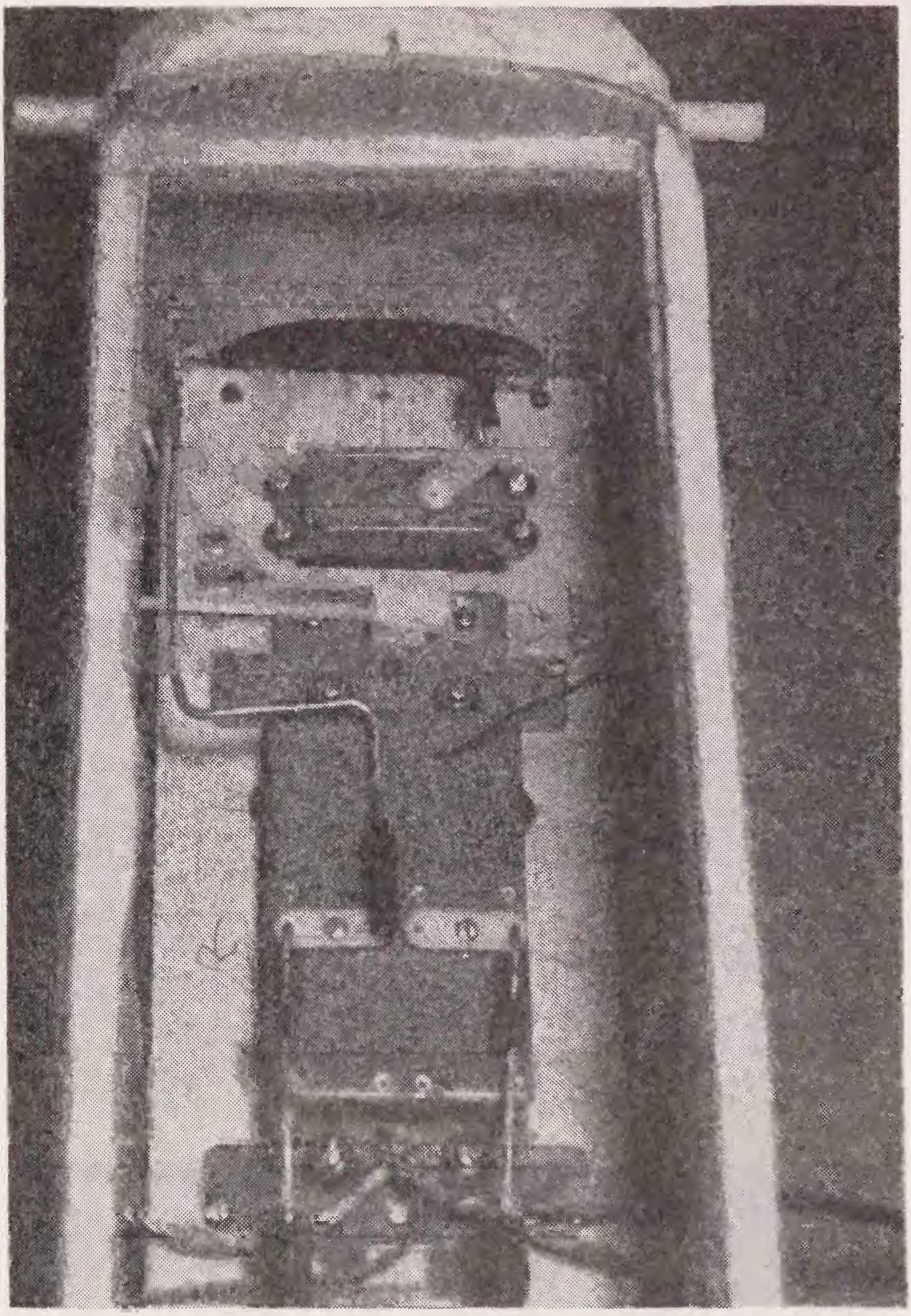


Fig. 9-12. A radio installation, the forward servo controls the throttle and the two push rods going to the rear are for rudder and elevator control. The two servos for R and E are in the same package with the receiver making a neat and simple installation. Note cables going to batteries which are forward and underneath this installation.

the model on a smooth runway if possible and let it go, headed into the wind. It may take off right from the ground. Try this first if you can using the philosophy that if it takes off, it will fly correctly.

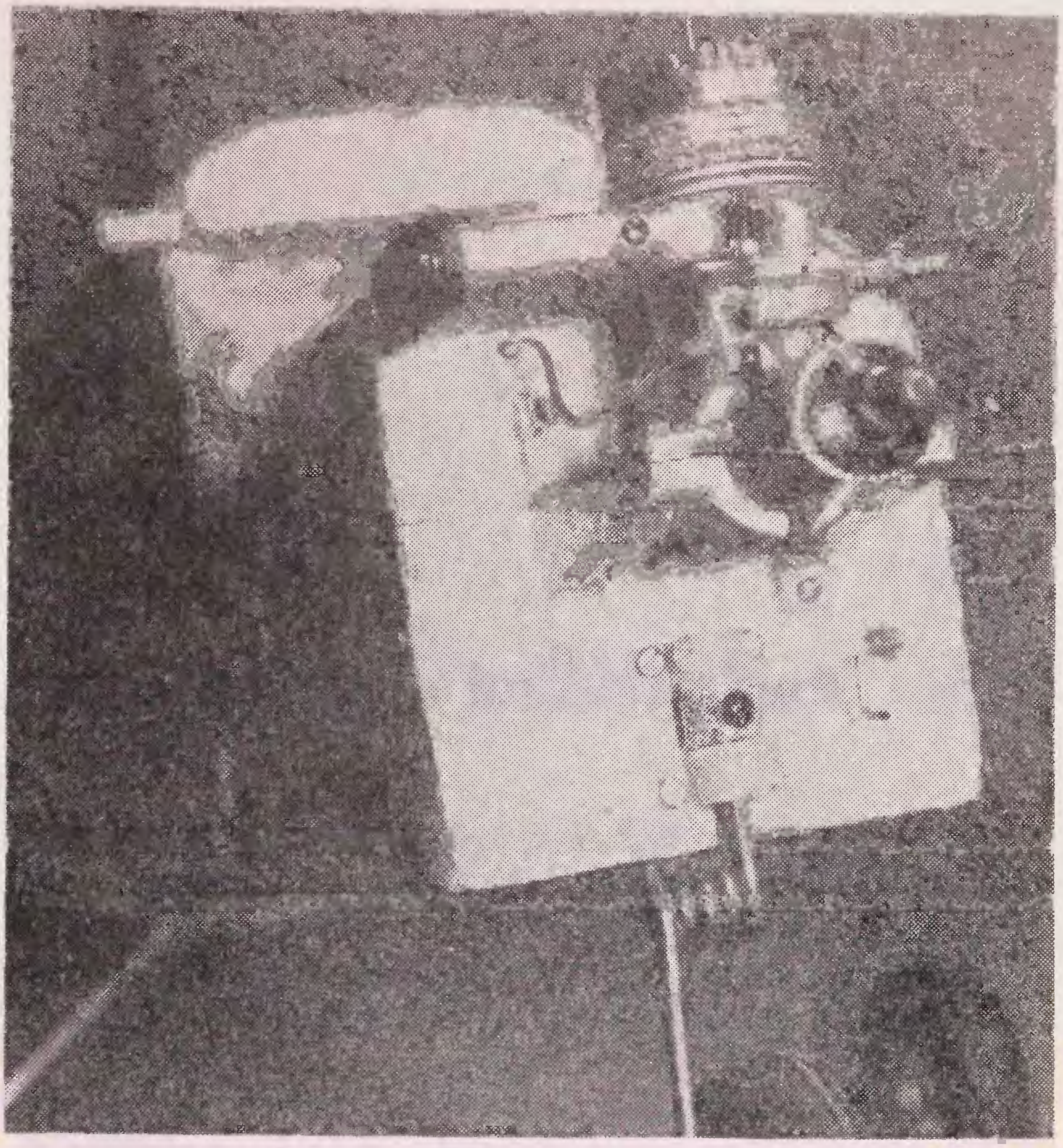
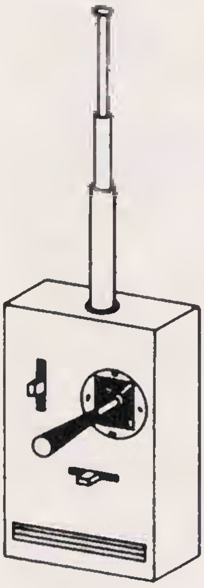


Fig. 9-13. Nose wheel and throttle linkage. Some details of the nose wheel steering push wire which is attached to the rudder servo arm, and some details of the throttle control push wire.

If it doesn't take off, then launch it exactly as you did in the test-glide phase. Try to let it gain at least 75 feet of altitude before you send a signal, unless the model turns so sharply that you think it's going to dive in. Then, of course, send a corrective signal (remember all that practice!) Keep it circling around you until the motor fuel is exhausted (you will have put in only 2 minutes worth of fuel), then circle around and land into the wind.

We should mention that it is now customary to fly the model right off the strip. Since you have engine control and have checked it out by taxiing around the concrete or whatever, you can get the model into position, advance the throttle, and let it gain full speed. It will take off, or you might have to give it just a little up elevator, but be careful. Get an experienced pilot to help you at this stage.



10
Radio Control of Model Cars

There is a lot of fun and high degree of skill when you radio control your model racer in a sporting event. Like model-airplane Sunday flying, this is to be found almost everywhere nowadays, especially in the mall parking areas of cities. Of course school grounds, parks or anywhere that you can get a relative smooth surface will do for these big events.

Not only can you radio control a racer, but you can also have realistic tank battles, in which the tanks might fire projectiles or launch rockets. Or you might haul items with model trucks, and through a more elaborate radio-control system, load and unload cargo. Naturally you will want lights, brakes, door openings, horns and so on in your model vehicle; this makes a lot of fun in the construction and imagination and working out of the control capabilities.

CAR KITS

It is possible to find almost any kind of car kit and finished cars at toy stores, model shops, and hobby-supply houses. Prices range from \$7 or \$8 for a very simple little electric-powered model to as high as \$500 to \$800 for a scale-model racer with just about everything. Of course these prices include the radio-control equipment and all accessories.

We won't try to give you all there is to know about model cars in this chapter. We already have seen some cars in the chapter on servos; we will expand on that to show you how you might build a

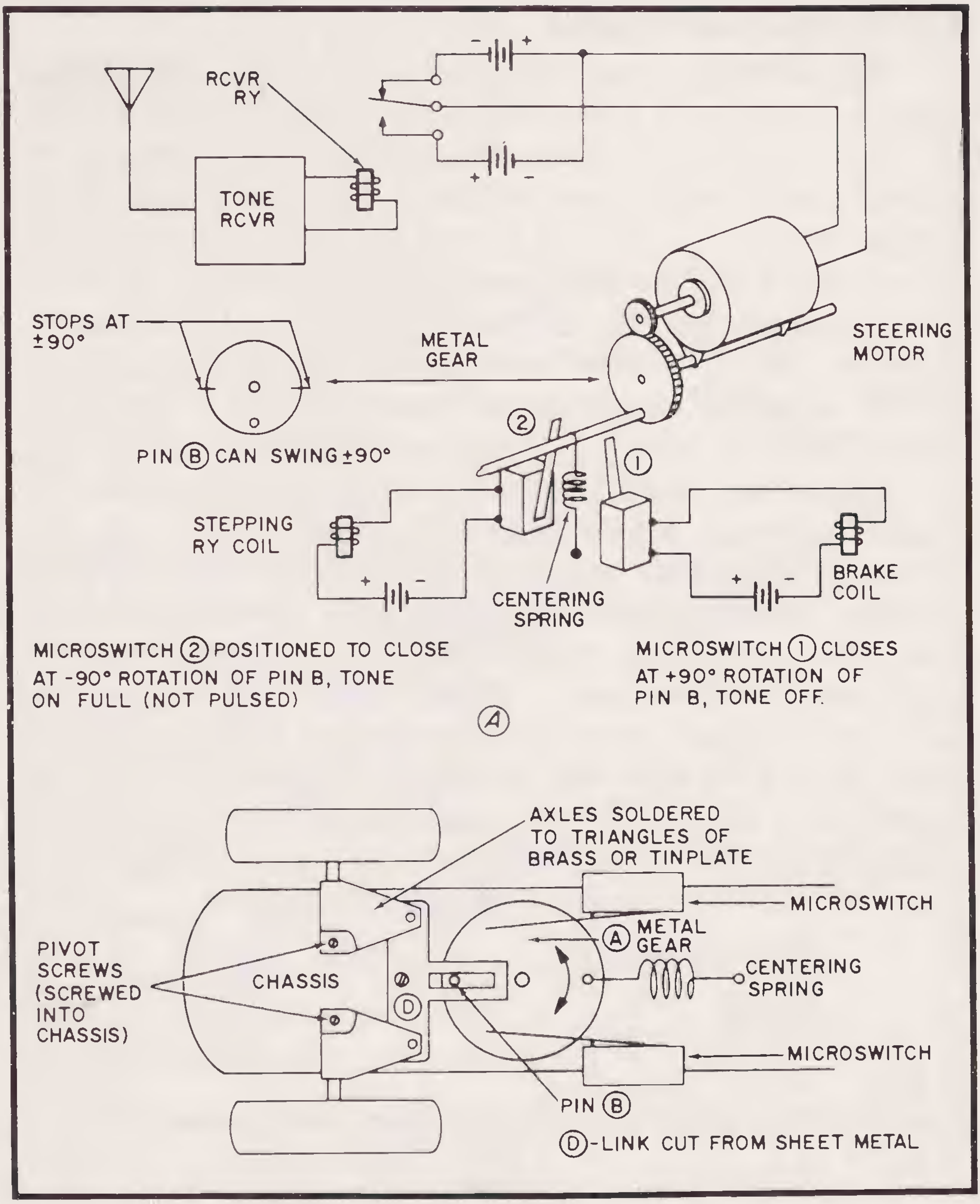


Fig. 10-1. The basic pulse-control system for model cars.

simple model car, use it with a radio-control system constructed from circuits previously given, and then show you just a little of the model-car racing world as it now exists. In *Model Radio-Control*, we go into model cars in much more detail, an expansion of information found here; so, if this be your pleasure, take a look at that work.

Model-car racing and control is a big sport. There are national events with them just as there are with airplanes and boats, although car events are not as well known. If you investigate through your hobby shop, dealers, or supply houses you can find out the location and time of these events and perhaps participate. Meet the challenge of the other race drivers and equipment. See if you can return home with one of those priceless trophies.

A BASIC MODEL-CAR SYSTEM

Now, let's look at some pictures to see how we would control a model car—a racer or sporty town car. Examine Fig. 10-1.

The output of the receiver is connected to a relay (or the receiver relay is used) to pulse the voltage from two batteries to the steering motor. This motor is geared down and has a centering spring; it works just like the systems explained earlier in this book. Notice, however, that two microswitches with long lever arms are used. One will be actuated when the tone is sent continuously because the pin on the driven gear will depress its lever. The other is actuated when the tone is not being transmitted.

When a tone is sent continuously, the on microswitch (No. 2 in Fig. 10-1) is closed. It in turn operates a stepping relay of, say, four contacts (available from many radio parts houses) that is cyclic in operation. The ON tone starts the drive motor, and it keeps running while steering (pulsing) is transmitted. To stop the drive motor you simply send the On tone again. Further, the next time you send the full On tone, the drive motor starts, but this time, if you've wired the circuit suitably, the motor runs in reverse so you can back up. The next ON tone gives OFF again, and the one after that cycles the system back to forward drive. Thus you will cycle through these operations (see *Model Radio Control* TAB No. 74):

1st on—forward
2nd on—stop
3rd on—reverse
4th on—stop

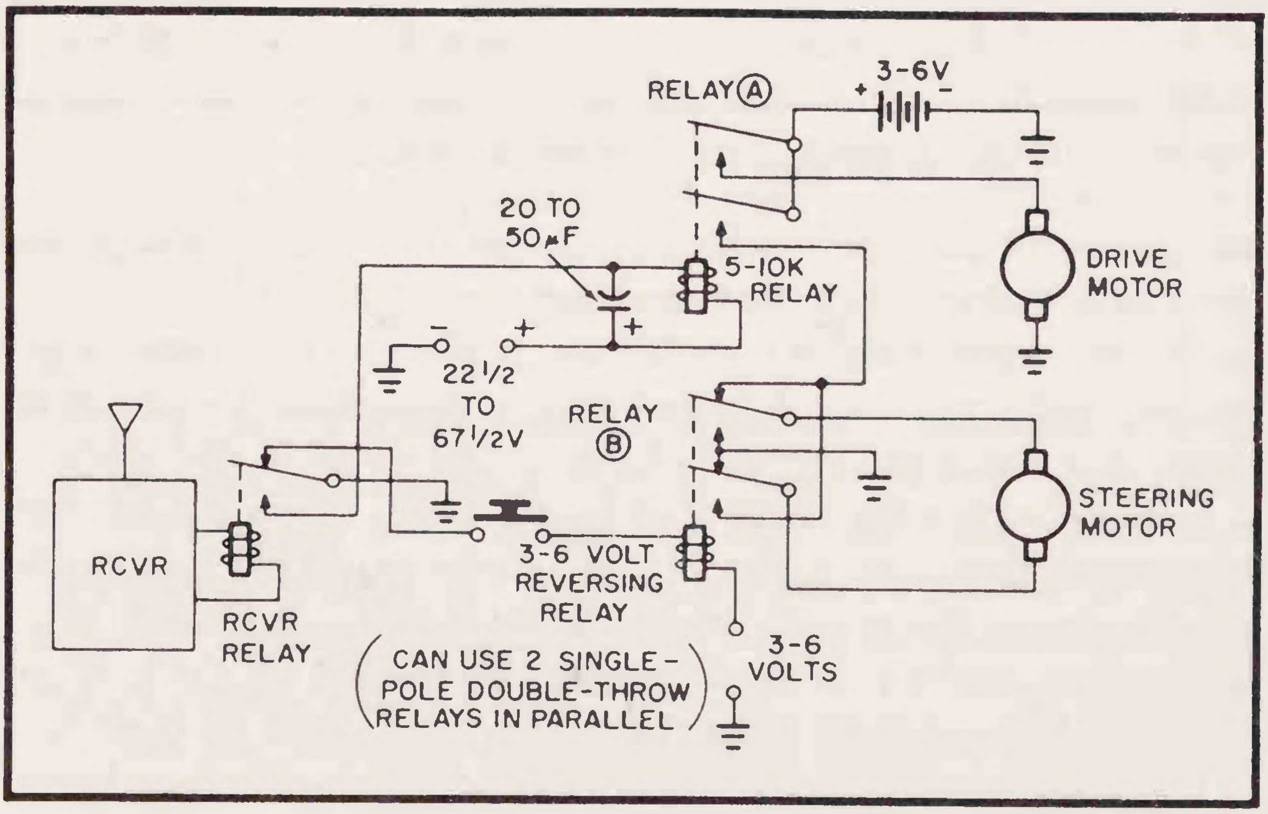


Fig. 10-2. A simple forward-run and steering system.

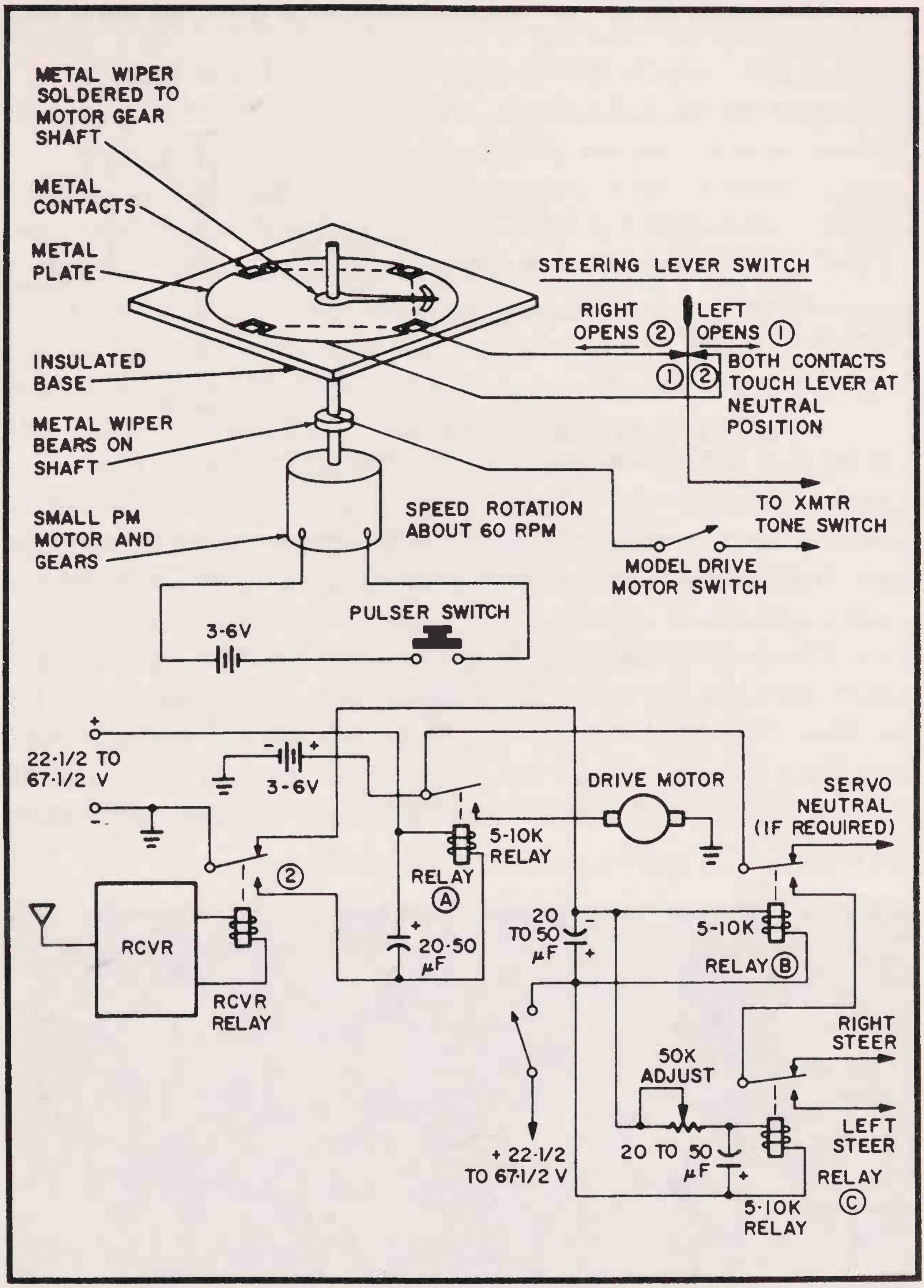


Fig. 10-3. A system for a commercial-type servo.

and then the cycle repeats. You can get a four-contact stepper relay by specifying it by this description from radio-parts houses.

In Fig. 10-1 you can see also how the steering motor is connected to the front-wheel linkage by two small metal triangles that have axles soldered to them, and a slotted T-plate in which the steering-motor pin (B) is fitted. The two microswitches are positioned so their levers are moved by pin B when it is rotated to the 90° position in either direction.

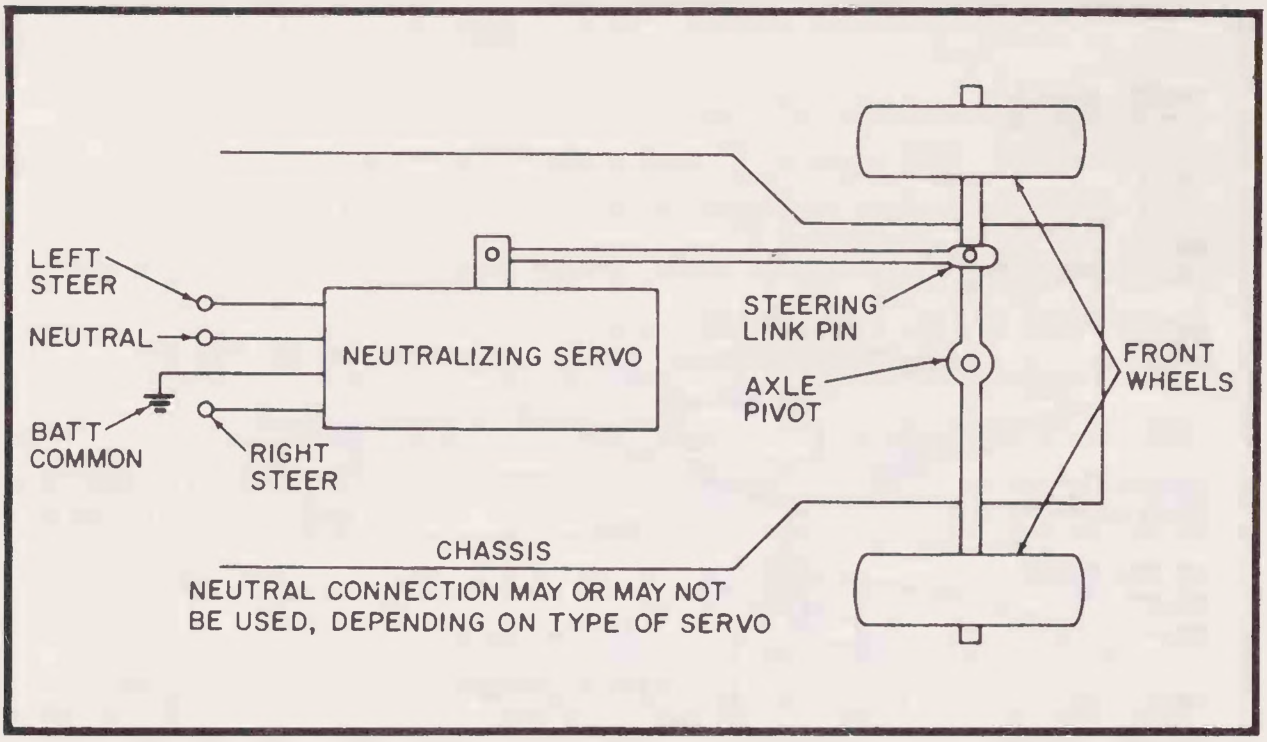


Fig. 10-4. Connections and placement of the self neutralizing servo in the model.

The second microswitch applied brake power by closing a circuit to a braking unit. Model shops have such brake units for model aircraft, and they can be used in model cars. You might need one if you approach a turn too fast and want to slow down slightly without going through the cycle of stopping and restarting your drive motor.

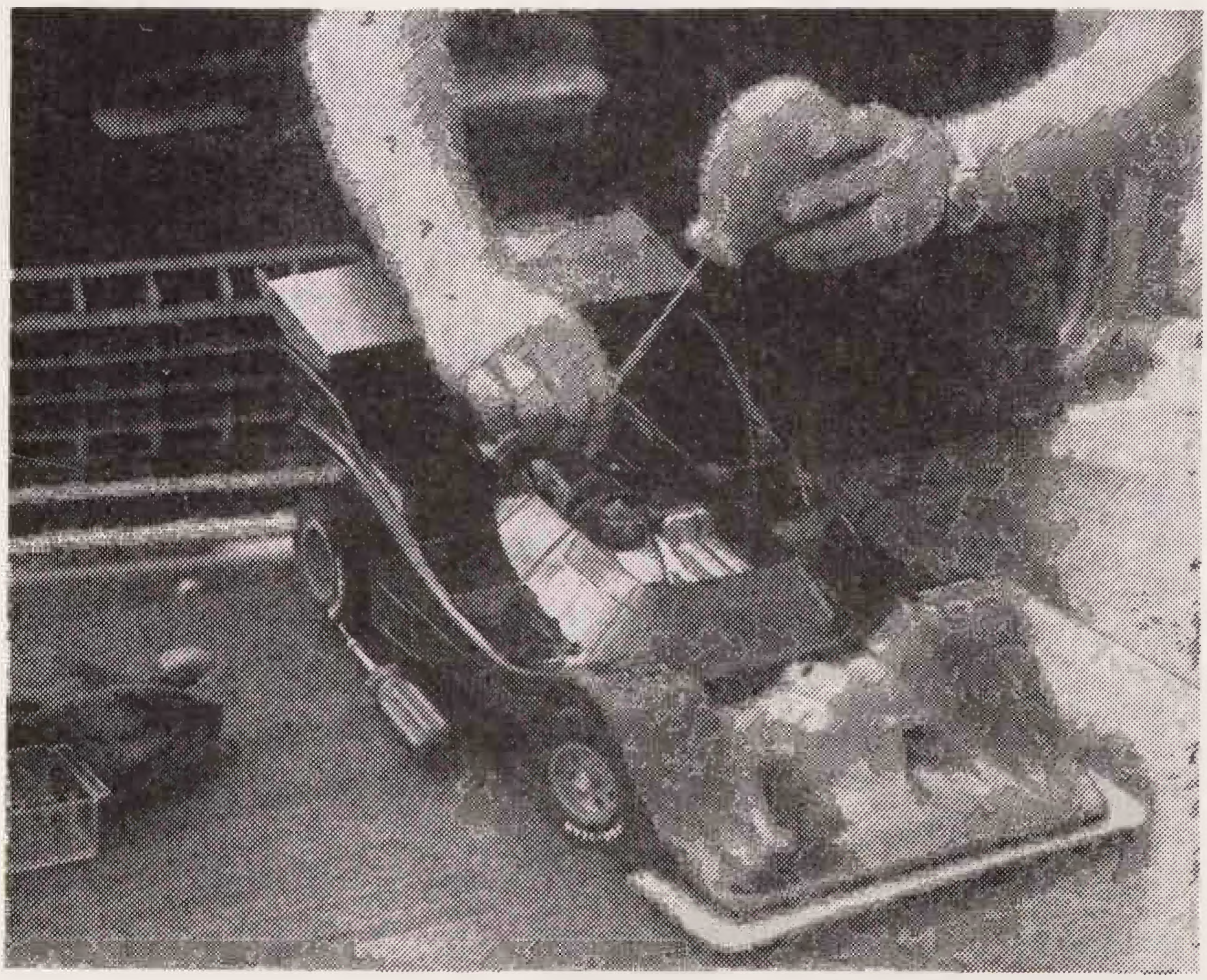


Fig. 10-5. A modern racing model being fueled.

A SECOND SYSTEM FOR MODEL CARS

This system, Fig. 10-2, is really a little simpler than the first one. Only the radio receiver and a couple of relays are required.

When you send a pulsing signal to the model, the time delay on relay A keeps it closed as long as pulses are being received, causing the model to go forward. Relay B will pulse in step with the receiver relay; as it pulses, it applies a reverse voltage to the steering motor. (This relay must be a double-pole double-throw type, or two single-pole double-throw relays wired in parallel as indicated.) So when a pulsed tone signal is received the steering motor steers according to the width—spacing idea.

You can use any of the pulse-width-pulse-spacing devices described earlier. You can then start the model, by starting the pulsing, steer the model by varying the pulse width and spacing, and stop the model by stopping the pulsing. Notice the switch in the relay-B line. Turn this switch off immediately when you stop the pulsing, otherwise you run the battery down. The steering motor can be the same as described in Fig. 10-1. A pulse-width-spacing transmitter and receivers are made by Ace R/C.

A SYSTEM USING A STEERING SERVO

This system requires that you transmit one of the following types of signals for control; a series of narrow pulses, widely spaced for steering right; a series of wide pulses, narrowly spaced for steering left; full tone for drive motor forward, and no tone for drive motor off.

When you close the drive-motor switch at the transmitter, the tone is transmitted continuously because the steering level switch (Fig. 10-3) has connected both the large and small segments of the rotating pulser-arm unit together. When you push the steering lever to the right, the circuit to the large segments (metal plate) opens so that the only time the tone is sent is when the rotating arm is on the small metal tabs. If the steering lever is moved in the opposite direction (left), the circuit to the tabs is opened and the tone is transmitted only when the arm is on the wide metal-plate segments.

In the model, the pulse causes relay A (Fig. 10-3b) to close and remain closed (because of its time constant). Thus the model's model drive motor operates as soon as a continuous *or* pulsed tone is received. When narrow pulses are received, relay B also closes, but relay C does not because of its delay circuit, consisting of R and the 20- to 50-μF capacitor across its winding. This means the voltage from the battery will be routed to one servo terminal (see Fig. 10-4).

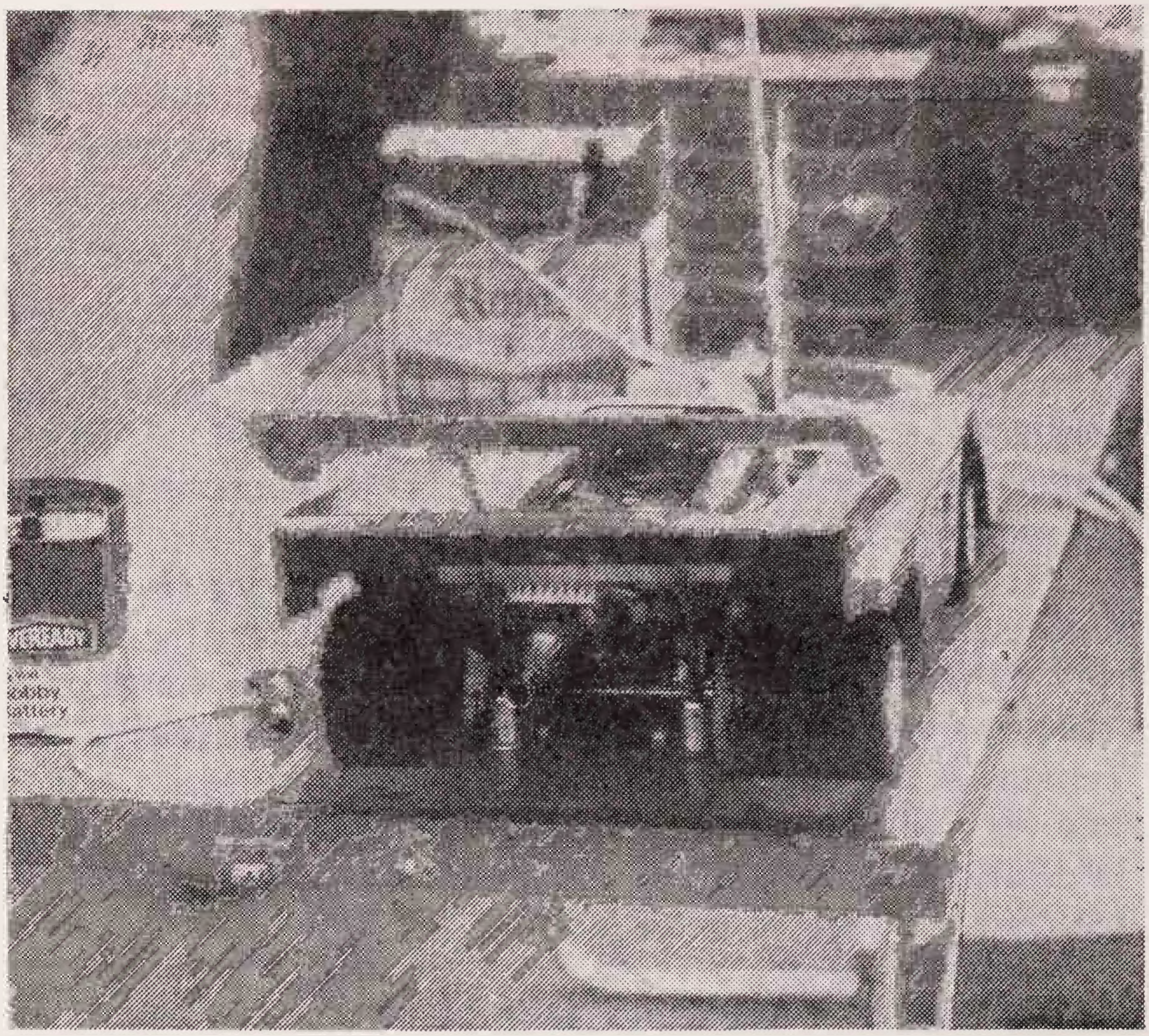


Fig. 10-6. Rear view of model car.

When wide pulses are transmitted, *both* relay B and C will close (if you adjust R properly) and thus the voltage from the battery is routed to the second servo connection. Now you have left steering. When a constant one is transmitted, the receiver relay is closed against contact 2 (Fig. 10-3b) so that only relay A is energized. Also, since the deenergized position of relay B connects the voltage to the neutral terminal of the servo, the result when a continuous tone is transmitted is that the model runs straight ahead. Here, again, you will want to incorporate a switch so you can disconnect the batteries when the model is not operating and avoid running them down. This is a slower-acting system, but it is simple and great fun to use.

Make a mental note that most toy automobiles have a little transmitter which is hand held, and they use a small receiver in the model which usually has a small relay as part of its construction. You might get one of these and use them in the system just described. Most regular radio-control systems available nowadays do not have relays as their output element. You need to obtain one to use with such systems as the Wee-1 single channel transmitter and receiver available from Ace R/C, or use one from a toy model as we have just mentioned. The difference between the two will be that the Wee-1

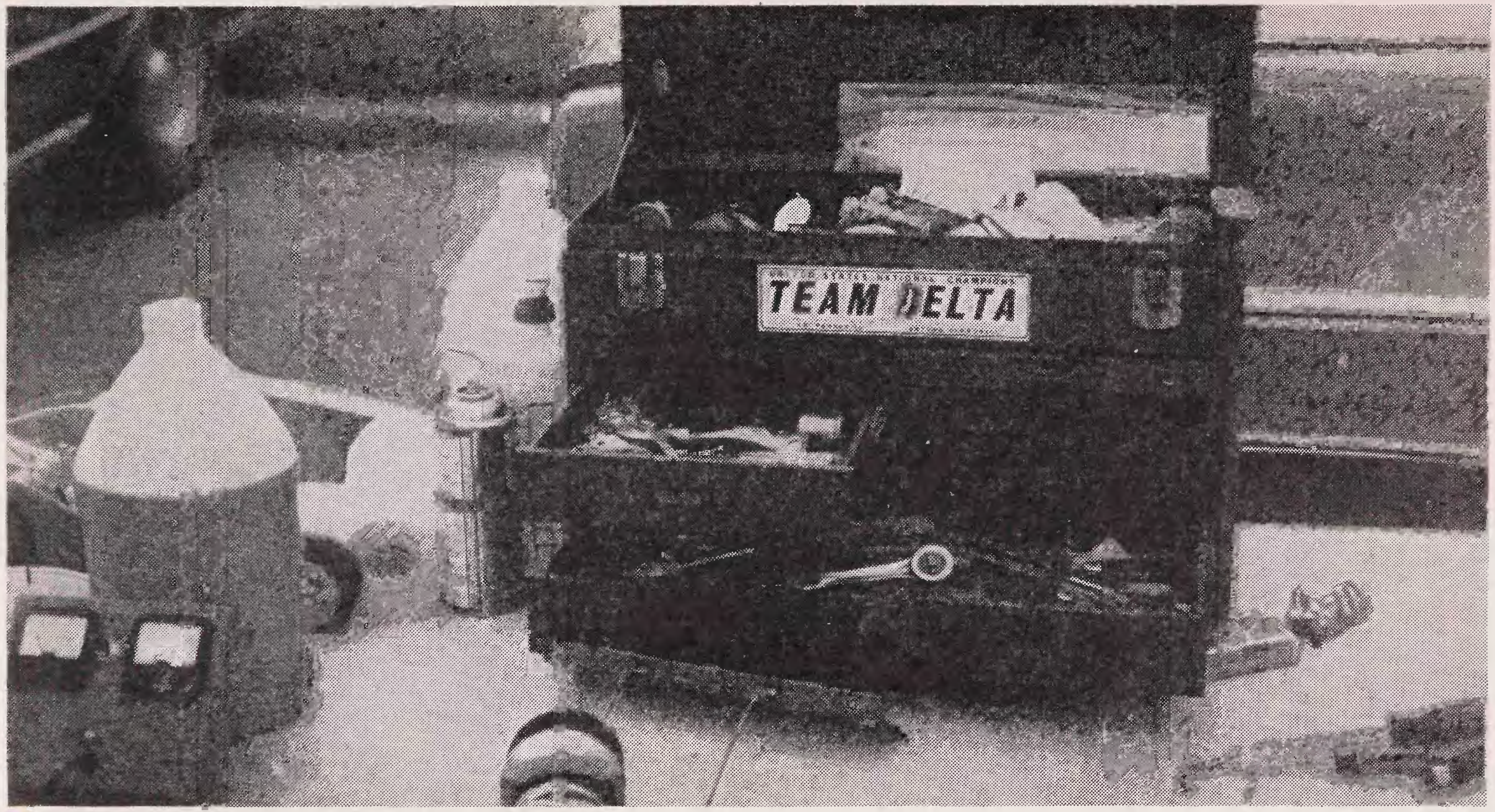


Fig. 10-7. Team Delta workbench view.

uses a tone, and has good range and is available on all R/C frequencies, the toys are usually carrier operated, have a limited range and are available only on the Part 15 FCC frequencies which also have other services operating on them.

THE MODERN RACING CAR

In Fig. 10-5 we see an example of the modern racing model which was exposed to view inside in the chapter on servos. Notice the glo-plus battery to the right. Benches are near the automobiles because the electric-starting machines for these models require 12 volts to operate. Fuel has a high degree of methane for power. The radio-control equipment is two channel digital proportional. Controls are steering, throttle, and brakes.

The wide-track tires, gearing to the drive wheels, muffler exhaust, and the aerodynamic plate which holds the aft end down to the track are seen in Fig. 10-6.

The racing was held on this event in a shopping mall parking lot, and believe me, what a crowd gathered to witness the driver's skill and, of course, crashes etc. It is very nice to know that anyone, from as young as can understand the steering wheel control to as old as can hold the transmitter, can participate in these events. Due to the different spot frequencies, there are usually from two to six cars running at the same time in an event.

Yes, it takes some mechanical skill to put a car together and keep it going, just as with the big ones. In Fig. 10-7 you see a typical

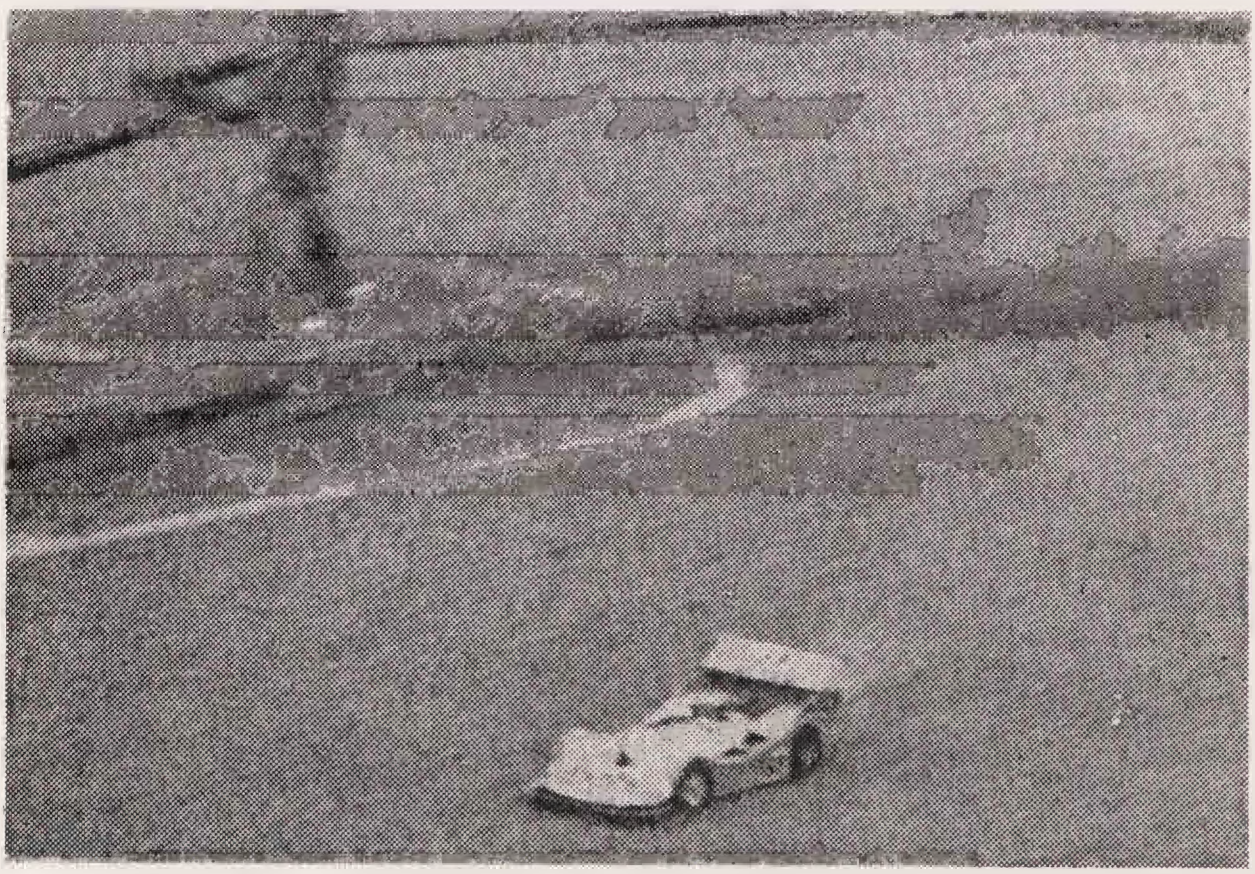
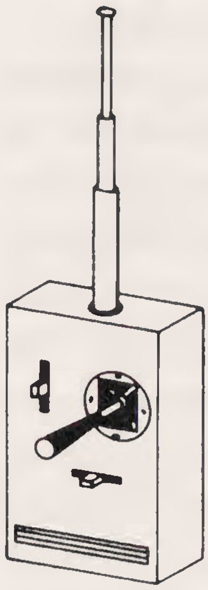


Fig. 10-8. The winner!

tool box from the veteran race-car driver. In the foreground is the engine starter. It is an electric motor with a friction drive output which is held against the rear wheel of the racer until the engine in the car (a glo-plug type) starts running properly. The meters on the left measure batteries levels and amperages used when the system is activated. Batteries are ni-cads, which have a long life, as they only operate the radio and servos. They can be recharged at home or even from the car battery if you make or purchase the charger to do this. A roll of paper towels is used to wipe the cars clean, just as you do with airplanes, as the exhausts spew forth oil when running. The large bottle is fuel. It may be specially mixed by the knowledgeable modeler, or it may be purchased. A type is usually recommended by the model-engine manufacturer. Finally, in Fig. 10-8, you see one car (incidentally this was the winner of this event) coming down the track at full speed, under perfect control. The driver had completely out distanced the other three in the race and had the home stretch all to himself. He was 14 years old! Of course Dad, Mom, and Sis helped with the preparation of the car prior to race time. What a nice pit crew.



11
Radio Control Of Model Boats

Is there anything more beautiful and graceful than a sailboat heeling before a gentle breeze as it skims through the water, responding to your slightest command? Figure 11-1 shows a gorgeous boat, courtesy of Dumas Boats, Tuscon, Ariz. Figure 11-2 shows it again, turn completed tacking along a course that will lead it into open water.

Radio-controlling model sailboats is a real challenge, because you not only have to master the radio commands and system operation, but you must also learn how to sail. There is more to it than just turning a rudder: You have mainsheet and jib to control. Sailboating may be new to some of you, so I'll list a few important points:

1. You cannot sail your boat directly into the wind. The closest is an angle of about 45° to the direction of the wind (Fig. 11-3).
2. When sailing *close hauled* (at 45° to the wind), most of the driving force is provided by the lower pressure on the back of the sail. The shape of the sail is an airfoil, like an airplane wing, so it's important to keep the wind flowing smoothly over the sail. If the jib is *trimmed* properly (positioned at the proper angle to the wind), it will increase the velocity of the air over the back of the sail and thereby increase the pull of the sail. If you sail too *high* into the wind (turn the boat too far into the wind), the sail will *luff* (flutter) along the mast because the wind is striking both sides. To stop luffing, head the boat downwind until luffing stops.

Fig. 11-1. Star-Class sailboat making a turn.

3. To *come about* (sail with the wind coming over the other side of the boat), have the boat *close hauled* (Fig. 11-3) and moving well. Turn it sharply into the wind and hold the rudder until the sail starts to fill on the other side, then return the rudder to center. To sail into the wind, first sail

close hauled on one side, then come about and sail close hauled on the other tack. This is called *tacking*—zigzagging into the wind. If the boat is balanced properly, with the center of the wind pressure on the sail slightly to the stern of the center of pressure of the water on the keel, the boat will have a slight tendency to head up into the wind. This tendency is counteracted by setting the rudder to head the boat a little downwind, thus keeping the boat on a straight course. If the rudder has to be set at a sharp angle to do this, then the mast should be moved slightly forward by drilling a new hold in the deck.

A boat on a *starboard tack* (with the wind coming over the starboard—right—side) has the right of way.

4. To sail in the other direction, on a close reach, a broad reach, or before the wind (Fig. 11-3), the most important

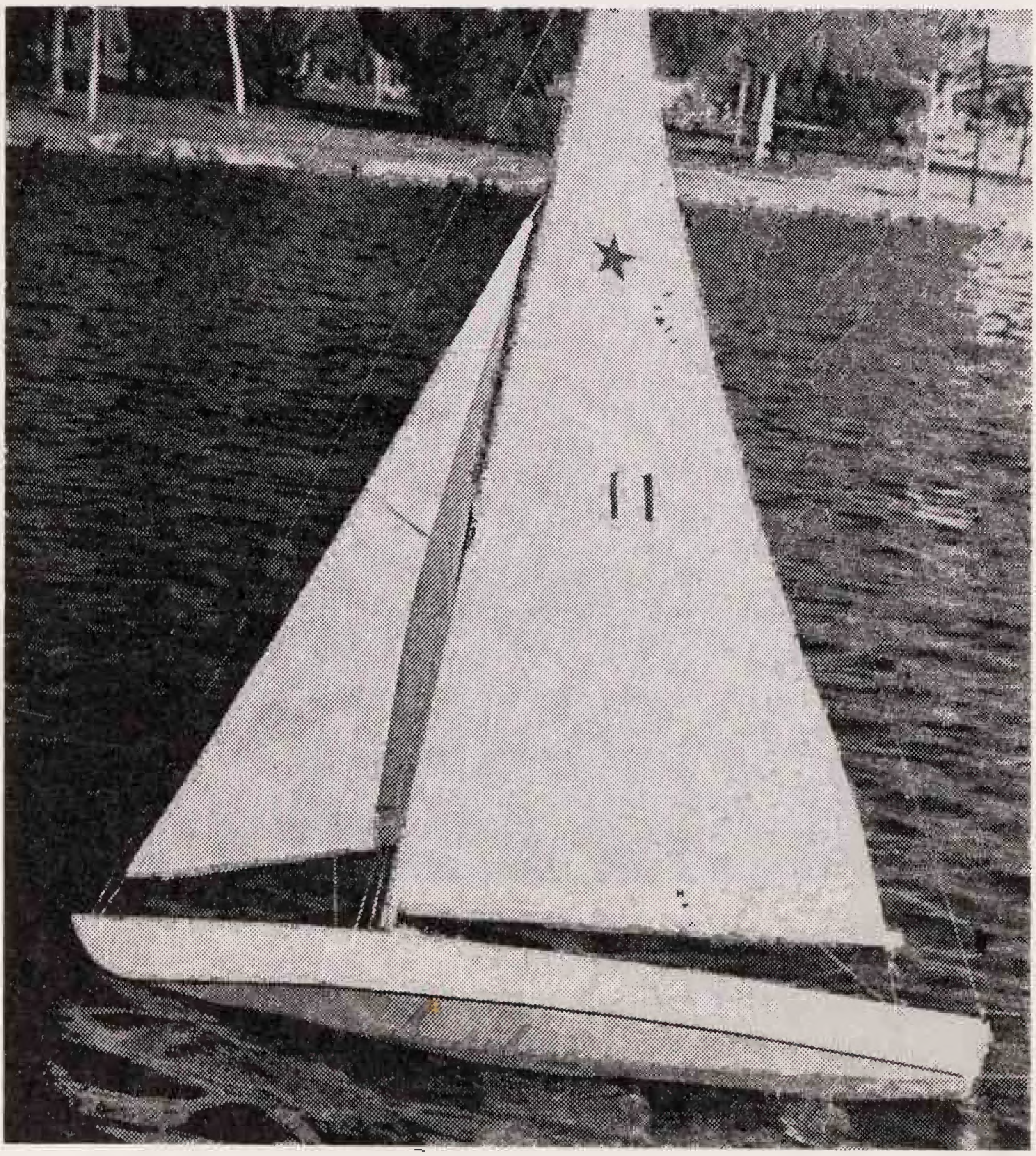


Fig. 11-2. Star-Class sailboat on a straight run at an angle to the wind.

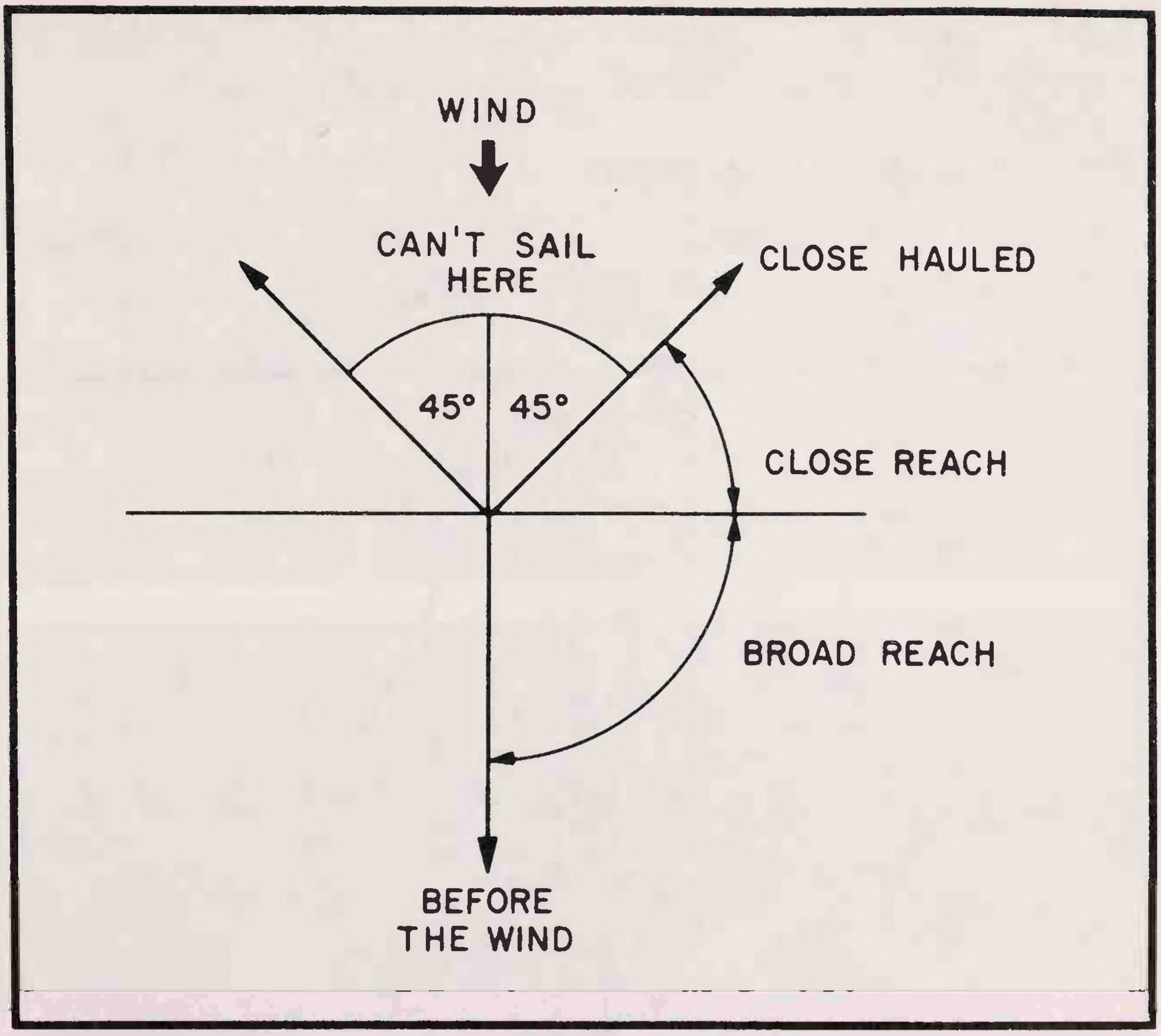


Fig. 11-3. Pointers on wind and sailing.

thing to remember is to set the sail so you get the largest force driving the boat forward (line AD in Fig. 11-4).

If the sail is trimmed too tightly, you will use much of the force in tipping the boat or driving it sideways (line AC) instead of driving it forward. If the sail is out too far, it will not present enough area for the wind to push on and you won't get maximum forward thrust. You must keep adjusting the sails for the wind conditions and the course you want to follow, or adjust them for the course and wind and then use the rudder to keep things under control. This means you want to radio-control the mainsheet and the jib as well as the rudder (and perhaps an auxiliary electric motor just in case of trouble). Figure 11-5 shows how the sail radio-controls are placed in the hull and how the mainsheet and jib are connected to the runners.

The servo for this equipment consists of an electric motor driving a lead screw along a track. There are two such units, one for the main sheet and one for the jib. The control-cord arrangement (Fig. 11-5, lower photo) insures that the lines will not hang loosely and get tangled. When the hatch is closed the opening is slight enough and centered enough so that the boat will not ship water even if it lists rather sharply into the wind. The construction plans for such boats, included in kits, have complete radio-control installation instructions, just as radio-controlled model-airplane kits do.

EQUIPMENT AND INSTALLATIONS

Another type installation—which uses a two channel brick digital radio to operate the rudder and a switch which in turn controls a

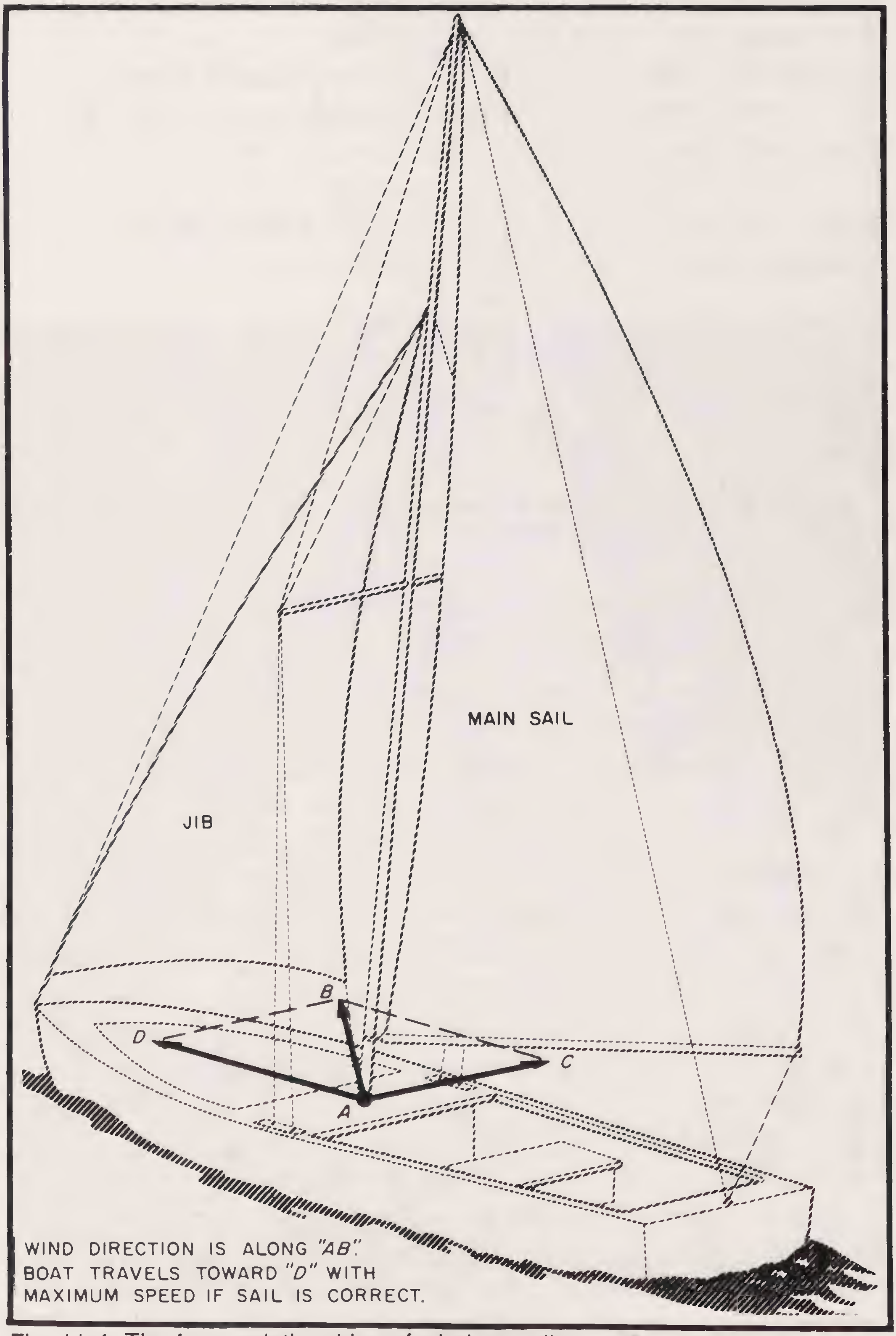


Fig. 11-4. The force relationships of wind on sails.

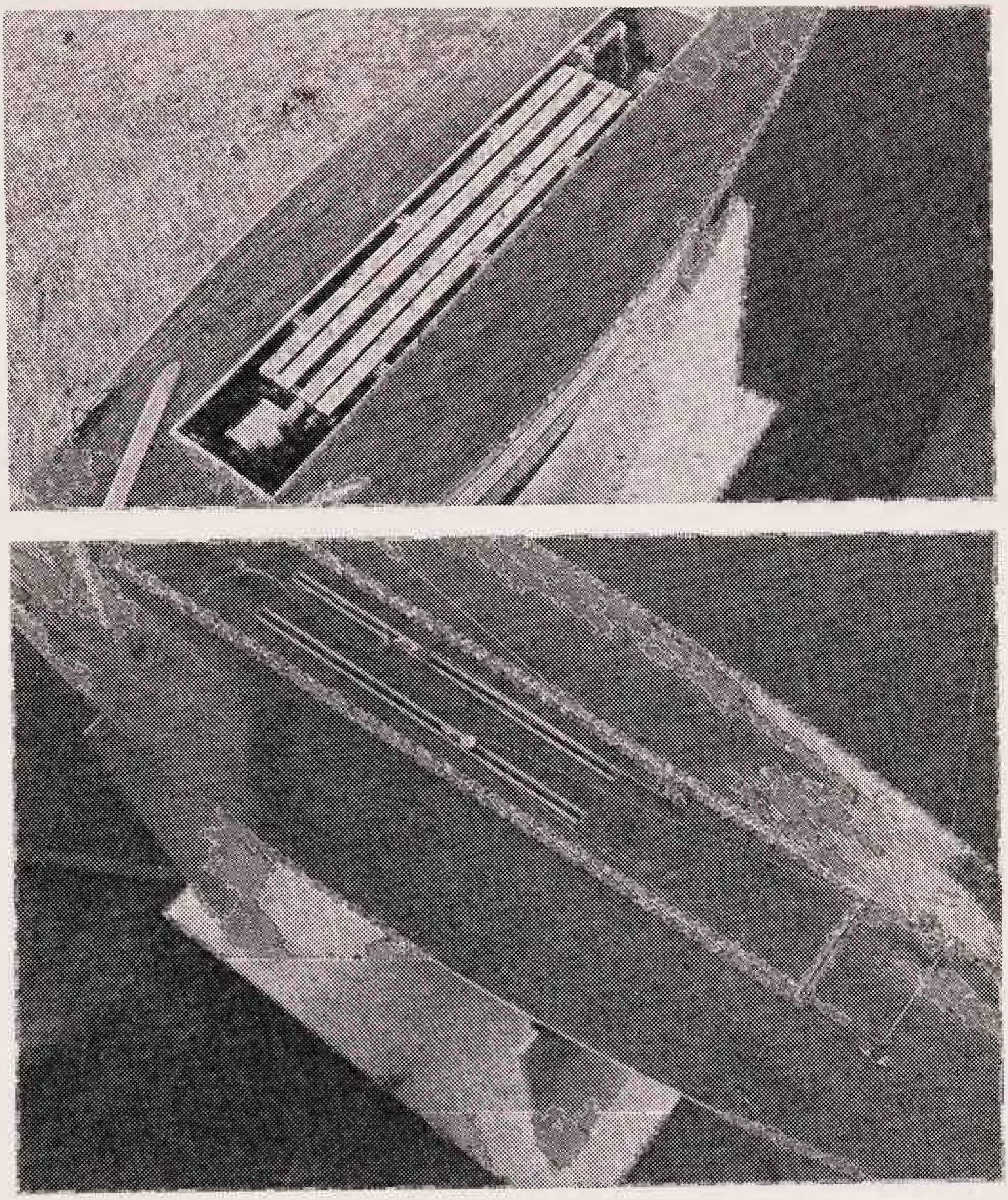


Fig. 11-5. Sail-control equipment in a sailboat. (Courtesy Dumas Boats)

motor-driven gear train which, in turn, turns an arm which controls the main sheet and jib simultaneously—is shown in Fig. 11-6.

Of course you will want this installation below deck or provided with a good water-tight plastic cover to keep spray and waves out of the equipment. The radio antenna may be run up the mast, if it is not aluminum. Note the information concerning the routing of the antenna in the diagram. If the mast is aluminum, be careful it is not a multiple length of the frequency you are using or a submultiple length. You might have to route the receiver antenna forward along the jib sheet to keep it away from the mast if the mast absorbs too much energy. Of course since the mast is insulated from the deck by plastic fittings, it might also be a good source of re-radiated energy. You just have to try it out and see what location is best.

Let's examine that auxiliary mainsail and jib control mechanism a little closer through Fig. 11-7. You see that the switch to control the rotation of the motor, shown in Fig. 11-8, is moved to forward or reverse rotation position by means of the linkage to the radio-control servo. To stop the sail motor at either extreme, the two microswitches, operated by the shaped cam on the output shaft, open the battery circuit at the limits of travel; so you have here either one setting of the sails or a second setting of the sails and no position in-between. If the DPDT switch were on with a middle off position, then, by juggling the servo arm position carefully through radio control, you could set the sail at different positions between the extremes of travel, and when such positions were reached you would cause the servo arm to put the DPDT switch in the off position, removing battery power.

In some installations, Fig. 11-9, you will note how the use of airplane-type servos are used to control the sails and rudder in a sailboat. In this case the turn limiting feedback potentiometer was removed from one servo motor so that it would run continuously in a forward or backward direction. Then limit switches, such as the microswitches just discussed, were added to keep the motor from tightening up so much that it would break the strings. A drum-type wheel was added to the servo output shaft to wind up the sail cords, and the owner had a system so he could position the sails to any point within the maximum and minimum limits established by the limit microswitches. The radio equipment was housed inside plastic boxes, as well as being sealed in the hull when the cover was bolted down against its rubber seal to insure that water would not damage the equipment or cause faulty operation. Notice the mainsail cord coming up just aft of the hatch through a tight grommet.

But sailboats are not the only craft which lend themselves to radio control. A beautiful boat that always attracts attention is shown in Fig. 11-10. This model can have lights, various speeds forward and reverse, and, if you are skillful at using radio-control mechanisms, a device for launching the lifeboat. You might also add winches, which you can run to let out "fishing line," and then reel in your "catch." Don't hook too large a fish however. There are lots of fun possibilities with this kind of model, as you can control many, many things on and in it. Then, too, it always looks nice on a fireplace mantel in the den or in some other location in the house.

Another model, which is easy and fun to control, is shown in Fig. 11-1. It is complete and ready to sail if you don't want to spend the time building a boat. So this, like the model airplanes which are

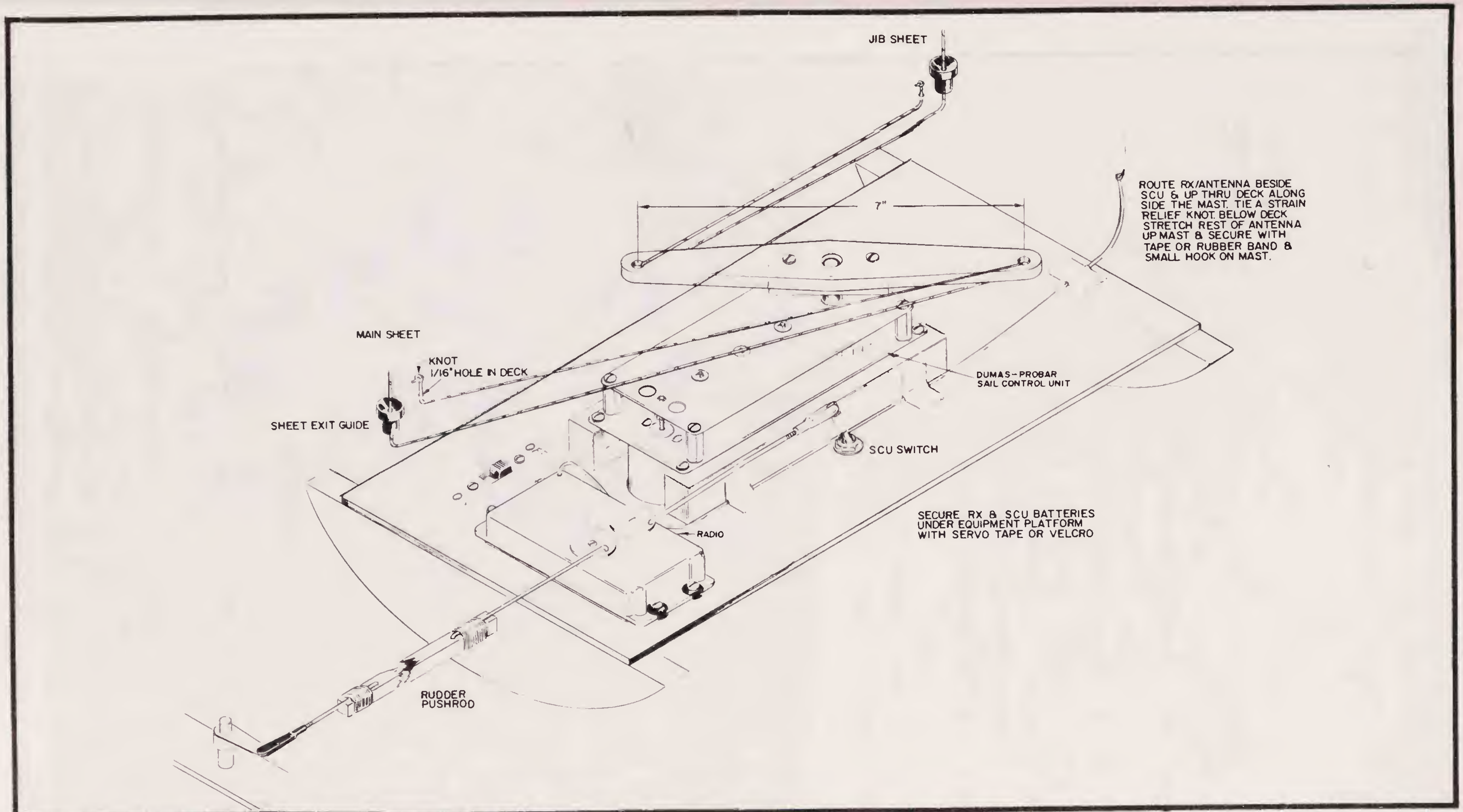


Fig. 11-6. A Digital Radio installation. (Courtesy Dumas Boats)

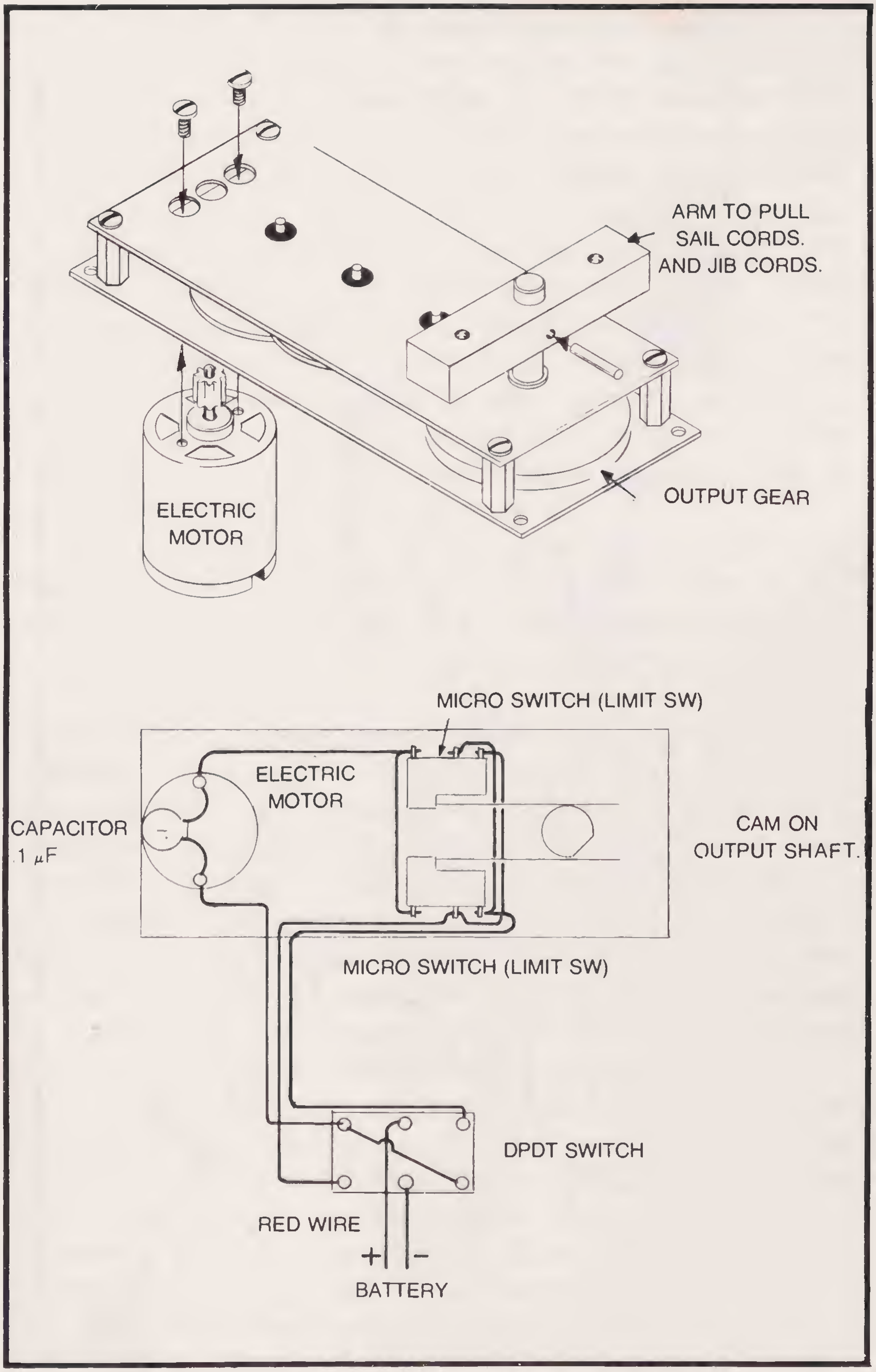


Fig. 11-7. The wiring and sail control mechanisms. (Dumas Boats)

ready to fly, is also ready to use when *you* put the radio installation in it. The motor is already mounted.

Speaking of boats, we show you in Fig. 11-12 the relative size of a model yacht compared to its proud owner, Mr. R.B. Balderidge of Bayshore, Texas, a fine friend who contributed so much to our boat sailing experience. The sail comes down for transport. Note the long slender rudder which is moved by radio. When you steer such a vessel, you use both rudder and maneuvering of the sails. It's a real challenge.

RACING BOATS

For those of you who want a faster model, a racing boat may be the answer. Racing boats are certainly pretty to watch, and they perform magnificently. But they require a firm, sure, quick hand on the controls and a quick eye to keep up with them.

Figure 11-13 shows such a racer coming by the control point under full power of its model motor. Glow-plug internal-combustion motors are used. There are types made especially for marine use. The motors have throttles and can be run from a slow idle to a fast roar as you send commands for throttle retard or advance to your motor-control servo.

In Figs. 11-13 and 11-14 we show two types of speedboats, one with an open engine and the other with a concealed engine. It is

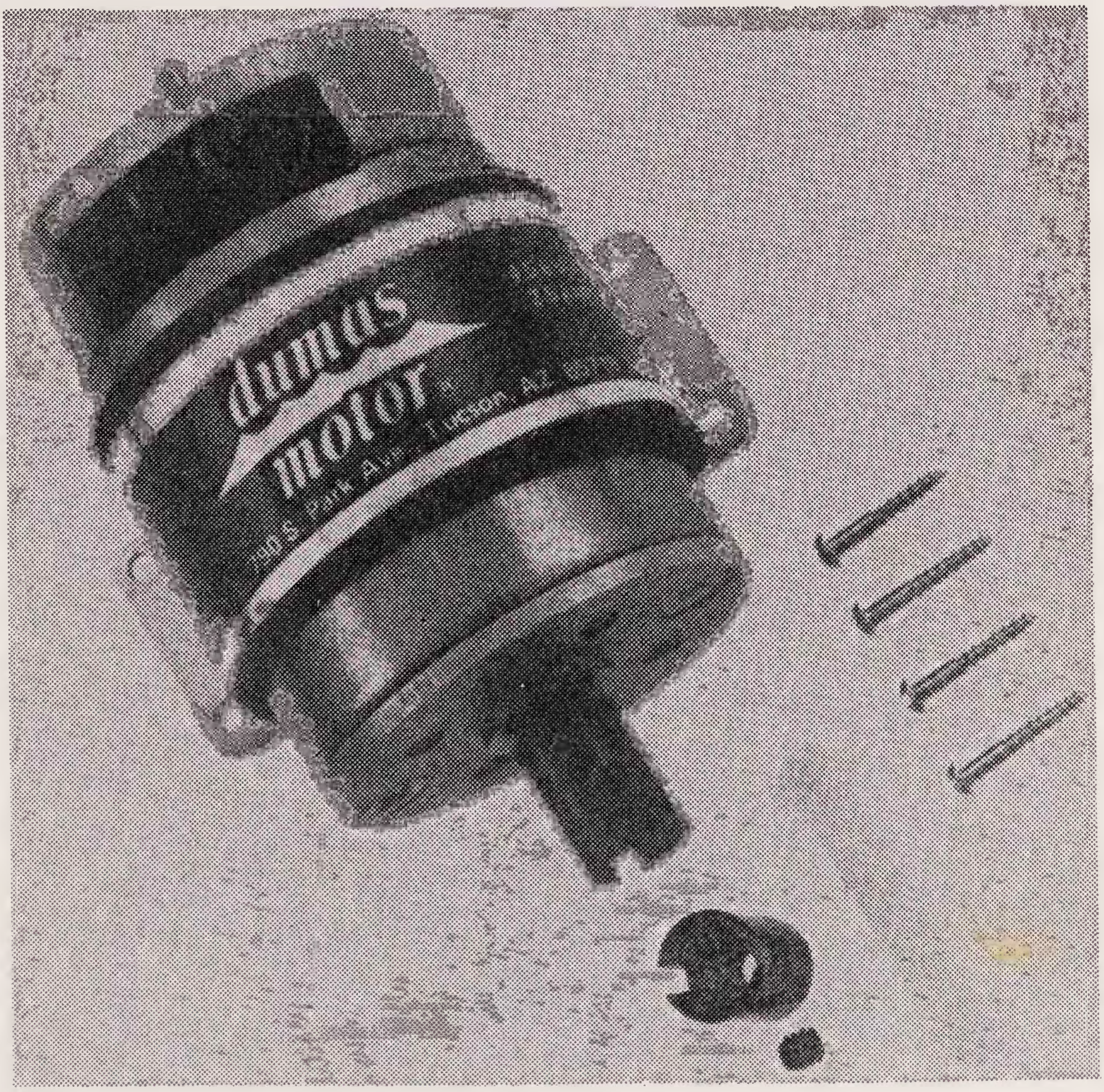


Fig. 11-8. The sail powering motor. (Courtesy Dumas Boats)

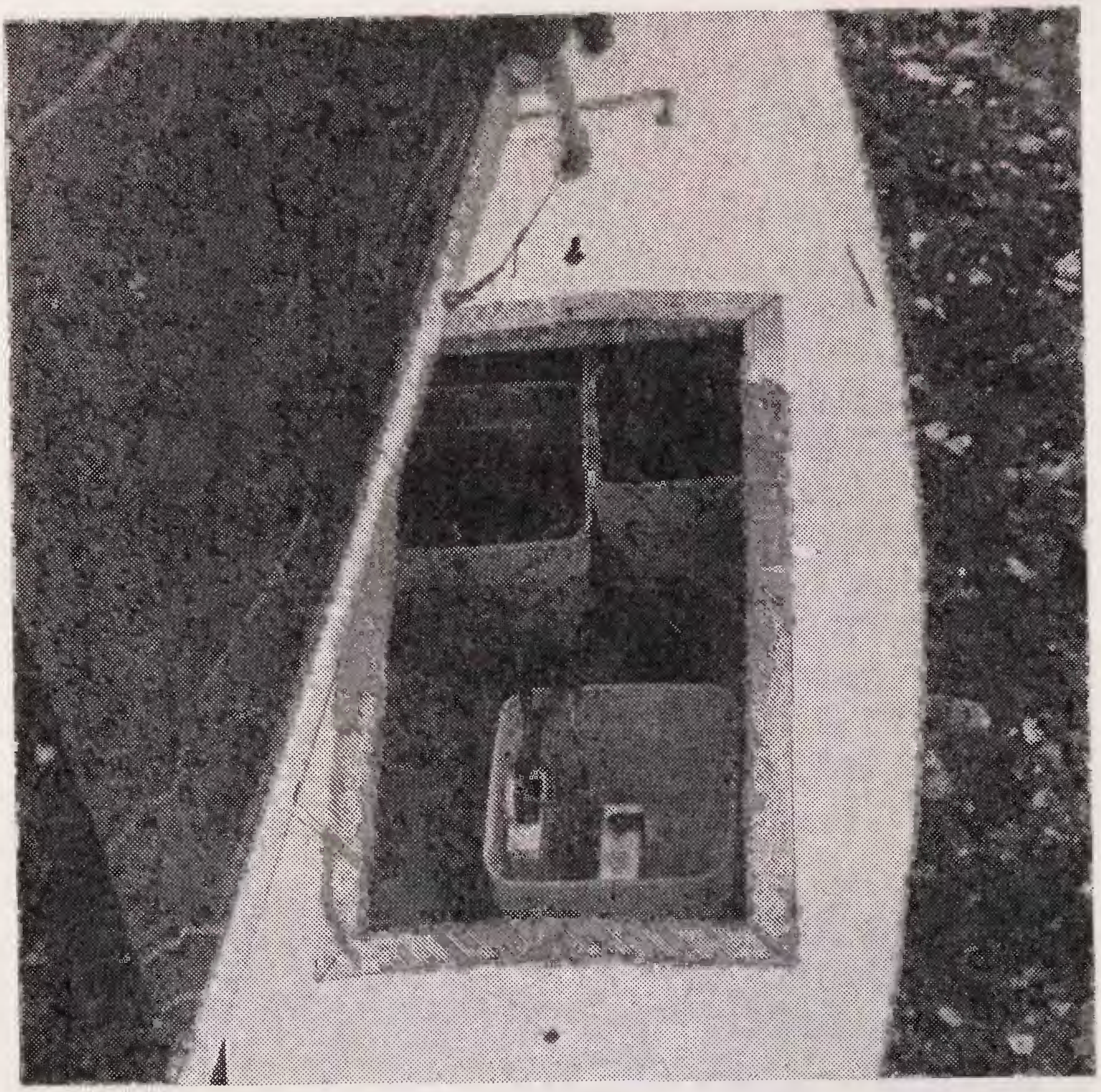


Fig. 11-9. A good waterproof installation concept. (Courtesy Bolderridge of Bayshore, Texas)

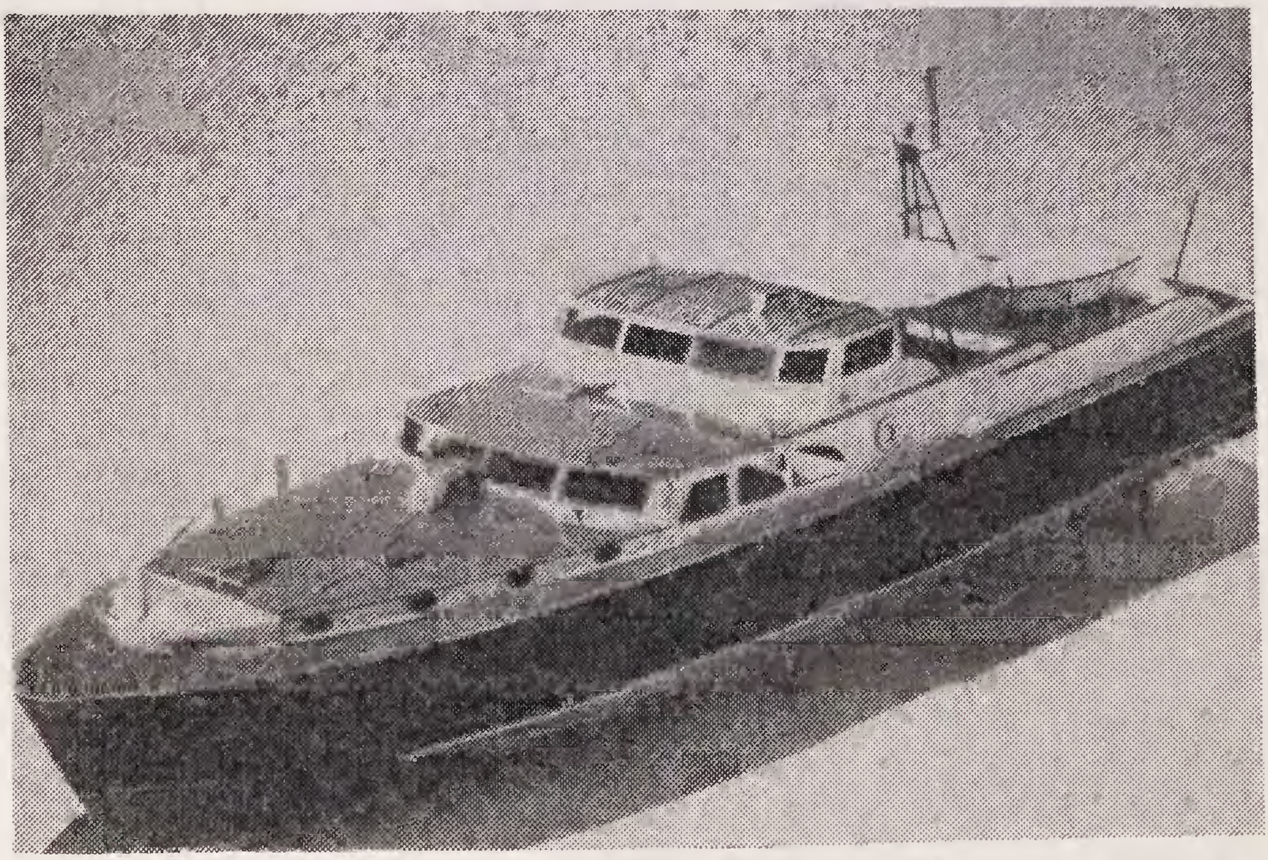


Fig. 11-10. The Dauntless No. 1121. (Courtesy Dumas Boats)


Fig. 11-11. MRC-RTF Boat Mariner, ready to sail. (Courtesy Dumas Boats)

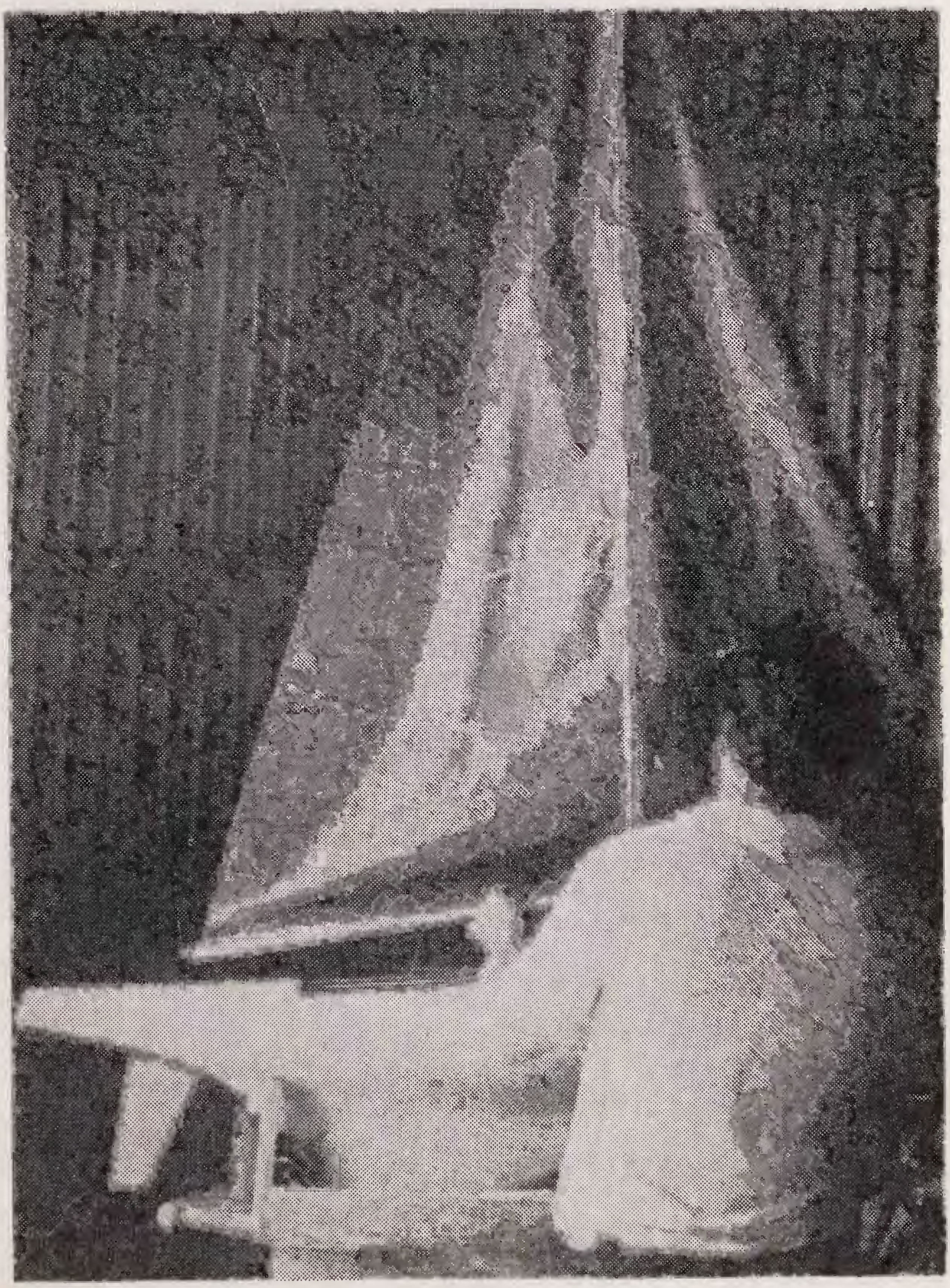


Fig. 11-12. Sail boater Balderidge and his model.

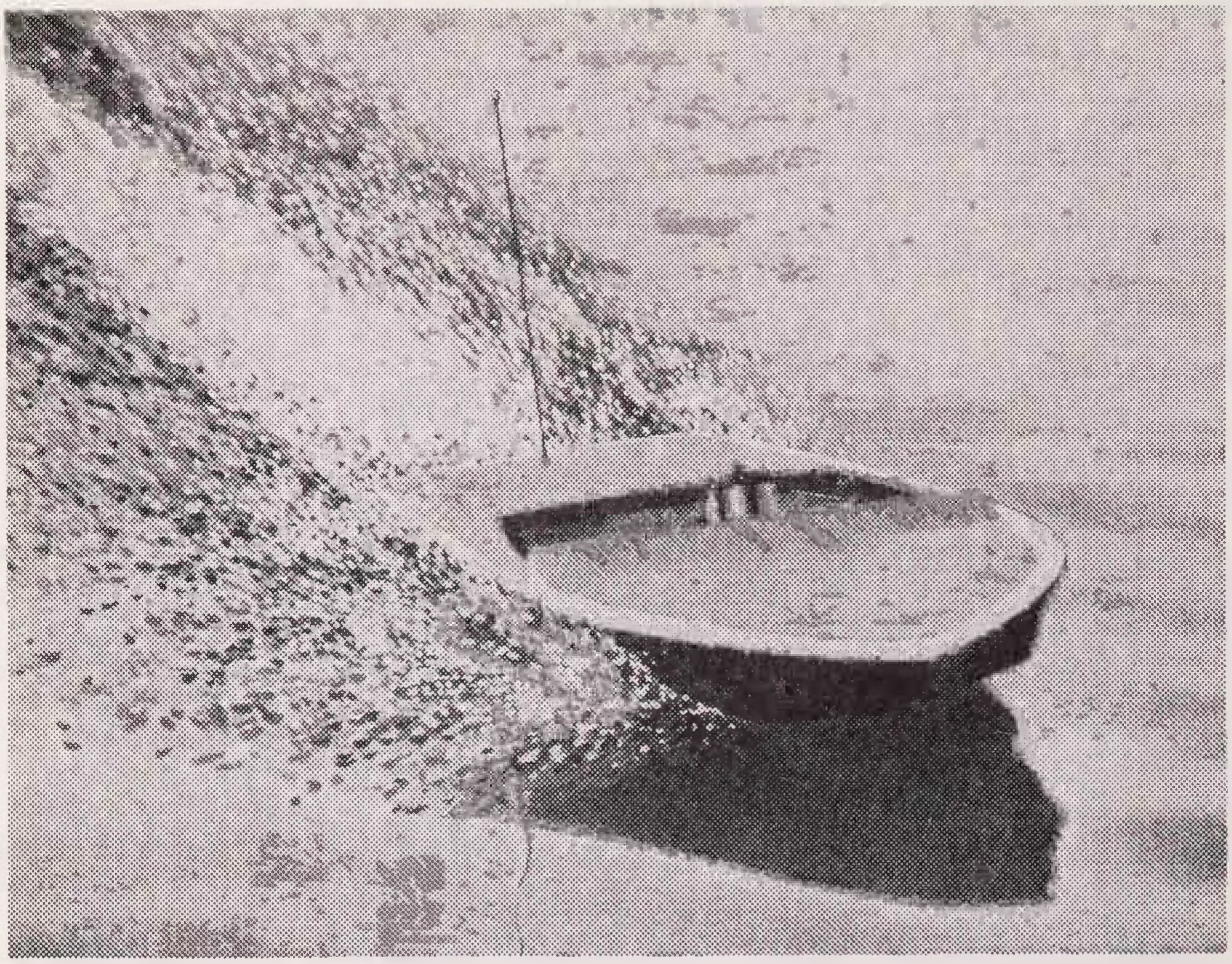


Fig. 11-13. SK Daddle speedboat powered by a McCoy 60 engine. (Courtesy Dumas Boats)

amazing how fast these boats can go with electric engines powered by ni-cad batteries. Of course with glow-plug engines—such as shown in Fig. 11-15 and the water-cooling intake for this model in Fig. 11-16—you get speeds that make you gasp. A radio installation for this kind of racing boat is shown in Fig. 11-17.

Other installations to give you some ideas as to how to do it are shown in Fig. 11-18. While these apply to older installations, as far as the radio equipment used was concerned, the ideas are still valid as to placement and arrangement of the equipment. In fact, these are

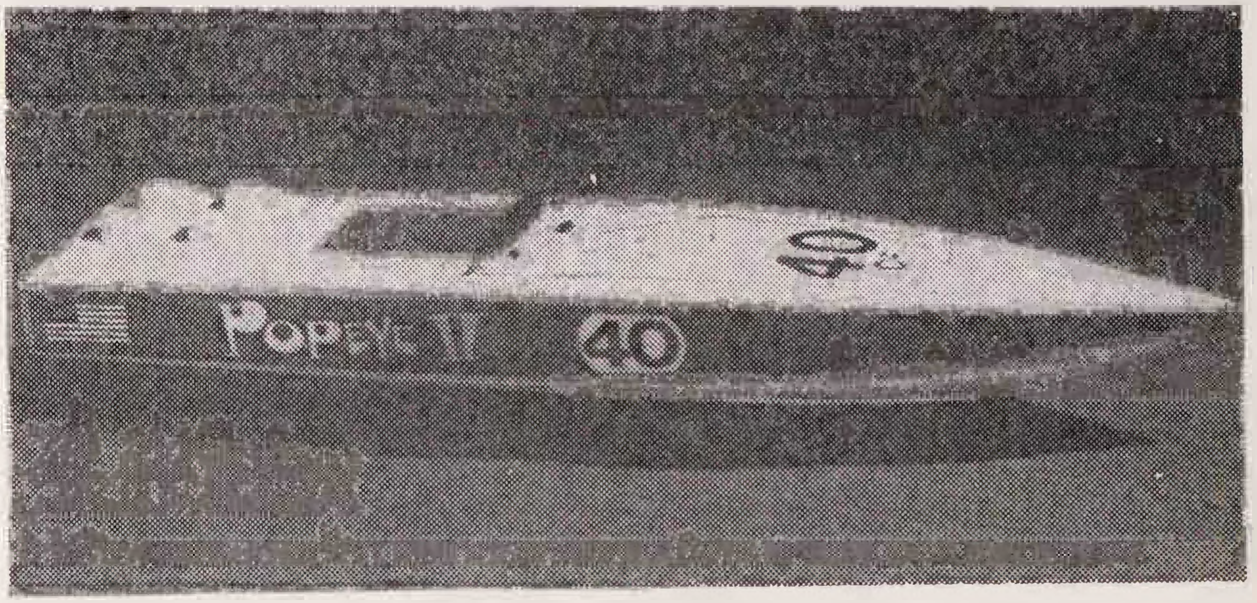


Fig. 11-14. Speedboat with a concealed engine.

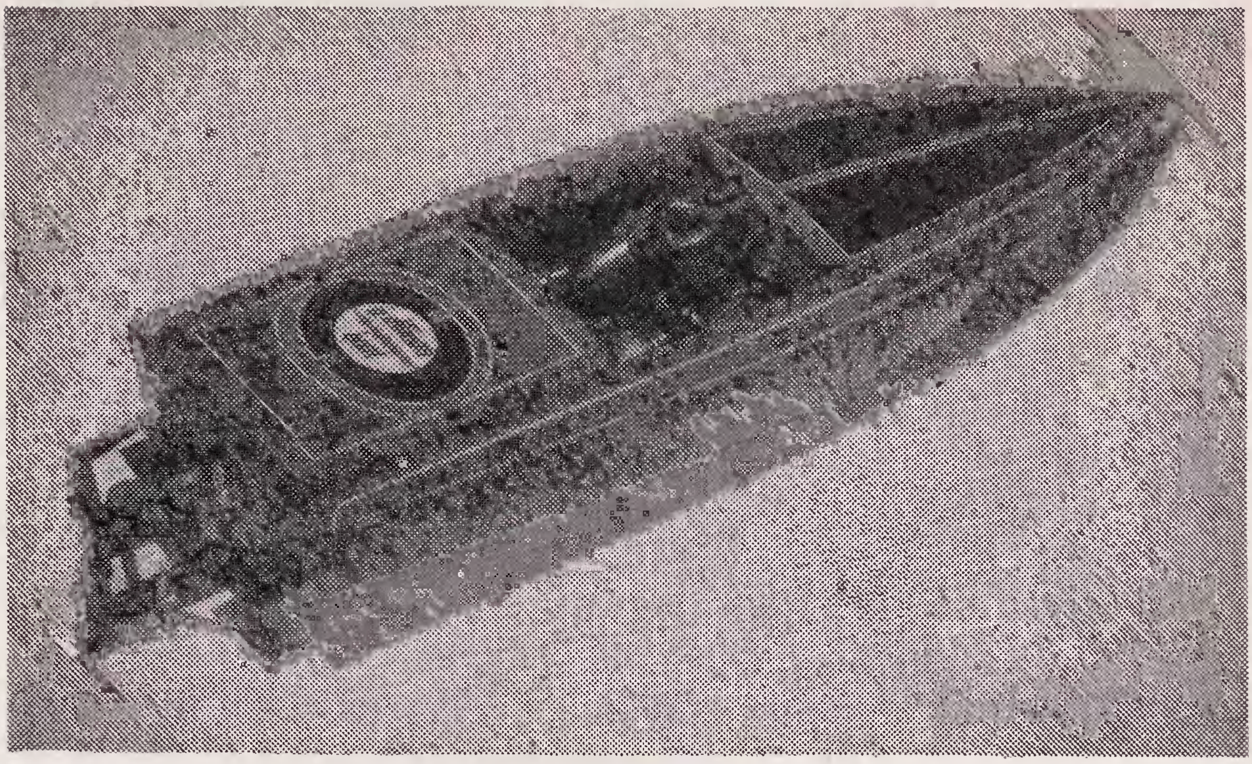


Fig. 11-15. Water cooled engine. (Courtesy Dumas Boats)

Fig. 11-16. Water cooling intake. (Courtesy Dumas Boats)

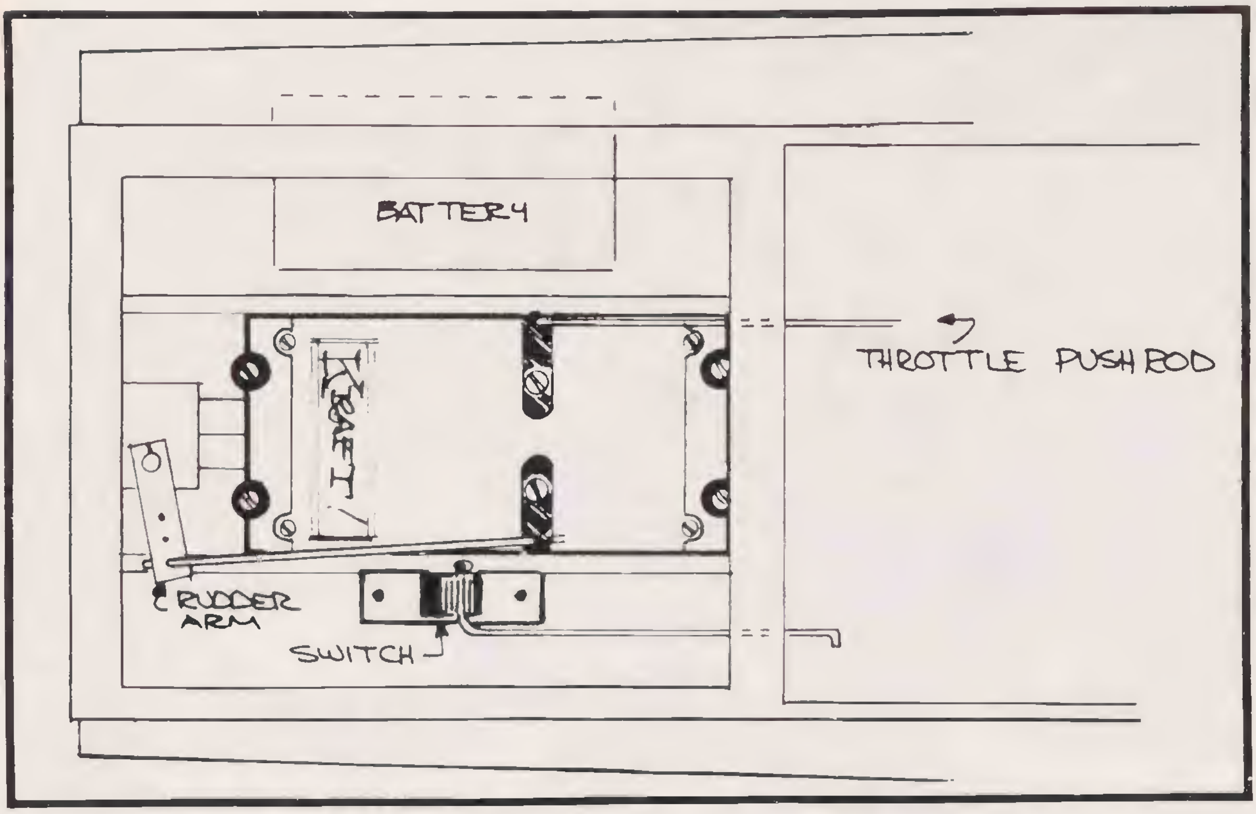


Fig. 11-17. Speedboat radio installation for digital radio equipment. Hatch is sealed watertight.

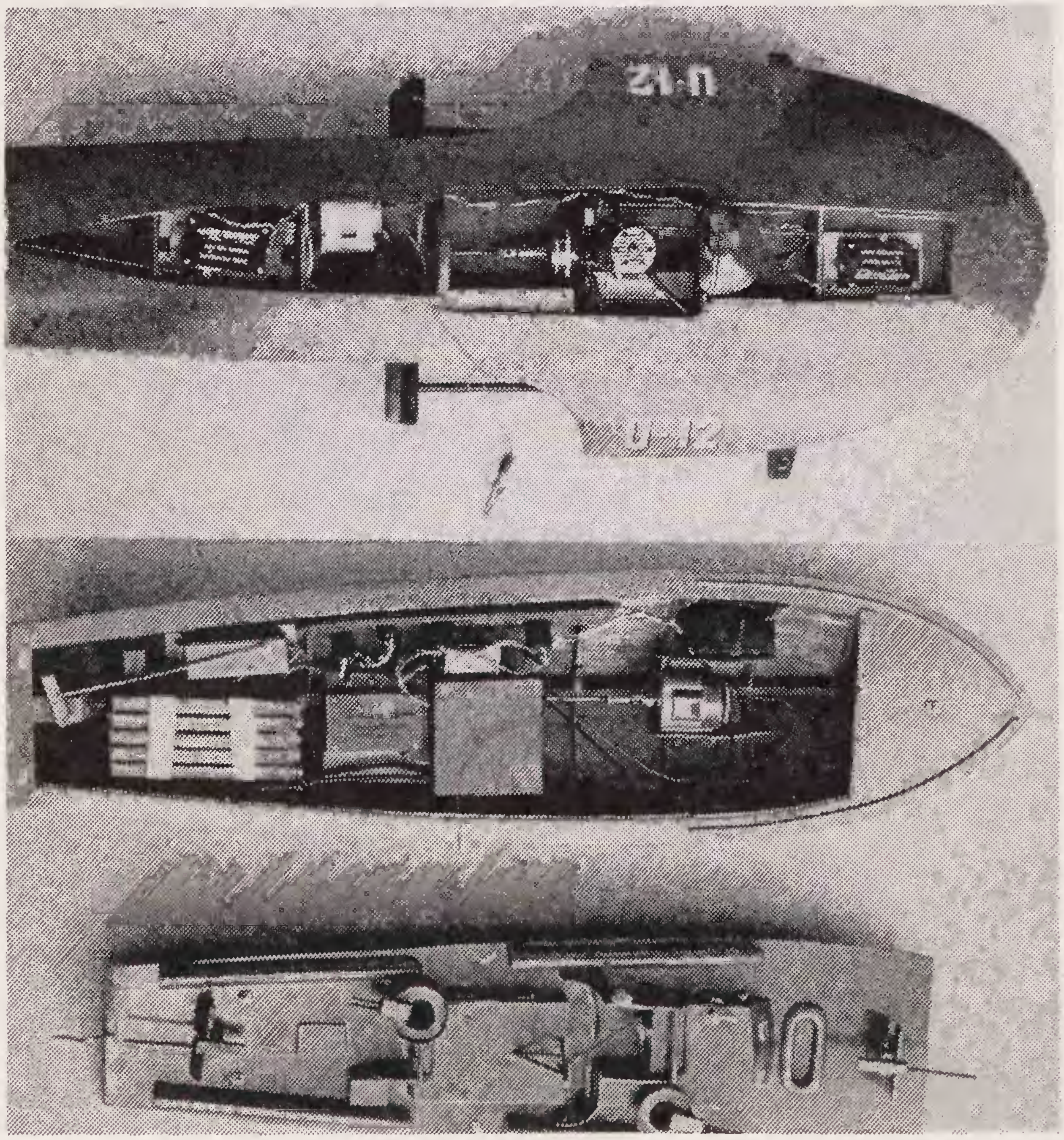
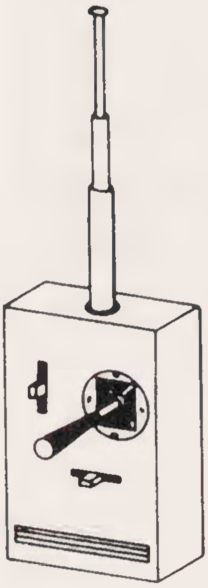


Fig. 11-18. Radio installations in motor-powered model boats.

small boats, and with currently available equipment, which is small and compact and light, the actual space required and water displacement will be less than for these boats; see Fig. 11-18.

Remember always to wrap your boat equipment in plastic or put it in watertight containers. Water is very corrosive to radio equipment. Some boaters have even thought of sealing the radio sections in plastic. But, in any event, make your seals tight, your connections firm and strong, and keep all connections bright and tight. Then you should have no trouble, and you'll love sailing or racing or just sport "fishing" with your boating models. And it's nice also if it's hot and the water is fine—you can always go swimming with it!



12

An Early Digital R/C System

We include the diagrams to an early system because many are still appropriate to the R/C systems of today. If you, like ourself, love to look over circuits which have been proved successful with an eye to modification or updating, then you will like the circuits that follow.

This was an early digital system that went under the name of its developer—a wonderful friend of ours—Howard Bonner. It was called the Bonner Digimite System. So we include it for your information, background, use, and development as you see fit. We always find its circuits of value, and if you did construct the whole system, it would work fine for you just as the modern systems do. Of course we would be remiss not to point out that getting all the parts for this system might be more difficult then getting a good modern digital radio control system kit. The Bonner Digimite System is no longer manufactured.

Figure 12-1 shows the relative size and components of the four-channel system.

Figure 12-2 shows the eight-channel transmitter with the auxiliary panel modification added at the top.

The circuit diagram of the receiver and the decoder unit is shown in Fig. 12-3. A superheterodyne receiver is used to feed the multivibrator gating system, which decodes the digital pulses into control signals. The receiver incorporates a fail-safe circuit and a voltage regulator.

Figure 12-4 shows the circuit for the servo unit. A pulse amplifier feeds transformer T1, which in turn drives the transistor-

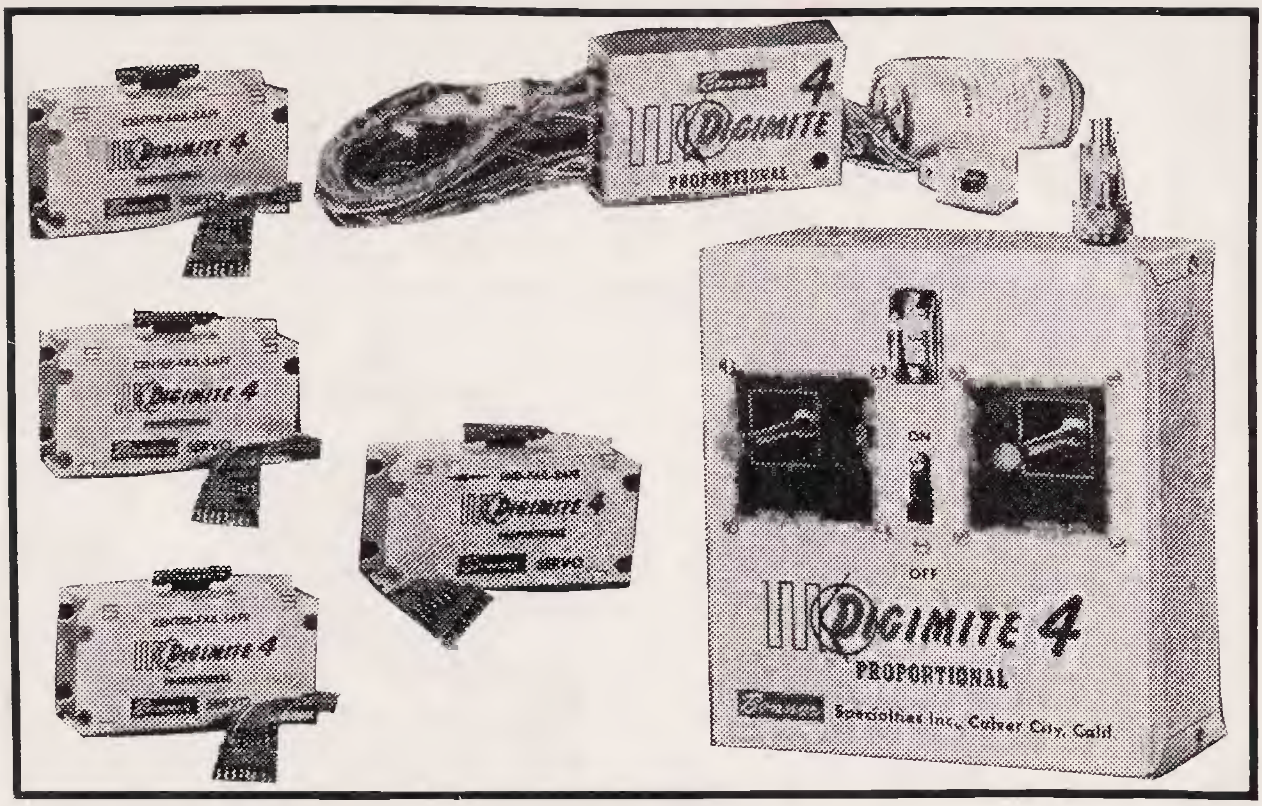


Fig. 12-1. The Digimite Four—a fully proportional digital-control system. The transmitter, receiver (lower right) and the four servos are shown.

current amplifiers. They drive the servomotor. The servomotor is well filtered to reduce interference.

The final unit is the transmitter, shown in Fig. 12-5. The units shown in Fig. 12-1 and 12-2 are no longer available as they appear here, or under the name Digimite.

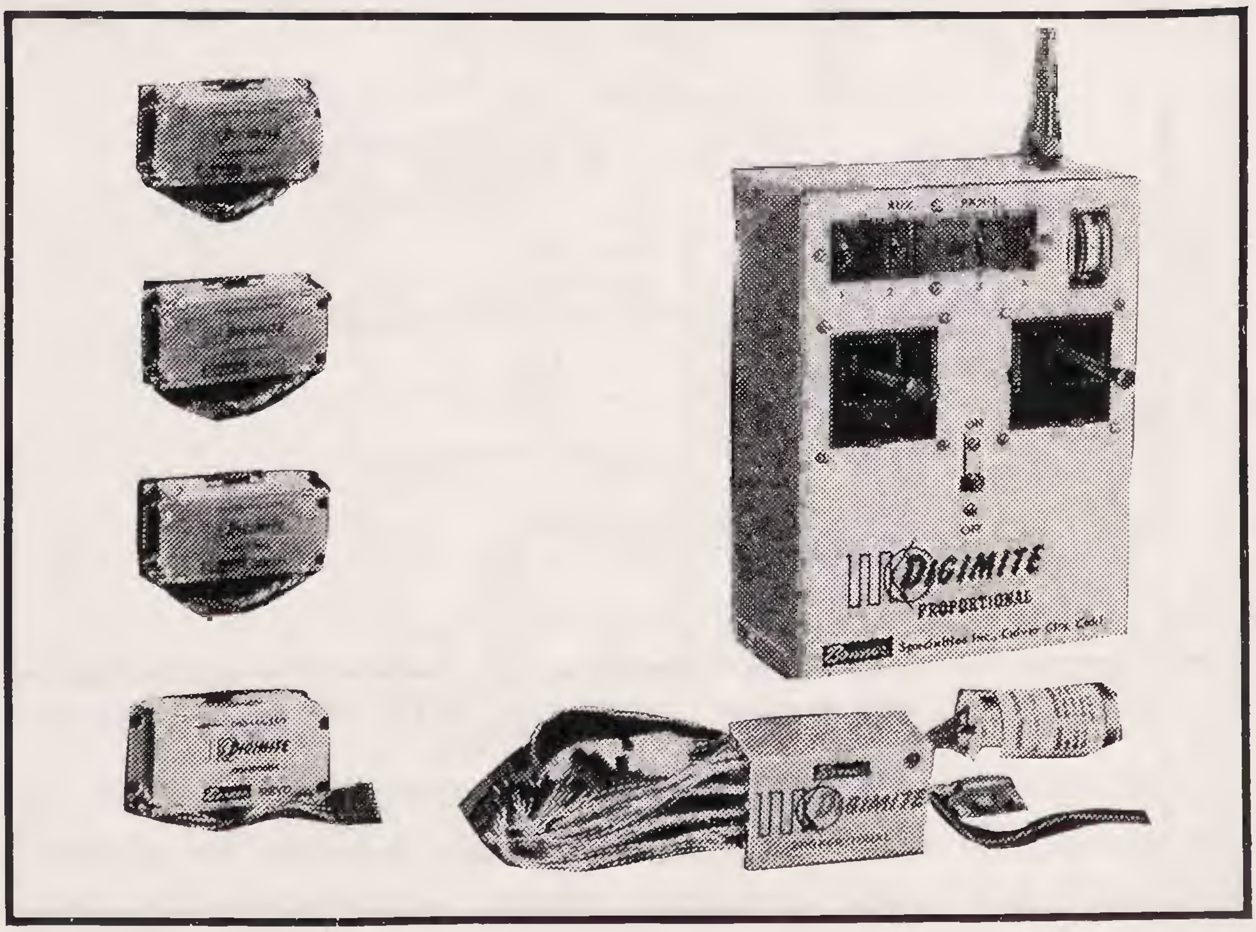


Fig. 12-2. The Digimite-8 system ready for installation. Note the circular battery pack to the right of the receiver.

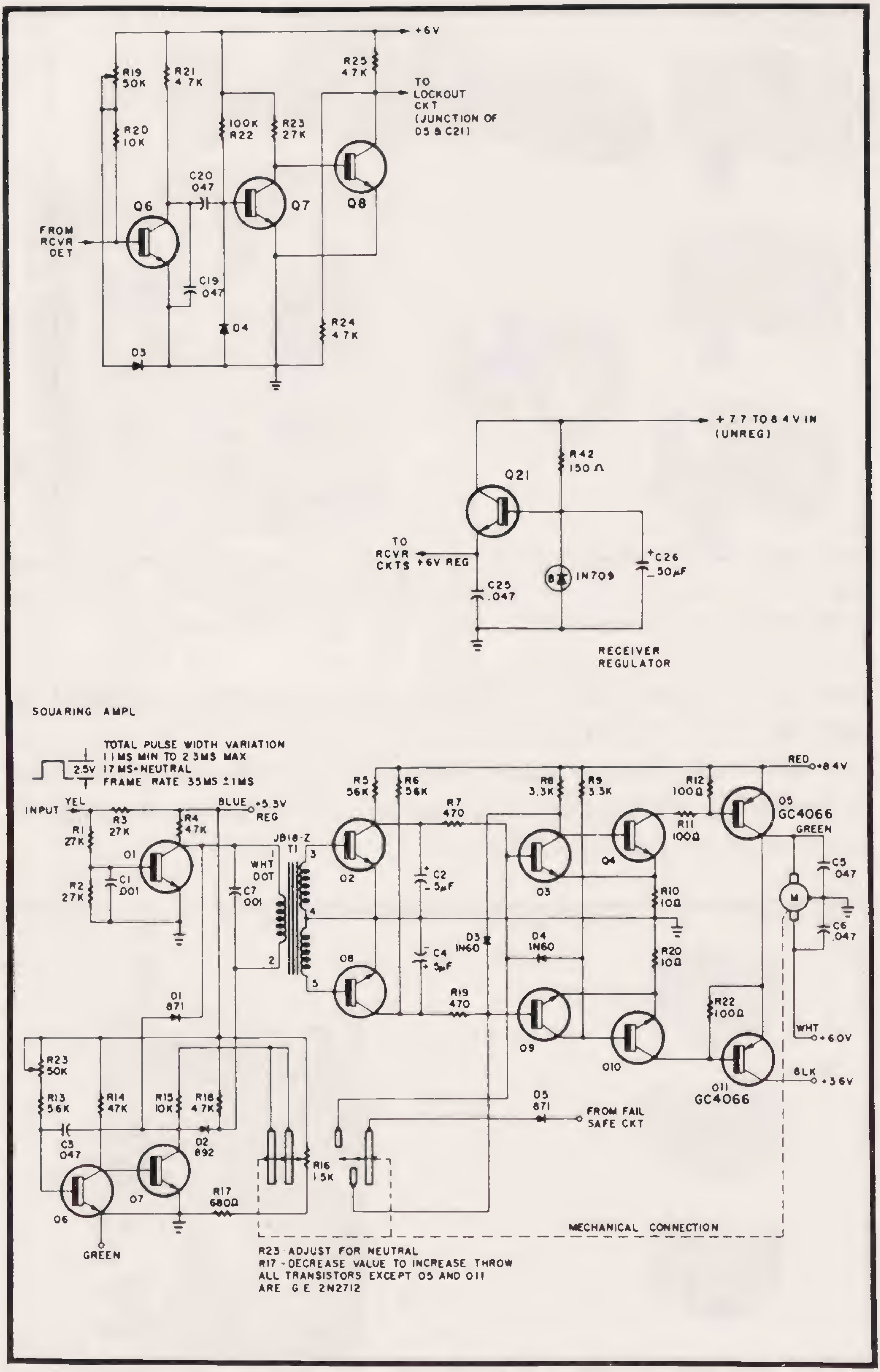


Fig. 12-3a. The Digimite receiver and decoder. This is the eight-channel unit.

So we come to the end of this book a little sadly. I always enjoy going over new developments in radio control. I hope my explanations have helped you understand them. I tried to include every important type of circuit and technique, and more than one example of the most important ones, so you can use this volume as a refer-

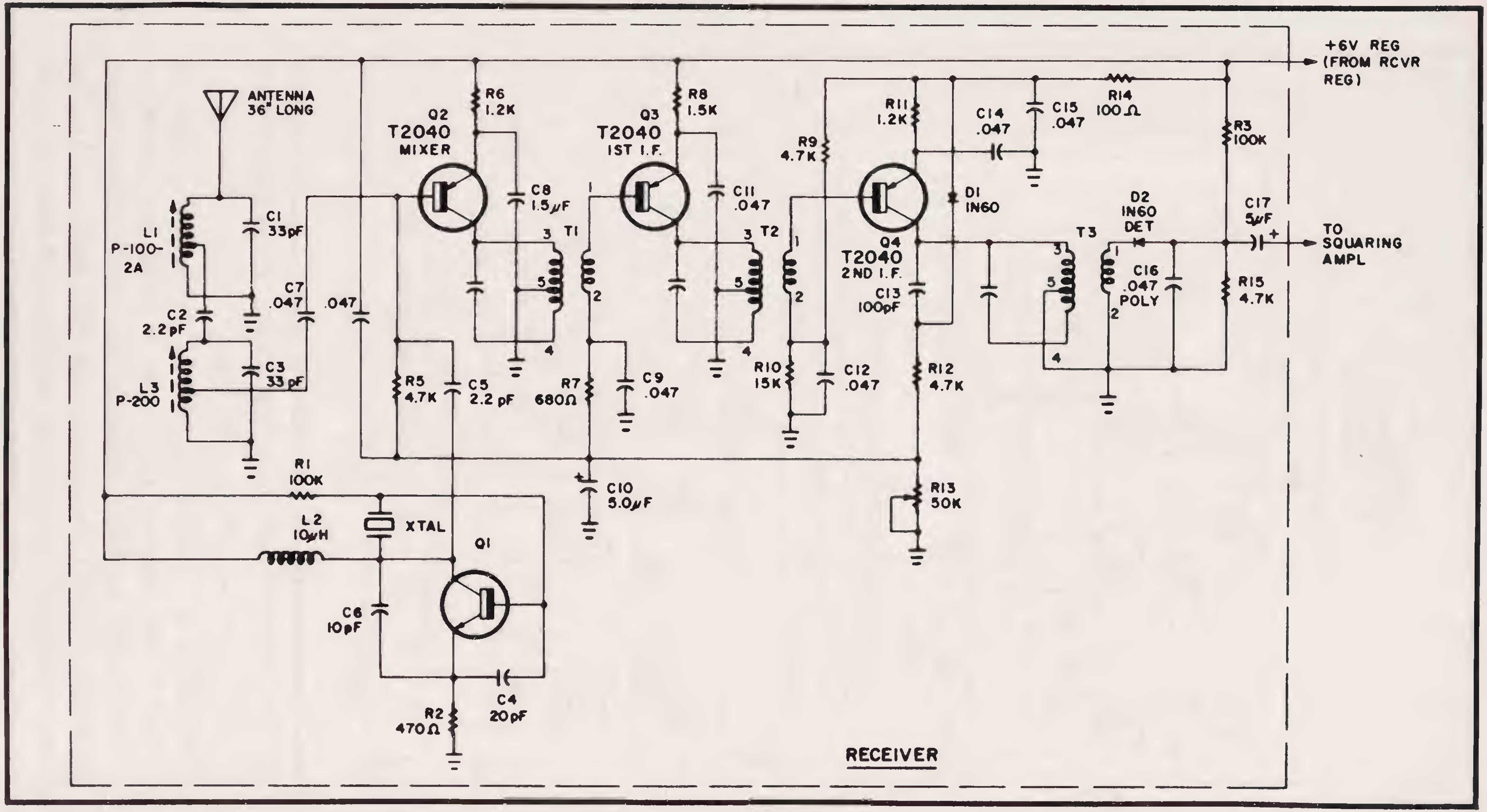


Fig. 12-3b. The Digimite receiver and decoder. Continued from page 246 and continued on page 248.

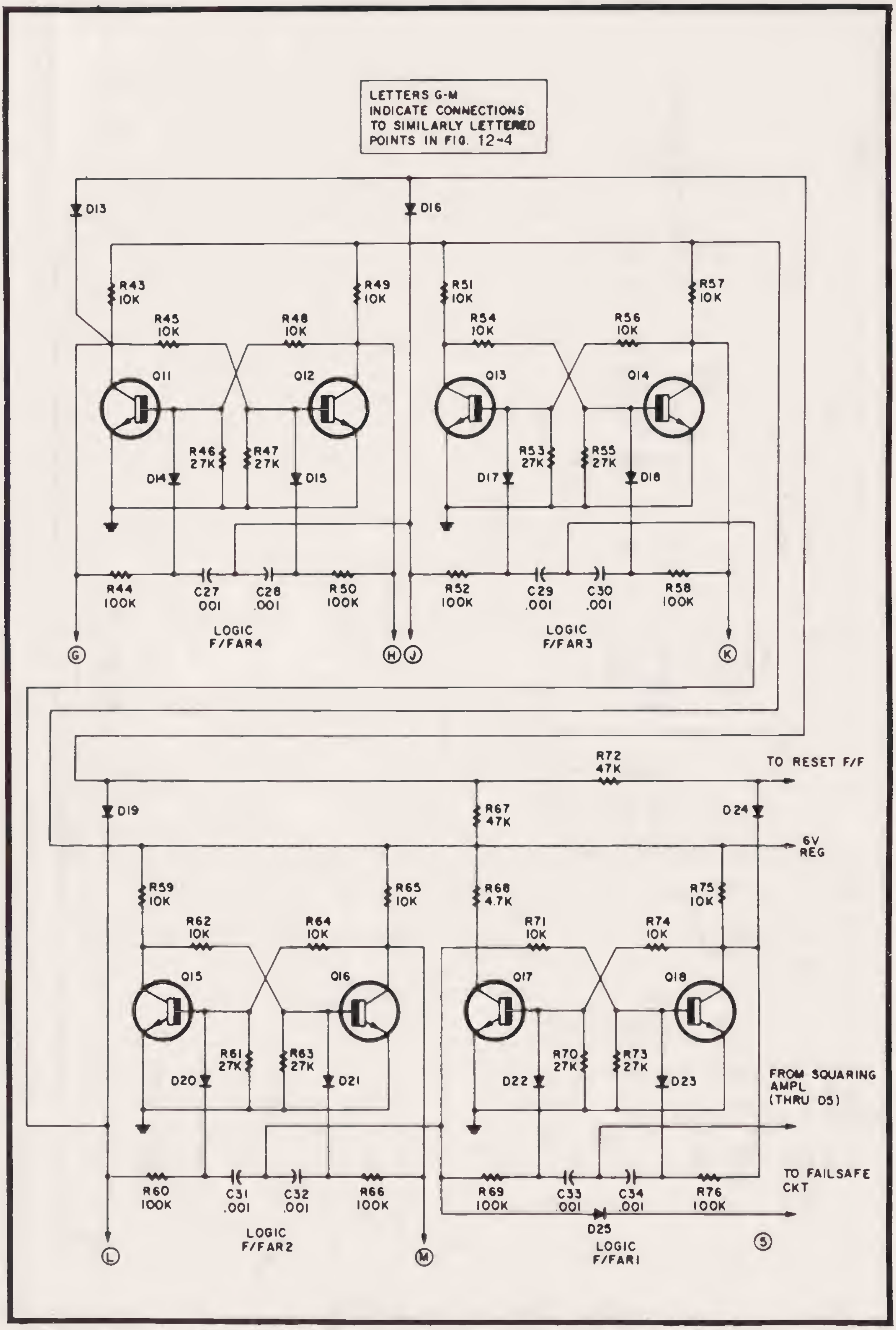


Fig. 12-3c. The Digimite receiver and decoder. Continued from pages 246 and 247.

ence. I included projects from the simplest to the most complex so that anyone at any stage of radio control could find something understandable and, hopefully, suited to his taste. I included "quickies" for those who like to experiment but don't want to make a big project out of it, and some projects large enough that you could spend as much time as you liked in development.

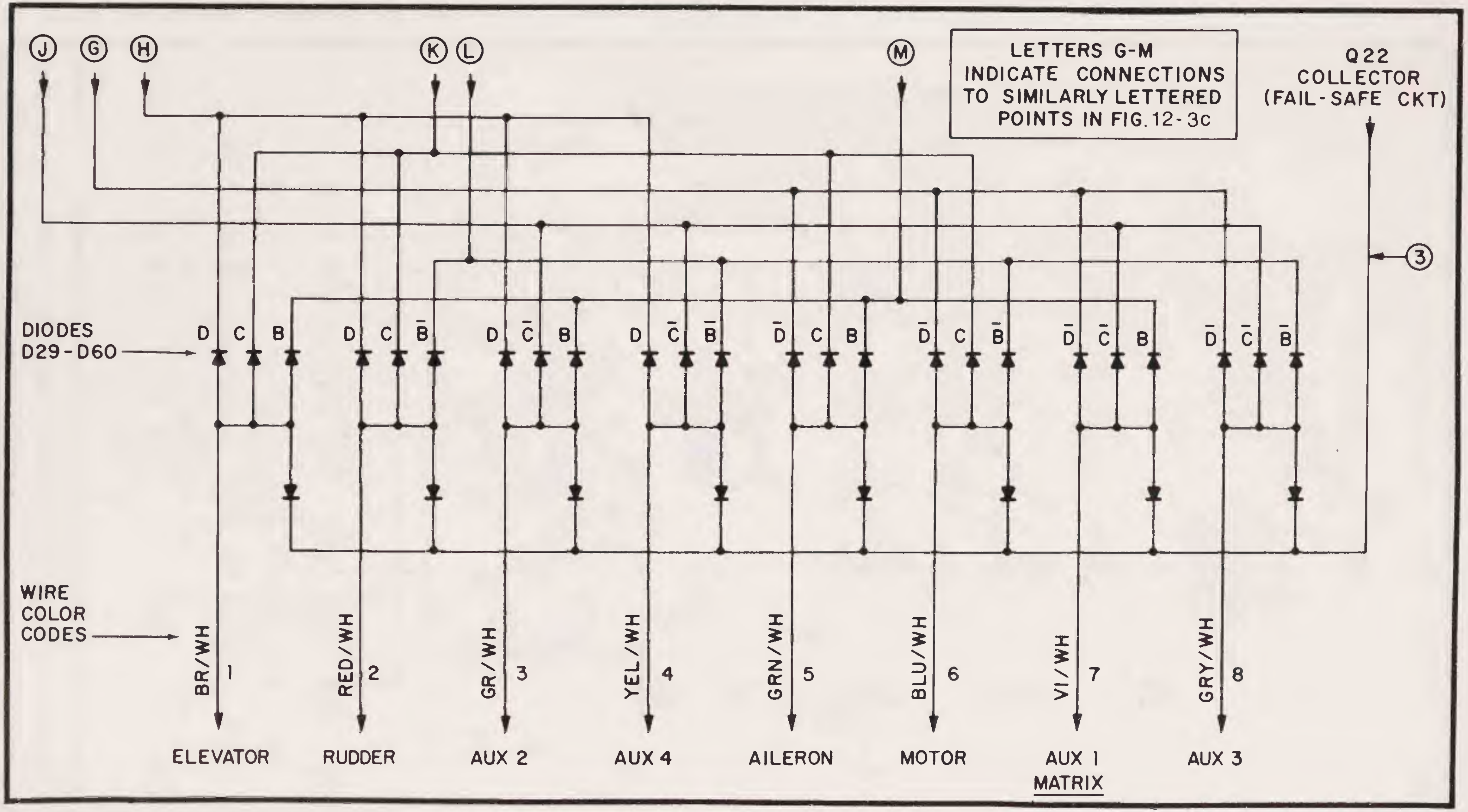


Fig. 12-4. The Bonner servo circuitry.

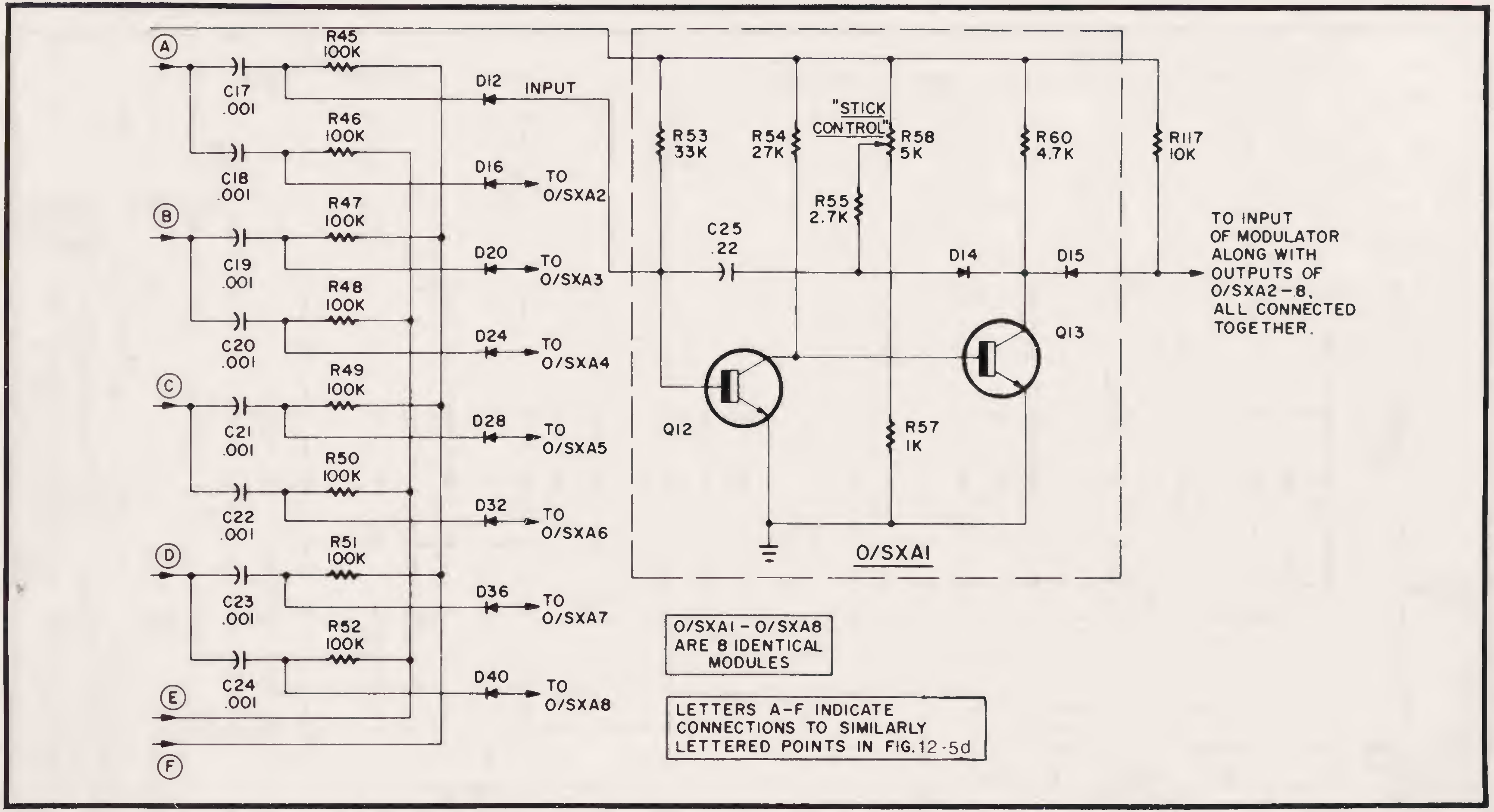


Fig. 12-5a. The Digimite transmitter and coder for eight channels.

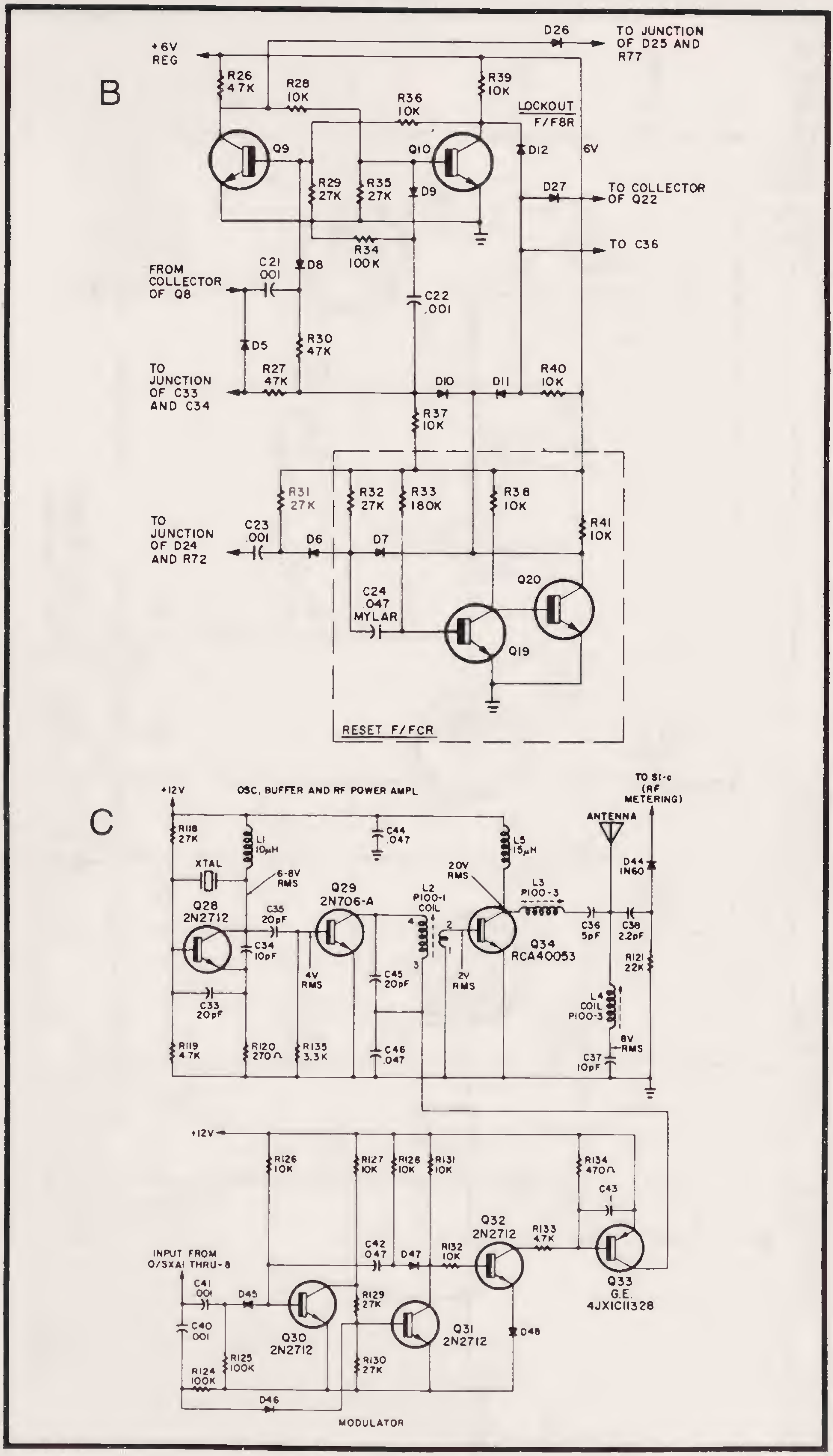


Fig. 12-5. b and c. The Digimite transmitter and coder. Continued from page 250 and continued on pages 252, 253 and 254.

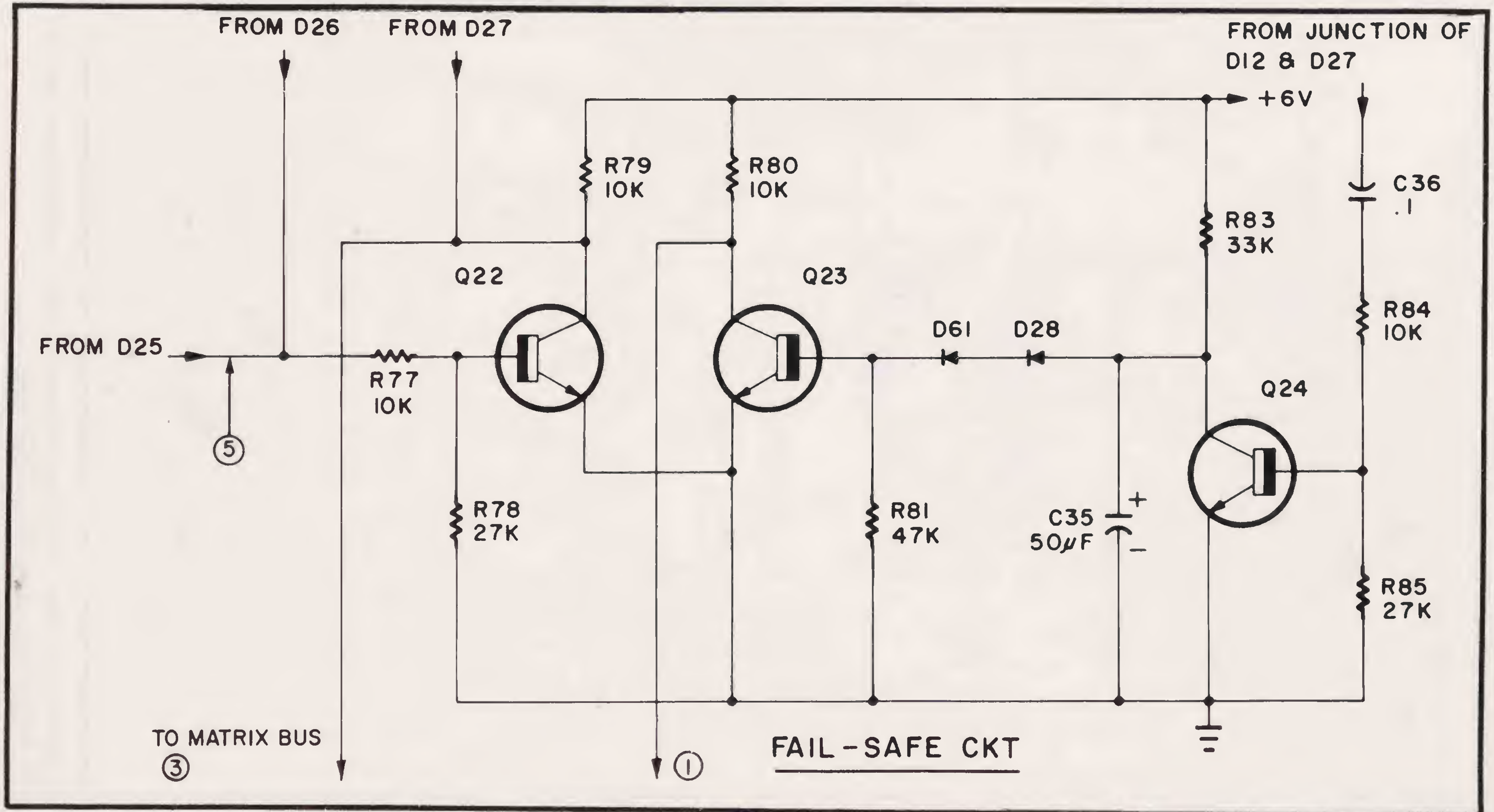


Fig. 12-5d. The Digmite transmitter and coder. Continued from pages 250 and 251 and continued on pages 253 and 254.

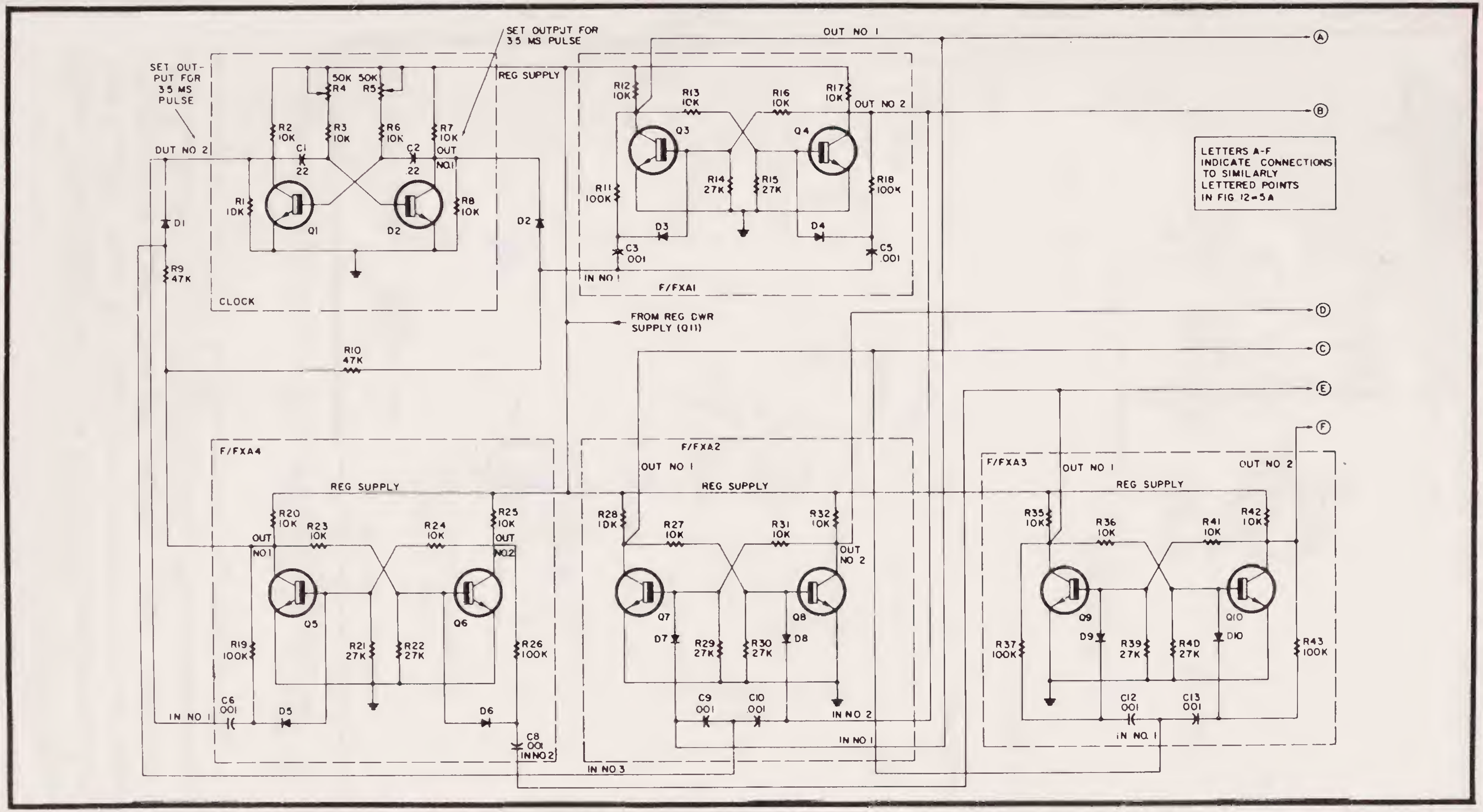


Fig. 12-5e. The Digimite transmitter and coder. Continued from pages 250, 251 and 252 and continued on page 254.

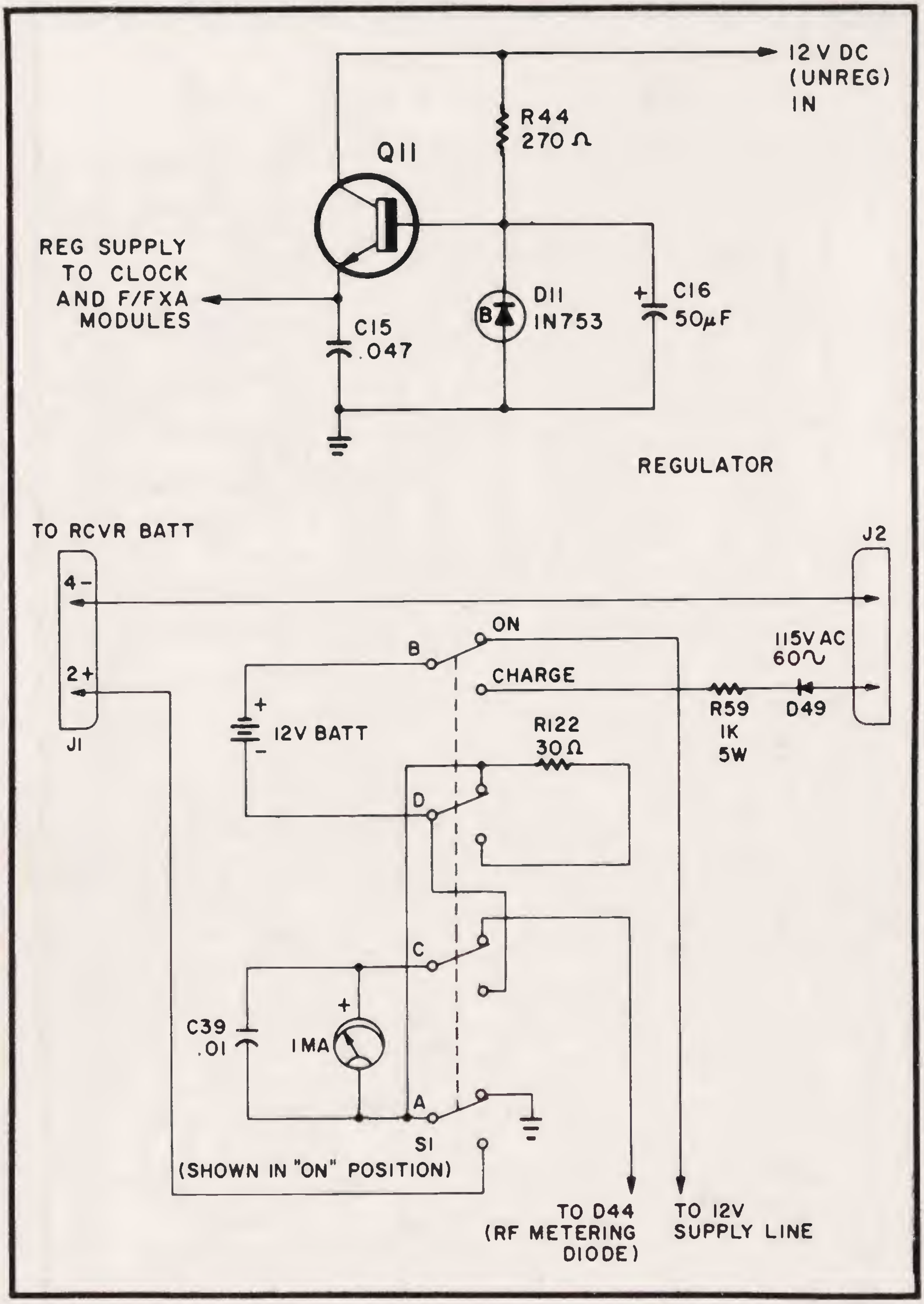
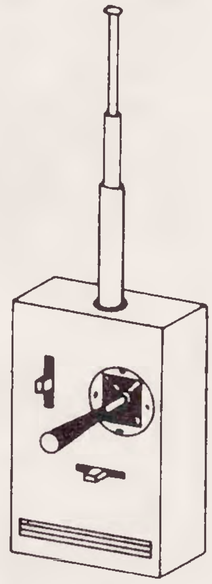


Fig. 12-5f. The Digimite transmitter and coder. Continued from pages 250, 251, 252, and 253.

I might suggest that this volume be used as a textbook for courses in radio control. It contains explanations as well as "laboratory exercises." Finally, the book has material in it which I think is useful to everyone interested in citizens band, radio-amateur communications, and communications in general. Happy flying, boating, car racing, or whatever.

Index



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RADIO CONTROL MANUAL—
System Circuits Construction—3rd Edition by ' tward L. Safford Jr.

the thrill of controlling models remotely with a small radio transmitter excites you, here's a thorough treatment on the radio control of model airplanes, boats, cars, and rockets—o' any type of model- - hand, reference and construction guide describing the varic... ystems and circuits used, from simple 1- and ... annel types to digital and pulse code designs.

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The author is a professional writer who has authored many TAB books. He resides in Houston, Tex.

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