# Model Control by Radio

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# MODEL CONTROL

# by RADIO

*by*

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# Preface

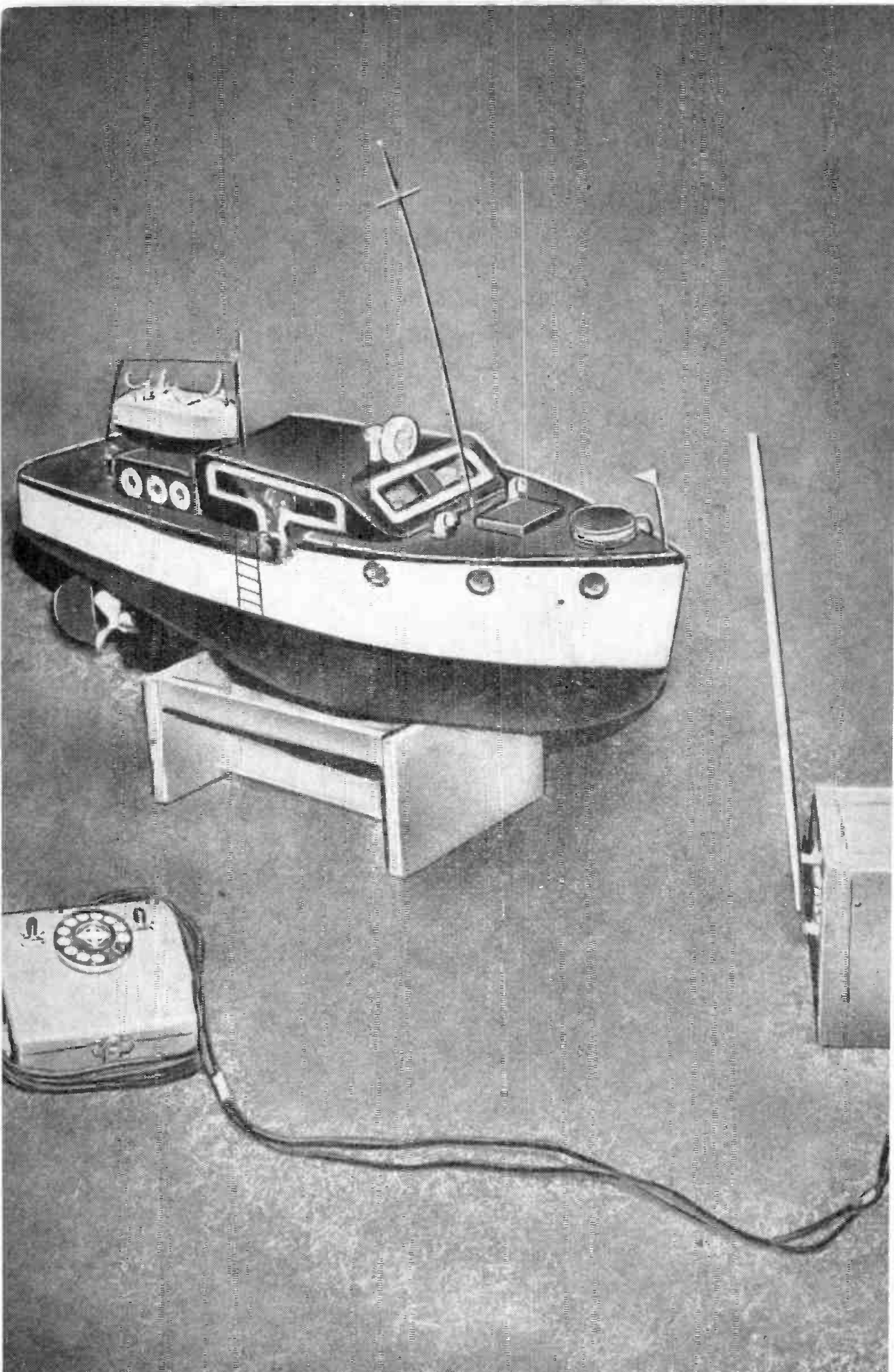
As IN YEARS GONE BY, when 200 meters and below was an unexplored field to radio amateurs and experimenters, so today the field of radio and electronic control is a known, but comparatively unexplored, region. The words, "telemetering," "guided missiles," and "television," are now household bywords, and radio and electronic control is coming into ever greater prominence. Radio and electronic control, a natural and logical extension for radio ham operators, is more than just a continuation of radio communications. For the greater part, ham radio and experimental radio have been almost purely electronic. In this relatively new and exciting hobby of radio and electronic control, mechanical skill and ingenuity must be used together with electronic knowledge.

In the following pages, the author has tried to set forth, in a practical manner, the basic concepts of radio control so that the experimentally minded may conduct investigations and those who wish to increase their knowledge may do so without the burden of complex mathematics. Although the ideas presented are not necessarily new, it is hoped the control concepts gathered here will give the reader a full picture without resorting to hours of research and investigation.

This book is so arranged that those having the necessary knowledge of radio control can eliminate basic theory and proceed immediately to the section on construction. The possession of a radio amateur operator's license is helpful and, for control operation on certain frequencies, a necessity.

Radio control circuits make extensive use of relays. Every relay not mentioned specifically as being normally open or normally closed due to circuit conditions is considered to have its armature pushing against or touching the upper contact of the relay when the relay is in a nonenergized position. This holds true for both single-pole, single-throw and double-pole, double-throw relays.

The publishers acknowledge with thanks the cooperation of the following in supplying material for this book: Fig. 202, Fig. 504, Fig. 703 — *CQ* Magazine; Fig. 801 — Raytheon Mfg. Co.; Fig. 802, Fig. 810, Fig. 901, Fig. 907, and description of resonant-reed decoder and pulse-rate decoder, pages 85-86 Model Airplane News; text on pages 87-89 — Capt Wm. Sydnor. Photographs by Gordon Folkers.



Radio-controlled model boat using a telephone dial coder.

# Chapter 1

## Basic Concepts

ELECTRONIC CONTROL means that some device, or devices, will perform various operations through the use of electric currents. Typical everyday examples are:

(1) Speed control of electric motors;
(2) Automatic elevator systems;
(3) Automatic heating or cooling systems;
(4) Radio control of boats, planes, cars, etc.;
(5) Aircraft automatic pilots.

Generally speaking, the control field might be divided into two broad groups. The first includes those in which the control is an automatic process, not requiring human attention once it has been set. Into this group would fall 2, 3, and 5 of those mentioned above. The second group is that in which control is governed by a human operator, and into this group would fall 1 and 4. These could also be of the automatic type; however, in this book human control will be assumed.

In any control system, the ultimate objective is to control the flow of power in a regulated manner from a primary source to some device, so that desired operations will be performed.

For a control system to become operative, certain functions must take place within the system itself. These are performed by the major components, illustrated in block form in Fig. 101.

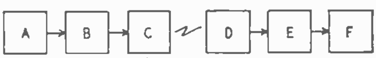



*Fig. 101—Block diagram of control system.*

The functions of these components are as follows:

(A) The command source which originates the command (by means of a control);
(B) The coding device which converts the command into a signal suitable for transmission;
(C) The transmission system which sends the coded command to the desired destination;

(D) The receiver;

(E) The decoder, which interprets the command and causes power to flow to the desired translating system;

(F) The translating system or device which converts this flow of power into heat, light, or mechanical energy.

When all of these are in operation, a control system is functioning. This is the general picture. Now let's consider these components in more detail, starting with block A.

## Command Source and Control Devices

The command source is the human operator. The technique which an operator uses in building a control device to issue the command is limited only by his own skill and ingenuity. The control device can be very simple, such as a switch having a limited number of contacts. Alternatively, the control device can be complex and may actually be a prototype of the control used in the craft which is being operated. It is advisable to have the control simulate the desired remotely controlled action: if the control is a switch, a motion of the switch to the left should mean a motion of the remotely controlled craft to the left; a forward motion of the switch would result in a forward motion of the controlled device. Such a control arrangement may not always be possible, but should be used whenever conditions permit.

The control operated by the command source (or human operator) can be an ordinary toggle switch. This is satisfactory when commands are not sent frequently and when a limited number of maneuvers are to be performed. When it is desired that the transmitter send out a succession of pulses rather than a continuous tone, the use of a push-button switch is more practical than a toggle switch. The push-button switch could be of the type used on doorbells.

The most obvious control, and one which will immediately suggest itself to those having transmitter experience, is a telegraph key. The key can control the operation of a transmitter for either continuous or intermittent (pulsed) operation. The telephone key switch, sometimes called an "anticapacity" switch also lends itself very favorably to control work.

In short, any device which can make and break one or more circuits can be used as the control by the operator. This would include, in addition to the simple control devices already mentioned, such complicated units as the telephone dial, rotary switches, and multiposition lever switches. In the photograph facing page 7 a telephone dial is used to control a transmitter to send commands to a radio-controlled boat.

Ultimately, the type of control you use will be determined by the amount of control and the flexibility of control you want to exercise over your remotely operating craft.

# Chapter 2

## Coding and Coders

Block B of Fig. 101 is the coding device. The mechanical or electronic construction of the coder itself depends upon the system of coding employed, and may also depend upon the type of transmission used. It is necessary, before considering the component itself, to understand the methods of coding.

### Methods of Coding

Coding of commands, so that they are made suitable for transmission, can be arranged into two basic groups. The first of these might be called the continuous-wave types, and the second the pulse types. The continuous-wave types are associated with uninterrupted frequencies of constant amplitude, or continuous carriers, while the pulse types are thought of as carriers which are broken intermittently or in which the modulation of the carrier is broken in such a manner that pulses are transmitted.

In the first category, an example of coding would be to let one frequency, say of 7,000 kilocycles, represent one command, a frequency of 7,150 kilocycles a second command, and 7,300 kilocycles a third. It can be seen that the separation of commands in kilocycles would be dependent upon the selectivity of the receiver or, for example, the magnitude of the output deviation of a frequency-modulation detector from the center frequency.

Another example of coding with constant frequencies is to modulate a constant carrier with the desired command, either by frequency-modulation or amplitude modulation. In this case, tones or subfrequencies may be used to modulate the carrier, and each different tone or subfrequency then represents a different command. This system is perhaps the most commonly used today in radio control.

The second general type of coding refers to systems in which pulses represent the commands. The pulse may be radio-frequency energy, or it may be a tone used to modulate a carrier and which is pulsed to convey the desired information.

Pulses may be further broken down into two groups, the first of which is called pulse codes, and the second variations of pulse rates. The transmission of r.f. pulses is controlled by the coder at the transmitter.

## Pulse Codes

Pulse codes can exist in six distinct groups:

(1) Pulse sequences (numerical),
(2) Pulse-width variations (spacing constant),
(3) Pulse-spacing variations (width constant),
(4) Pulse sequences (pulse presence - pulse omission),
(5) Pulse-rate variations,
(6) Pulse amplitudes.

This, however, does not mean that a code will consist of just one of these six methods. It may be composed of a combination of the above arrangements, depending upon the application. Now for a closer examination of each, in turn.

## Numerical Pulse Sequences

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

Motor on .......................... one pulse
Motor off .......................... two pulses
Motor full speed ................... three pulses
Motor half speed ................... four pulses

If a great number of commands are to be given, the number of pulses in the last sequence will require a comparatively large amount of time. We must consider the relative spacing between the pulses in each numerical sequence and the spacing between sequences. The interval between all pulses in a sequence or command should be the same; the spacing between each sequence should be much longer, or at least long enough so that the decoder in the receiver knows that a command has been given and thus be able to distinguish it from others following. If four commands were sent, one after another, they would appear as shown in Fig. 201.


*Fig. 201—Four transmitted commands.*

One of the best examples of a coder which puts commands into the numerical sequence form is the telephone dial. In this case the telephone dial performs the dual function of coder and control device. This unit has a cam on the underside which closes a set of contacts a given number of times when a number is dialed. It is spring-powered and has a friction governor so that when the dial is pulled back and released, the pulses come at a uniform rate and with uniform duration and spacing. The time it takes to dial a second number is so much longer than the interval between the pulses that the decoding equipment at the telephone office knows that a new number or command is being transmitted.

## Pulse-Width Variations — Spacing Constant

The second form of pulse coding is that in which the pulse width varies, but the spacing between the pulses remains constant. An excellent example of this is the code used in radio telegraphy. A series of short pulses might be used to represent one command and a series of long pulses a second command.

A simple coder suitable for transmitting this arrangement might be a motor-driven arm made of some conducting material such as copper, aluminum, or brass. This type of coder is shown in Fig. 202. The arm rides over concentric

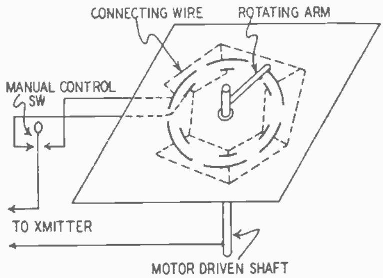



*Fig. 202—Motor-driven coder.*

contacts, one set giving short pulses and the other set long pulses. By closing the circuit to the proper set at the proper time, the correct command would be transmitted. The coder is just a means of keying a transmitter. The manual control switch is used in conjunction with the coder. The position of the control switch determines whether the transmitter will send out a series of narrow or wide pulses. The photograph (Fig. 203) shows a small transmitter

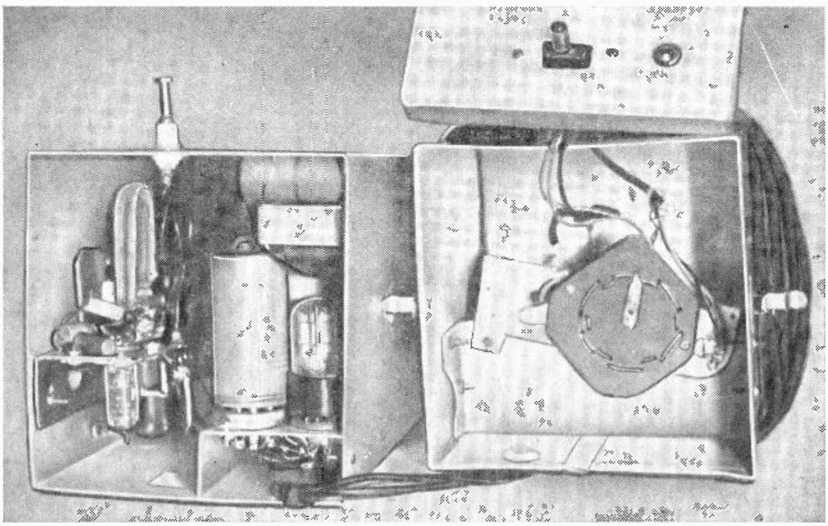


*Fig. 203—Motor-driven coder which will give equally spaced long or short pulses.*

(left) and a coder (right). The coder is the same type appearing in Fig. 202. Note the single-pole, double-throw manual-lever switch immediately above the coder. This is our control switch. When, for example, the control switch is pushed toward the left, the coder opens and closes the transmitter, resulting in a succession of wide pulses. Short pulses are produced when the control switch is pushed toward the right. When the control switch is in the center (or neutral position), the transmitter is open-circuited and does not operate.

## Pulse-Spacing Variations — Width Constant

In this coding system the pulse width is constant, but the spacing varies. To illustrate the use of such a sequence we should first visualize a unit of time, say 1 second. All commands will occupy this length of time. If only four pulses are used to convey the commands, then the spacing between them in this 1-second period would determine which command was transmitted. This is illustrated in Fig. 204.


*Fig. 204—Pulse width constant; pulse spacing varied.*

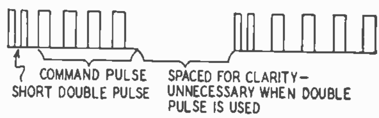



*Fig. 205—Commands preceded by short double pulse.*

With this system, since the spacing of the pulses varies, it might be advisable to use some means other than a long time interval between commands to allow the decoder to distinguish one from another. Each command might be started with a double pulse of some fixed duration. It would signal the fact that a command is coming, and each time it is received it would inform the decoder that a new command was on the way or that the previous command was going to be repeated. The pulses serve to separate the commands, however used. A sequence of this type for two different commands is represented in Fig. 205.

An example of a coder which will provide a variation in either the pulse width or spacing is shown in Fig. 206. When the tube conducts, the flow of

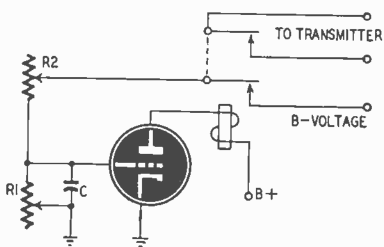



*Fig. 206—Coder for variation in pulse width or spacing.*

current closes the relay in the plate circuit, connecting (through the bottom contacts of the relay) the grid circuit to a source of B minus voltage. This voltage is sufficiently high to drive the tube to plate current cutoff. The relay then opens. However, during the time the relay was closed, capacitor C in the grid circuit had an opportunity to become charged. This charged capacitor holds the tube cut off until the capacitor can discharge through the resistance across it; then the action repeats.

By having a variable resistance R2 in series with the capacitor C, the time it takes for the capacitor to charge will be controlled, thus regulating the length of time the upper contacts of the relay cause the signal to be transmitted. Under such circumstances we are actually governing the *width* of the transmitted signal or pulse.

When tube current flows, the relay, being in the down position, closes a transmitter circuit and puts the transmitter on the air. The size of the resistor R1 determines the time it takes the capacitor to discharge, governs the time the signal is *off* the air, and thereby controls the pulse spacing.

## Pulse Sequences (Pulse Presence — Pulse Omission)

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

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

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

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

In one system using this particular pulse-coding sequence, the motor-driven arm passed over a number of contacts every revolution. Four of these contacts were the command contacts; a fifth caused a receiving motor to slow down; a sixth notified the receiving motor to speed up. A seventh contact was used to energize the particular circuit set up by the command pulses.

It might be mentioned that this type of coding is the one used in modern teletype printers and typewriters. When a key of the typewriter is depressed, it makes a motor-driven arm send out the right sequence to cause the receiving unit to print the right letter.

## Pulse-Rate Variations

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

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

A coder might present this arrangement of pulses to a transmission system in several ways. One instance would be to use a thyratron type of tube, for example, an 884 gas tube connected as a sawtooth oscillator. The firing rate of the tube is controlled by the size of resistance and capacitance in the plate circuit and by the amount of plate and grid voltage present on the tube (See Fig. 207-a.). If we hold the grid voltage and plate voltage at a constant value and vary the resistance R, we can change the firing time, either increasing or decreasing the number of firings per second. We can also hold the resistance constant and accomplish the same effect by using several capacitors attached to a rotary switch so that they could be inserted in the circuit one at a time. Such a circuit is shown in Fig. 207-b.

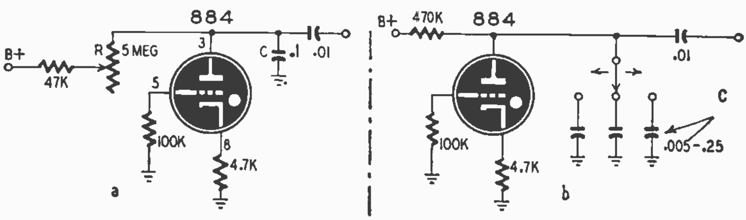



*Fig. 207—Gas tube used in coder circuit. Firing of gas tube controlled by varying R (circuit a) or by varying C (circuit b).*

It is also possible to vary the pulse rate mechanically by changing the speed of a motor which is driving an arm over a set of contacts.

## Pulse Amplitudes

Coding by means of variations in pulse amplitudes means increasing or decreasing the amount of power the transmitter puts out with each pulse or pulse train. This method is not recommended because of the tendency of the receiver to become confused, the normal signal varying as the controlled body moves and thus making it almost impossible to distinguish between a transmitted command or a fading signal. This coding method does have a high usability when applied to a wire transmission system. For example, at the receiving end a group of relays might be so arranged that some of the relays responded to pulses of a low voltage value, others to a higher value, etc.

The coder for this arrangement would simply be a contact selector which would select that contact having the proper amount of voltage for the command to be transmitted.

Mechanical-electrical arrangements, in some forms of coding, are quite elaborate. The ability to control, aside from the electronic standpoint, depends upon the operator's ability to transmit the commands easily and at the proper time.

# Chapter 3

## Transmission Systems

THE TYPE of transmission system we want to use may depend upon both the type of coding employed and the particular application of the control system. Conversely, it is possible that the type of coding will be second choice and the transmission system will govern its selection.

One example in which the transmission system is first choice is in connection with model aircraft. Here it is essential that the receiving component be as small and as light as possible. Since tubes are available which can accomplish the job of reception and decoding in one bulb (when the coding is of the pulse type), this is most commonly used.

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

(1) Radio or electromagnetic waves,
(2) Sound waves,
(3) Light beams,
(4) Heat waves (infrared),
(5) Wires.

### Radio Transmission

The transmitter may be unmodulated or it may be modulated by AM, PM, or FM methods. With non-modulated transmitters, pulse codes or sequences can be readily transmitted. We can use variations in pulse rates or different radio frequencies. With modulated transmitters, pulses, different frequencies, or pulse rates may be transmitted.

The power and size of transmitters are generally determined by the range to be covered, by the coding used (a modulated transmitter might be larger than a nonmodulated unit), and by the transmitting antenna. The operating frequency has a pronounced effect on the size of the transmitter.

The power and size of the transmitter are also determined by the type of primary supply used. It might work from 110 volts of house current, use a Vibro-pack energized by a car battery or operate from dry-cell batteries.

The frequencies on which the transmitter will be operated are designated by the Federal Communications Commission and comprise the amateur bands and the citizens' band. These bands are broad, extending in segments from 160 meters down into the tenths-of-a-meter region. The frequencies used (of those allocated) may be determined by the type of system to be controlled, taking into consideration whether or not the receiving device is always to be in sight, whether the antenna is small or large, and whether using a particular band for operation would unduly crowd it or cause interference.

Generally speaking, the shorter wavelengths (1 to 6 meters), are best suited for the hobbyist's control system since the units and antennas may be small. Radiation is not overly great, will not cause interference, and yet has adequate range for purposes of radio control.

The transmitter power depends upon the type of receiver to be used and the distance to be covered. For a given distance, it is possible to cut down on transmitter power requirements by increasing the sensitivity of the receiver or, conversely, it is possible to cut down the size and weight of the receiver by increasing the transmitter power.

For a given amount of transmitter power, judicious choice of an antenna makes possible the greatest efficiency. A transmitter operating on high frequencies, with a beam-type antenna and an output of 5 watts, can have as much range as a transmitter with 50 watts working into a poor antenna.

## Sound-Wave Transmission

This might, at first, be thought a method with limited application. However, there are cases where this is the solution to a control problem. Radio transmission systems operating on other than the citizens' band require a license; a sound system does not! A sound system might be merely a public address system which propagates pressure waves in the direction of the controlled body, and the receiver would be merely an audio amplifier with a microphone as an input. Coding could be either different tones or a single pulsed tone.

To answer the question immediately as to the disturbing effect of transmitting pulses over a sound system; if the input to the sound system were from an audio oscillator tuned to 15,000 cycles, few people could even hear the tone when it was transmitted.

With this tone frequency, practically all the aspects of radio control would be present except that the transmitting range would, of course, be limited.

## Light-Beam Transmission

It is conceivable that light beams might be used as a transmission system. Light beams can be modulated and the signals received and decoded. There is one big disadvantage to using light beams for control: the receiver must always be so orientated that it can see the transmitting source. If a mobile controlled unit were turned so it could not see the transmitting source, the control link would be broken.

## Infrared-Wave Transmission

Infrared waves, like light beams, can transmit intelligence and like light beams they have the disadvantage that the receiver must always see the transmitter. Infrared transmitters and receivers are not commonly used.

## Wired Transmission

This is perhaps the most common method used between fixed transmitting and receiving points. It is possible to attach a pair of flexible wires to a model car or boat and investigate the control techniques easily and simply. One or multiple pairs of wires may be used, but since this method is the most obvious, details will be left to the reader.

# Chapter 4

## Receivers

THE AUTODYNE, or regenerative type of receiver, consisting of an oscillating detector and audio section, might be thought an ideal type of receiver for a control system. Although the gain and selectivity of this type of set is excellent, its very selectiveness almost eliminates it. A receiver of this type has so pronounced a tendency to drift and become detuned from its signal that it is seldom used for control work.

### Superregenerative Receiver

The superregenerative receiver has very wide application in radio control. It employs the least number of tubes, has a very high gain, and is not unduly selective. Because of its broad tuning, it does not lose signals easily. Superregenerative receivers designed for control applications may have from one tube to as many as a superheterodyne, depending upon the distance and the type of coding to be employed.

The basic superregenerative receiver is an oscillating type of detector. There are three possible circuit variations:

(1) In the first circuit (Fig. 401), a grid voltage builds up across a resistance

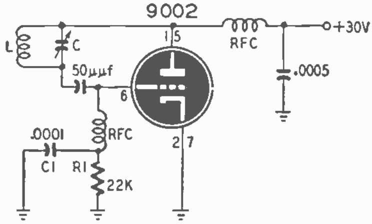



*Fig.* 401—*Superregenerative receiver.*

R1 which has a capacitor C1 across it. This grid voltage, produced when the grid draws current, makes the grid negative with respect to the cathode. The grid voltage builds up and finally reaches an amplitude sufficient to cut off the flow of plate current in the tube. Capacitor C1, which has become charged, discharges through resistor R1, thus holding the tube in a condition of plate current cutoff for a small portion of time. When the charge on the capacitor drops to such a value that the grid voltage is small, the tube again goes into a regenerative state, into oscillation, and the entire cycle repeats itself. In a self-quenching circuit, the output of the tube consists of bursts of r.f. energy which are fairly evenly distributed, as illustrated in Fig. 402.

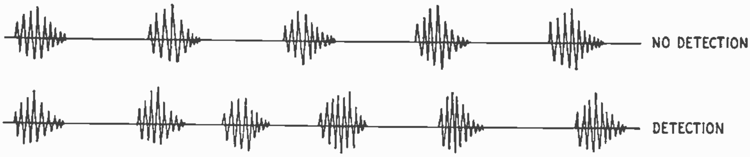



*Fig. 402—Superregenerative r.f. output with and without signal. Spacing of r.f. depends upon signal strength.*

When a received signal is present in the tank circuit L-C, it causes these bursts of r.f. energy to come closer together, the amount depending upon the signal strength. If the signal is modulated (that is, the strength is varied), the spacing between the bursts varies, and when these signals are converted into currents, they flow strong and weak, reproducing the modulated signal.

The important point in connection with this type of circuit is that each time the oscillations build up, they reach a saturation value and thus the detector is good only for the reception of modulated signals.

(2) The second superregenerative circuit (Fig. 403), is somewhat modified.

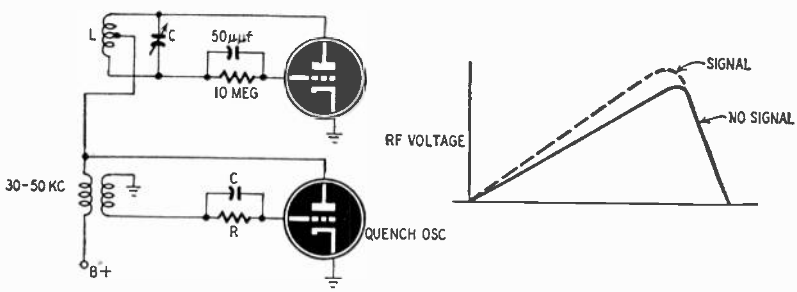



*Fig. 403—Superregenerative receiver using a separate quench oscillator. The r.f. voltage increases with signal.*

Here a second voltage of a sinusoidal type, produced by a quench oscillator, is impressed on the tube so that it cuts off the tube when the negative half cycle of the sinusoid is present. The tube can be caused to cut off before it reaches saturation value. In this case, not only can modulated signals be detected (in the same manner as before) but pulses can also be detected. The presence of a pulse of radio-frequency energy in the tank circuit L-C, can cause the *amplitude* of the bursts of r.f. from the tube to increase. These pulse amplitudes can then be separated and made to operate a relay tube if so desired. The quench oscillator frequency is not critical and may range from 30 to 50 kc. The quench oscillator grid coil may be tuned, or untuned, as shown. R and C provide grid leak bias for the quench oscillator.

(3) Finally, we can use a special type of tube in a self-quenching superregenerative circuit. The tube is a gas-filled triode, adjusted so that it does not superregenerate without the presence of a signal. When a signal is received, the additional energy in the tank circuit forces the tube to go into oscillation. These oscillations are then self-quenched.

The important point about the gas-filled triode is that in the nonsuperregenerating condition, the tube, because of its gas content, draws a relatively large amount of plate current, enough to operate a sensitive relay. When signals are received, and the tube does go into superregeneration, the high grid bias causes a severe drop in the plate current. The large plate current swing makes this an ideal one-tube receiver for control purposes. For the hobbyist, the superregenerative receiver is the most applicable since it is small, simple, and operates on high frequencies.

## Superheterodyne Receiver

Superheterodynes can be used in radio control work, since they are adaptable for either pulse or modulated continuous-wave reception. Superheterodynes require more than one tube and tend to become large and heavy. The circuit is rather complex, especially at high frequencies.

## Plate Circuit Relays

In that part of the receiver where we would normally expect a loudspeaker, we have a relay or relays operating in response to the command signals.

Two basic methods are used to energize a relay in the plate circuit of the output tube of a receiver. In the first, shown in Fig. 404, the tube is biased to

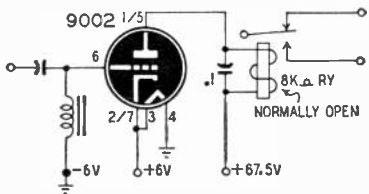



*Fig.* 404—*The relay is the plate load.*

cutoff by the cathode connection to the plus side of the 6-volt filament. The grid is returned to the negative side of the filament which is connected to ground. When a signal is received, it drives the grid sufficiently positive to override the initial bias, permitting the tube to conduct. The resultant flow of plate current closes the relay. The requirement here is that the grid circuit of the tube should have very little d.c. resistance. When the grid goes positive and draws grid current, we do not want it to develop a bias which will assist the fixed bias and thus prevent the tube from operating. Most often a transformer or choke is used in the grid circuit. These components have a high impedance to the signal, but little d.c. resistance.

The second method (Fig. 405), is to remove the bias from the output tube so that the large flow of plate current normally results in a closing of the relay. In this case a high resistance in the grid circuit develops a high bias upon receipt of a signal, causing plate current cutoff. Under these conditions the relay opens and makes a contact in the open position.

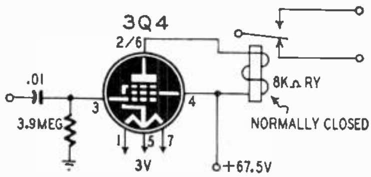


*Fig. 405—Normally closed plate relay.*

When the output tube of the receiver controls more than one relay, the output is called a decoder, and will be discussed in the chapter on decoders.

# Chapter 5

## Decoders

ONCE THE COMMAND, in code form, has been transmitted from the control point and received at the remote location by one of the methods previously mentioned, it is then fed from the receiver into the decoding section. This, as mentioned earlier, causes power to flow to that circuit which the coded command designated.

The actual type of decoder used will depend upon the choice of coding, allowable size, weight requirements, and the amount of power available. The decoder and the unit which it controls must have power to operate. Another factor which enters into the type of a decoder used is the human one, the imagination and ability of a constructor to visualize and construct units heretofore unknown.

Decoders, like some of the other parts of the system, can be subdivided into several categories for more logical discussion. The two basic decoder types here are:

Electro-mechanical,
Electronic.

Each type may consist of methods which are frequency or pulse selective. Electromechanical decoders consist of:

Frequency-selective types
(a) resonant relays
(b) resonant reeds
Pulse-selective types
(a) relays (single relays, delay relays, and relay chains)
(b) steppers (relay or motor driven, cyclic or reset)
(c) motor-driven commutators

Electronic decoders consist of:

Frequency-selective types
(a) bandpass, band-elimination (rejection) filters
(b) discriminators
(c) separate receivers
Pulse-selective types
(a) delay lines and coincidence circuits
(b) counting circuits
(c) amplitude-detecting circuits
(d) gating circuits
(e) discriminators (pulse rates)

Although this is not a complete list, it permits discussion of most methods of decoding used at the present time.

## Resonant Relays and Resonant Reeds

It is well known that any metal bar, when displaced and released, will oscillate at some particular frequency, determined by its length, thickness, and width. A tuning fork is the simplest example. Another method of making a metal bar vibrate is to suspend it within a coil in such a manner that one end of the bar is held rigid, the other end being free. The coil is then energized with an alternating current. As the frequency of the alternating current approaches that at which the bar is resonant, the bar will vibrate with a large amplitude.

This principle is used in both resonant-relay and resonant-reed decoders. The resonant reeds find their best application in powerhouses where they are set to monitor the line frequency. Others are used in aircraft to indicate the correct landing beam position.

As a decoding device, the armature is adjusted to hit a set of nonmovable contacts when it vibrates at its maximum swing, caused by feeding a particular frequency into its coil. As it vibrates against a fixed contact, it can make a power relay close. If this relay is of the delay type which will hold closed during the small breaks caused when the armature is away from the contacts, it allows power to flow to some controlled circuit.

Because the armatures of resonant relays and reeds can be made of different dimensions, they will respond to different frequencies. This type of unit may be used to decode a set of commands represented by different frequencies.

## Single Relays

In the pulse-selective field of electromechanical devices, the ordinary single-pole, double-throw relay can be used to discriminate between some sequences. For example, suppose a sequence such as:

| | |
|---|---|
| Command # 1 | short pulses — long spacings |
| Command # 2 | short spacing — long pulses |

were transmitted. Because of the short pulses, the relay will spend a short amount

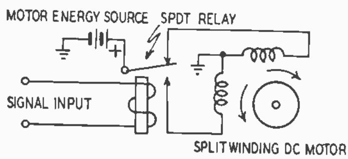



*Fig.* 501—*Forward and reverse motor rotation.*

of time on the "make" contact and, because of the long spacings, a longer time on the back or "break" contact. If each contact went to the windings of a motor so that the "make" contact caused forward rotation, and the "break" contact caused reverse rotation, the motor would move in a reverse direction with the first command.

With the second command the motor would move in the forward direction. If the pulses and the spacings were equal, the motor would not move. Thus, this single relay may be used to decode certain types of coding. An example of this circuit is shown in Fig 501.

## Delay Relays

Delay relays may be of two basic types: those which delay in closing; and those which delay in opening, but close instantly with a signal. A delay relay may be made by using resistance and capacitance, or both, in the relay circuit. A delay relay may also be constructed by connecting a high value of capacitance across a high-resistance relay, such as a Sigma 4-F.

In the latter case (Fig. 502), when a pulse is applied to the combination, the

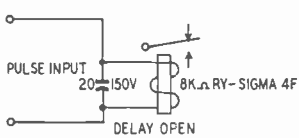



*Fig. 502—Delay in opening relay.*

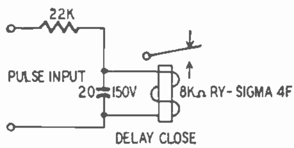



*Fig. 503—Delay in closing relay.*

relay closes and the capacitor takes a charge simultaneously. At the end of the pulse, the capacitor discharges through the relay and holds it closed for a period of time determined by the resistance of the relay and the size of the capacitor. This is a delay-in-releasing type.

A delay-in-closing type may be made by inserting a resistance in the energizing line, as shown in Fig. 503. When the pulse is applied, the capacitor, acting like a short circuit at the other end of the resistance, causes a large voltage drop across the resistance and does not allow enough current to reach the relay to close it. However, the capacitor will finally charge and current will pass through the relay, closing it, but only after an interval of charging time.

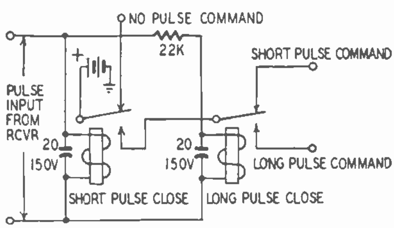



*Fig. 504—Delay-open relay and delay-close relay in shunt.*

It is possible to use two of these delay-type relays in a parallel (delay-open relay and delay-close relay, in shunt) to decode a pulse sequence. The circuit is shown in Fig. 504. Upon the receipt of short pulses with long spacing, the first relay will close. The second relay will not close since the pulse does not exist for a long enough time to charge the capacitor through the resistor. However, when signals consisting of long pulses with short spacing are received, both relays will close.

## Relay Chains

Relay chains are of varied and assorted types. They can count pulses and distinguish between long and short pulses or between pulses of different amplitudes.

Examine the circuit in Fig. 505. When the switch Sw is closed, RY1 is energized. Since capacitor C2 is shunted across this relay, it will become charged. If we open the switch, capacitor C2 will discharge through the relay winding, thus keeping the relay closed. During the time that this relay energized, the bottom armature of the relay has moved down and touches contact 4. This could close some circuit which we wished to be in operation.

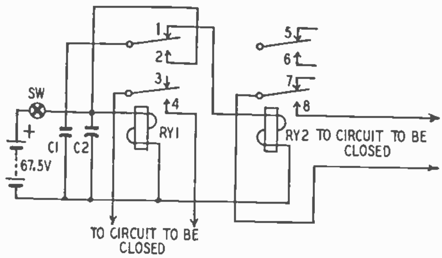



*Fig. 505—Relay chain using two relays.*

Now let's examine the top contacts of this relay (upper armature and contact points 1 and 2). Capacitor C1 is connected to the upper armature and the negative side of the battery. When the relay is energized, the upper armature touches contact 2 of the relay, placing C1 across the battery. As a result, C1 becomes charged. As long as the relay is closed, C1 is shunted across the battery and does no useful work. When the switch is opened, RY1 will be held closed by the discharging action of C2. When this discharging action is completed, the relay will open. When it does so, the upper armature will touch contact 1. This has the effect of removing C1 from across the battery and at the same time placing it in shunt across RY2. C1 will now discharge through RY2, energizing it. The lower armature of this relay will touch contact 8, closing another circuit. Observe that RY2 will not close until RY1 has opened.

In Fig. 506 we have a relay chain used to control the operation of a motor. Assume that V1 and V2 are the relay tubes of a receiver and that they respond to different audio frequencies. For example, V1 will operate when the frequency is 1,000 cycles per second, while V2 will respond to a tone of 2,000 cycles per second. We can also assume that our only object is to start and stop the motor shown in the drawing.

Over at the remote command post, the operator closes a switch, causing the transmitter to send out a signal which contains the 1,000-cycle tone. This signal might be a momentary one. Relay tube V1 will respond to this signal, and sufficient current will flow in the plate circuit of this tube to close RY1. The armature of RY1 will move down and touch contact 1. This has the effect of placing RY3 directly across the B-supply, energizing RY3 and closing it. The upper armature of RY3 will move down and touch contact 4. The lower armature will touch contact 5.

If, at the transmitter, the operator discontinues the transmission of the 1,000-cycle signal and substitutes a 2,000-cycle signal, relay tube V2 will operate. This will close RY2. This will connect the plus side of the battery to contact 5 of RY3. It might be thought that there would be no connection between contact 5 and its armature since RY1 opened in the absence of the 1,000-cycle signal. However, the discharge of C2 through RY3 manages to keep that relay closed for an additional short period of time.

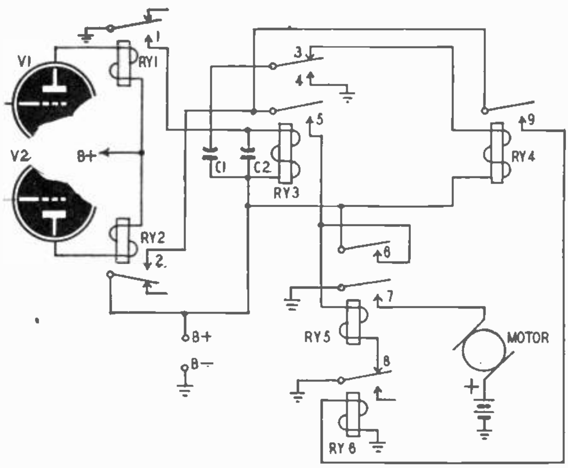



*Fig. 506—Relay chain used to control operation of a motor.*

Now let's take a look at RY5. One side of the relay coil is connected to the negative side of the power supply through the armature of RY6 and contact 8. The upper side of the coil of RY5 is connected to contact 5 of RY3. Since contact 5 touches the armature of RY3, we can continue tracing the circuit as far as contact 2 which is touching the armature of energized RY2. This point is connected to the positive side of the power supply. As a result, RY5 is across the power supply and becomes energized. When RY5 closes, one side of its coil is connected to B plus through its upper armature and contact 6. Since the other end of its coil is grounded through contact 8 of RY6, RY5 will remain closed, even with RY2 and RY3 open.

The motor circuit is now complete. One side of the motor connects to the ground or negative side of its power source through closed contact 7 of RY5. As a result the motor runs in the forward direction. Now the command operator opens the switch to the transmitter and reception of the 2,000-cycle tone ceases.

To stop the motor it is necessary that the 1,000-cycle note be transmitted again for a long enough time to energize RY3 and charge C1. Then the 1,000-cycle note stops. Now, after a time interval just long enough to allow RY3 to open, the 2,000-cycle note is transmitted. This finds RY4 closed due to discharge of C1 through its windings, an action that takes place as soon as RY3 releases.

Closing of RY2 connects B-plus through contact 9 of RY4 to the coil of RY6, causing it to energize. This breaks the ground connection to RY5, which, in releasing, causes the motor to stop. The key to this chain is that RY2 must close momentarily.

Another example of a relay chain decoder appears in Fig. 507. In this instance only one relay tube is used. It can be a 9002 or its equivalent. A feature of this circuit is that capacitor C2 must be larger than either capacitor C1 or C3. The ratio of capacitance should be such that C2 can hold its relay closed for a period of approximately 3 seconds, while capacitors C1 and C3 hold their respective relays closed for 1 second.

We can best understand the operation of this circuit by initially assuming that all the circuits are open and all the relays are in their normally open, or up, position. Note that C1 is directly across the B-supply, since one end of this capacitor is connected to B-plus, while the other side of the capacitor is tied to ground through contact 6 of RY2.

Now let's turn our attention to RY5. This relay, called a latching relay, is so designed that it will lock in and remain in the closed position when it becomes energized. It will remain locked in until it is released, either electrically or mechanically.

If, now, the remotely located transmitter radiates a short pulse which is picked up by our receiver, the signal will find its way to the grid circuit of the 9002 relay tube. The signal is such that it will result in an increase in the tube plate current and consequently RY1 will close. The armature of RY1 will move down and connect contact 1 to ground. If you will trace the circuit from this point, you will find that the upper end of the coil of RY2 has also become connected to ground through contact 4. RY2 is now effectively shunted across the power supply, and hence is energized.

During the entire time that RY2 was open, and with its contacts in the up position, C1 received a charge from the power supply. With RY2 energized, the upper armature of RY2 moves down, touches contact 5 and charged capacitor C1 is placed across RY3. RY3 will close and C3 will become charged. One side of C3 is permanently connected to B+. The other side of C3 becomes connected to B- when the armature of RY3 moves from contact 8 to contact 7.

Now let's go over to RY6. The coil of latching relay, RY5, is connected to the ground line through the top contact (contact 9) of RY3. If the transmitted signal should break momentarily while RY3 is energized, the receiver relay armature will touch contact 2 and energize RY5. Dropping out of the receiver relay at just the right moment caused the closing of some controlled circuit through contact 11 of the latching relay. Note that the downward movement of the upper armature of RY5 to contact 12 connects one side of the relay coil to B−, the other side going to B+ through contact 14.

If the signal is resumed, the armature of RY1 will pull down against contact 1. Nothing happens as far as this part of the circuit is concerned because RY2 is still energized, and being energized has broken the circuit from contact 1 of RY1, since the armature of RY2 moved down from contact 4 to contact 3.

Let's go back to RY3 which will open as soon as C1 has discharged through it. When RY3 opens, it places C3 across RY4. This relay will close and hold closed until C3 has completely discharged.

If the transmitted signal is broken again at just this time, RY6 will be energized through contact 10 of RY4. The armature of RY6 pulls down from contact 14 to 13. When RY6 is energized, it breaks the circuit to RY5, opening the controlled circuit.

If this is not desired at just this moment, the transmitted signal is not interrupted while RY4 is energized. Just as soon as RY4 becomes de-energized, the common line to contact 2 of RY1 is isolated from RY5 and RY6. If the transmitter is now stopped, receiver relay, RY1, has its armature touch contact 2. Nothing happens to change the condition of the circuits.

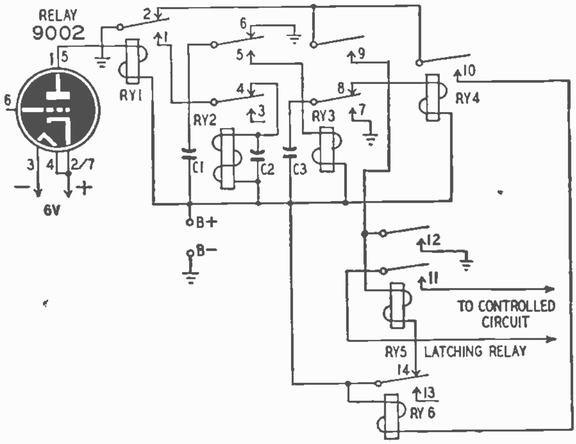



*Fig. 507—Relay chain decoder using only one relay tube.*

Now we can see why the capacitor across the coil of RY2 must be larger than the others. It must be large enough to hold RY2 closed for a long enough time for RY3 and RY4 to energize and de-energize so that if the receiver relay armature is resting on contact 1, it will not cause the chain to start re-cycling before the original action has been completed. With RY4 energized the armature of RY1 can rest against contact 2. When C2 finally discharges, allowing RY2 to open and again connecting its coil to contact 1 of RY1, the chain is again ready for another cycle to be started when the operator sends another signal. The key to the operation of the circuit is to break the transmitted signal when RY3 or RY4 is energized by capacitor action. The first operation starts the controlled circuit; the second stops it.

## Steppers

A stepper, as the word suggests, consists of an arm (or arms) which is moved to any one of a number of contacts, usually arranged in a circle or semicircle. The arm can be moved by relay power, rubber-band power (as in model aircraft), or by an electric motor.

One of the simplest steppers is that which can be constructed from an escapement. This can be a relay and a rotating arm, so arranged that the relay catches the arm every 90 degrees of rotation. (See Fig. 508-a.) To make this unit into a stepper, we merely add a contact wiper to the shaft connected to the bar and then arrange a series of four contacts 90 degrees apart so that the wiper will touch one of the contacts as the relay is closed. When the relay is opened, the wiper will move over to the next contact (See Fig. 508-b.) This stepper is known as a cyclic type, the wiper continuing to move around and around in a circle over the four contacts if the relay is pulsed over a long period of time.

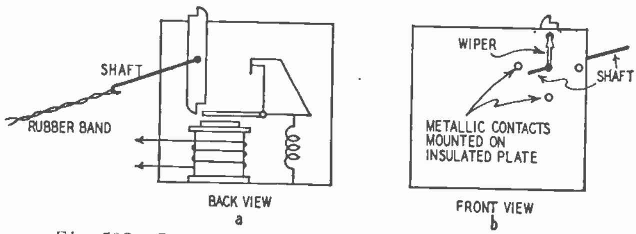



*Fig.* 508—*Back view (a) and front view (b) of a four-contact stepper, controlled by an escapement.*

Relay-driven steppers are those in which the relay itself forces the arm to move, generally by driving a ratcheted wheel when the armature is "pulled in." An example of such a stepper is illustrated in Fig. 509. In this case the multi-notched wheel allows a great number of contacts to be passed over by the wiper. This arrangement has a pawl which prevents the armature from pulling the notched wheel off the contact once it has pulled down and is released by the opening of the circuit to the relay. Notice the arrangement of the pawl. It will allow the notched wheel to move clockwise, but not counterclockwise. There is a reason for this. When the relay armature pulls down, it moves the wheel a small amount; then, due to a breaking of the circuit to the relay, when the armature is pulled

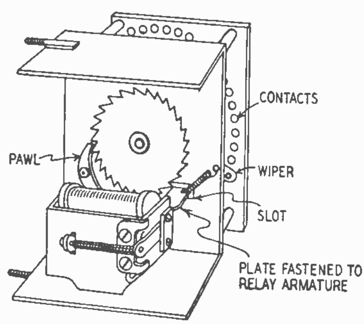



*Fig.* 509—*Relay-driven stepper.*

back up by the spring, it will not tend to pull the wheel back with it. This stepper wheel does not rotate except in small jerks every time the relay is energized, and then only in a clockwise direction.

A motor-driven stepper is one in which a motor causes rotation of the stepper arm, but the amount that the arm moves is governed by a relay. This type of motor driven stepper is described under coders and decoders, Chapter 10.

We have two possible choices when using a stepper in control work. The first is to connect the control circuit directly to the contacts themselves, making it possible to energize any one of several relays, but never more than one at a time. The second method is to energize latching and release relays from these contacts. This makes it possible to energize a number of circuits simultaneously.

In order to use steppers intelligently, we must know how to wire them so that the moving arm of the stepper does not energize any contact, but will energize a circuit when its motion stops. Again calling into use a delay relay, the circuit may be wired as shown in Fig. 510. As long as the stepper arm moves, both the

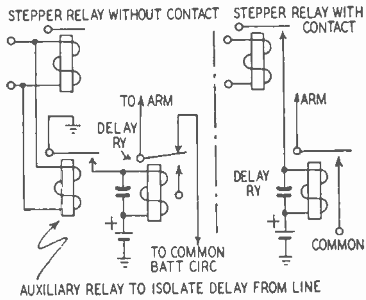



*Fig. 510—Stepper relay with and without contacts.*

stepper relay and the auxiliary relay are energized. This has the effect of putting the delay relay across the battery. The delay relay closes, keeping open the common control line. In a cyclic stepper where the rotation is continuous, when the stepper arm stops, the delay relay "drops out" (after its shunting capacitor discharges), closing the common line and energizing that particular circuit on which the contact arm rests. If the stepper is of the reset type, it is necessary to break the common line through both a delay relay of this type and also through a relay which is used to allow the arm to re-set so that the line is opened when the arm moves in *either* direction.

## Motor-Driven Commutators

The word commutator is familiar to anyone who has ever seen an electric motor or generator of the brush type. A commutator is a number of segments of conducting material, grouped together in a circular manner and insulated from one another. The brush makes contact with each segment as the commutator rotates. The segments may also be arranged in a circle, as shown in Fig. 511, and a rotating arm can sweep over them. The arm, driven by a motor, sweeps over each contact in succession. If the transmitting location has a commutator identical to the one used at the receiving location and the two arms move in exact synchronization, then a pulse code of the presence-omission type may be sent and decoded.

The decoding arm will fall on contacts 1, 2, 3, 4, 5, and 6, in succession, and then the action will be repeated. If the transmitting arm at the same time makes connection to contacts to the transmitter through switches, then, when the switch is closed for contact 1, a pulse will be transmitted every time the rotating arm passes over it. The transmitted pulse will arrive at the receiver and be sent along to the decoder. The circuit connected to the contact 1 there will then be energized.

If a relay chain of latching and release relays were connected to four decoder contacts, up to eight functions could be performed. The difficulty with this decoder is to maintain absolute synchronization of the two arms when they are separated. Governors or extra contacts may be used for this synchronization. If, for example, two extra contacts were provided, they could be so arranged that if the receiving arm of the decoder were slow, it would be on contact 5 while the transmitting arm was on contact 6. This would cause a signal to be received in a motor speed-up circuit, closing a relay and momentarily feeding the receiving motor a larger voltage. If the transmitting arm were slow and the receiving arm

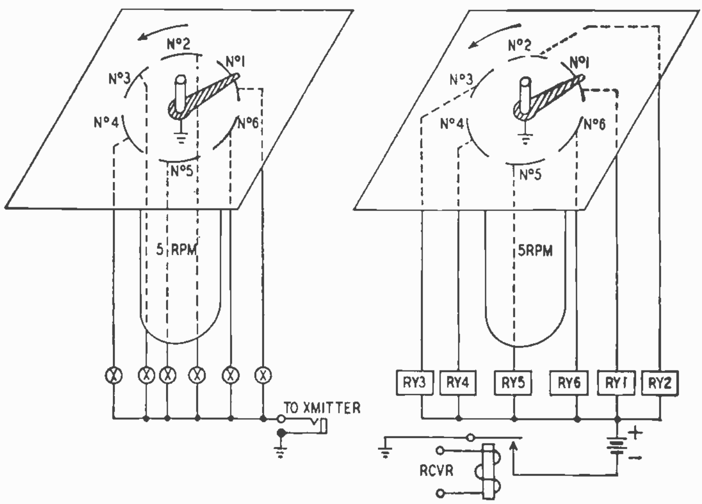



*Fig. 511—Motor-driven commutator-type coder and decoder.*

fast, then the transmitting arm would be on contact 5 while the receiving arm was on contact 6. This could result in a signal causing a relay to open momentarily, breaking the supply voltage to the receiving arm motor and thus slowing it down.

Having studied some of the methods of decoding electromechanically the various types of coded signals, now let's examine the electronic methods of decoding.

## Bandpass-Band Elimination Filters

Frequency-selective decoders of the electronic type constitute those decoders which use circuit elements in connection with vacuum tubes to decode signals consisting of different tones or frequencies. In most cases each tube in the output of the decoding section operates a relay which controls the flow of power to a particular circuit.

The bandpass filter is one of the most common forms of decoders when the code consists of audio tones. This device permits a restricted band of frequencies to pass and rejects all others.

There are two general arrangements for accomplishing this: one is to use a choke and capacitor; the second is to use capacitors and resistors arranged in a frequency-selective bridge circuit.

A choke and capacitor connected in series form a resonant circuit at some particular frequency. At resonance, the impedance of the circuit is a minimum, resulting in a maximum flow of current. However, each unit, the choke and the capacitor, does offer an impedance separately, and thus the circuit current passing through them creates a high voltage drop across each. These voltages are out of phase and cancel when looking at the unit as a whole; but taking only one unit of the combination, we find a large voltage that can readily cause a vacuum tube to conduct.

Although the series circuit has an impedance which is minimum at the frequency of resonance, at frequencies either above or below resonance the impedance increases. The further the frequency is away from the resonant frequency, the greater will be the impedance of the series circuit.

A method for determining the resonant frequency of a coil (L) and capacitor (C) in series is to apply the output from an audio signal generator to one end of the coil and one end of the capacitor, connecting a vacuum tube-voltmeter (or high-resistance voltmeter) across one element, as shown in Fig. 512.

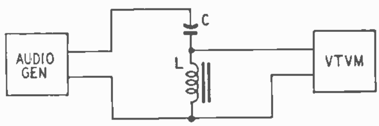



*Fig. 512—Finding resonant frequency of series L-C circuit.*

If the audio generator's frequency is changed or varied from the low to the high end of the range, there will be an abrupt rise of voltage shown on the meter as the resonant frequency is reached. At the point of maximum output, the reading on the generator dial will give the frequency at which the combination is resonant. It is assumed that the values of coil and capacitor are such that the two in series will resonate within the audio range. The same idea may be used in the radio-frequency range to determine the resonant frequency, if an r.f. signal generator and a suitable r.f. amplifier are used with the meter. The meter should read a.c. in both cases.

Series-resonant bandpass filters lend themselves quite well to circuits in control applications. If a number of these resonant circuits are fed from the last audio tube of a receiver and if each has a different resonant frequency, meters connected across the coils alternately peak as the signal generator is varied throughout its range. If the readings are plotted against the frequency, a chart such as that shown in Fig. 513 results. This chart indicates that frequency separation of the tones is taking place.

If a series of vacuum tubes were connected instead of the meter to each coil and if each tube were biased to require a signal of at least 0.3 volt to cause it to conduct, then each tube would conduct only when its particular tone was being transmitted and received. When one of the tubes conducts, it closes a relay in its plate circuit. Closing of the receiver plate circuit relay might permit delivery of power to a motor (making it turn) or could eventually result in the performance of some desired operation.

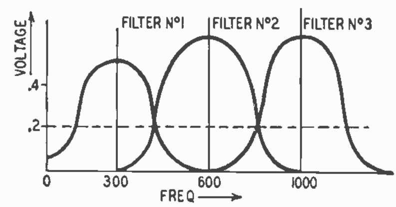



*Fig. 513—The voltage across either C or L is maximum at resonance.*

This is, at the present time, perhaps the most popular and simplest form of decoder used in radio control applications. Its principal disadvantage is that, if coils and capacitors are used as the selective elements, it becomes large and heavy when a number of tones are used. A further disadvantage is that it can receive and operate only with modulated signals. If a simple filter is used, the separation of tones should be great, and the choice of tones made so that no filter is tuned to a harmonic of some other tone. If more than six or eight tones are to be used, more elaborate filters must be constructed.

## Band-Rejection Filters

Another frequency-selective decoder of the bandpass variety, and one more desirable in some applications because of its reduction in weight, is the null-bridge type of filter. This filter can be constructed from capacitors and resistors and, when inserted in an amplifier (so that it controls the feedback), makes the amplifier frequency selective. It does so by allowing those tones or signals to which it is not tuned to degenerate more than the one at which it has its null.

A filter of this type is not really a band*pass* unit but a band-*rejection* type. One of the more popular types is the twin-T, illustrated in Fig. 514. The de-

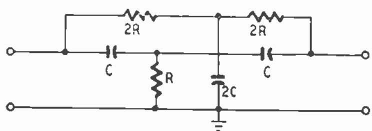



*Fig. 514—Twin-T band-rejection filter.*

termination of the frequency at which the circuit has its null is easy, using the following formula:

$$F = \frac{1}{6.28 \times 2\,R \times C}.$$

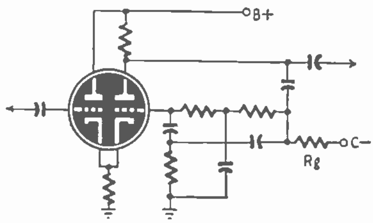
F is in cycles per second, R is in ohms and C is in farads.

The sample problem shown illustrates the use of the formula:
***Find:*** values of capacitance so that null occurs at 1,000 c.p.s. Let R= 1 megohm.
*Solution:* If R is 1 megohm, then 2 R becomes 2 megohms.

$$C = \frac{1}{6.28 \times F \times 2\,R} = \frac{1}{(6.28)\ (1{,}000)\ (2 \times 10^6)}$$

$C = 80\ \mu\mu f$, and so 2C becomes $160\ \mu\mu f$.

One method of using this network is shown in Fig. 515. The network is placed in the grid circuit of the second half of a duo-triode, the cathode being connected to the input half of the tube. This prevents any load on the filter itself, an important consideration. Resistor Rg, a grid return resistor, can be tied to a bias voltage. This type of filter is usually connected around the input or high-gain tubes of an amplifier and should be followed with the tube or tubes necessary to build up the desired frequency voltage to a value large enough to operate a power-amplifier tube. The power amplifier tube will have a relay in its plate circuit. A group of tubes which have the twin T as a feedback system can be fed from the audio section of the receiver, and from there the decoding is the same as for the L-C type of filter. The reasons for the choice of the twin T type of bridge over other types are that it has a common ground for input and output and is more adaptable than other filters which must operate above ground potential. A representative circuit employing the twin-T appears in Fig. 516. The values shown are not critical.



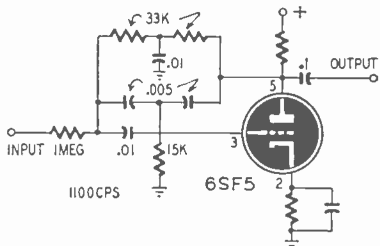




*Fig. 515—Twin-T in grid circuit of second half of duo-triode. Fig. 516—Typical Twin-T used in input stage.* *drawings courtesy of McGraw-Hill.*

## Discriminators

Another method widely employed in the decoding of signals where the tones or frequencies represent different commands is the use of a discriminator. In a discriminator, there is no output when the resting frequency is transmitted; a positive (polarity is assumed here) d.c. output when the frequency is lower than the resting frequency; and a negative d.c. output when the frequency is higher than the resting frequency.

The amount or value of the d.c. output is proportional to the deviation from the resting frequency, within the limitations of the circuits involved. Thus, a small d.c. signal can be produced with a small frequency deviation, or a large output for a large deviation. This circuit, then, becomes especially adaptable for proportional control. A circuit which can be used with audio or radio frequencies is illustrated in Fig. 517. Two vacuum tubes are connected to the output of the discriminator in such a manner that one operates a relay in its plate circuit with a positive signal, and one with a negative signal.

The explanation of the discriminator itself is relatively simple. L1C1 is tuned to a frequency higher than the chosen resting frequency. L2C2 tunes to a frequency lower than the resting frequency. Both L1C1 and L2C2 have resonant frequencies equally removed from the center or resting frequency. The two diodes are connected across one half of the resonant combination, so that one diode rectifier produces a positive voltage, the other a negative voltage, across the common 1-megohm load resistor R1.

When the resting frequency is received, it is exactly midway between the two L-C circuits. The equal positive and negative voltages cancel, and the output is zero. When the deviation is above or below the resting frequency, that L-C circuit whose resonant frequency is nearest the deviation produces a larger voltage than its opposite, and thus governs the polarity and magnitude of the output.

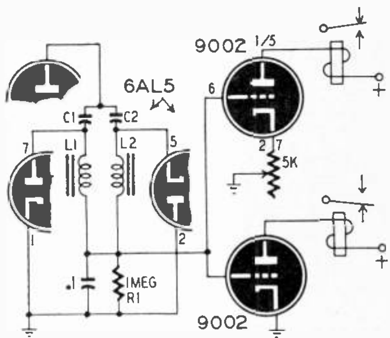



*Fig. 517—Discriminator used as a decoder.*

Note that one 9002 is biased by use of a 5,000-ohm variable cathode resistor. Normally the relay in the plate circuit of this tube is open. A plus voltage on the control grid of this tube would overcome the bias, the tube would conduct, and the plate circuit relay would close.

The second 9002 is normally conducting and so requires a negative signal voltage applied to its control grid to cut off the flow of tube current. This in turn would make the relay drop out on the back or normally closed contact. Thus, the plus or minus voltages from the discriminator cause one or the other of the plate relays to function.

## Separate Receivers

The final method of frequency decoding is that of using separately tuned r.f. stages to pick up different radio-frequency carriers. This corresponds to using separate receivers, one for each frequency or command.

## Delay Lines and Coincidence Circuits

Electronic pulse-selective methods, among which are included delay lines and coincidence circuits, are generally complex. Basically they consist of an arrangement of vacuum tubes, delay lines, and special circuits which form gates through which the desired pulses are channeled. This method of decoding is most applicable when applied to pulses whose duration and spacing can be measured in millionths of a second, generally too fast for the hobbyist's purposes.

A delay line consists of an arrangement of coils and capacitors in a series-parallel circuit, as illustrated in Fig. 518.

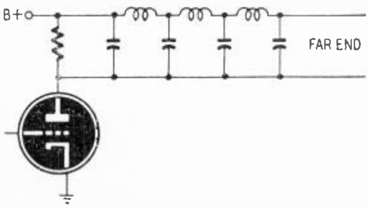



*Fig.* 518—*Fundamental delay line.*

A line of this type possesses some unique properties. When the far end is short-circuited and the impedance of the line is equal to the impedance of the driving source, no reflection occurs. However, it does take a definite amount of time for the current and voltage waves to pass through the coils and charge the capacitors of the line. Thus, this type of line delays the arrival (at the far end) of the impressed signal or, in this case, a pulse. The length of the delay is proportional to the size and number of the coils and capacitors.

In addition to a delay, a line may also be used to reflect a pulse from the far end, if the impedance of the line is not matched to the driving source. If the two impedances are unequal and the line is open-circuited at the far end, a reflected signal will come back in phase with the one impressed on the line. If the far end of the line is short-circuited and the impedances are unequal, the reflected wave will be 180 degrees out of phase with the incident or impressed signal.

With these points in mind, an application of this line in a decoder may be considered. Let the code be such that the spacing between the pulses represents the different commands, as illustrated in Fig. 519. Each command consists of a pulse pair, with varying spacing between them.

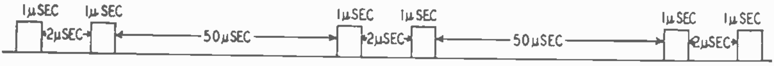



*Fig.* 519—*Command consisting of a series of pairs of pulses.*

The receiver will pick up an r.f. pulse of 1 microsecond duration. This pulse will be followed by a second r.f. pulse, also of 1 microsecond duration but separated in time from the first pulse by an interval of 2 microseconds. This particular pulse pair repeats at intervals of 50 microseconds as long as the command is desired or until a latching relay in the receiver has had time to close and lock. We can use this varying-spaced pulse-pair command in connection with the delay line circuit shown in Fig. 520.

The radio-frequency pulses are passed through the i.f. section of the receiver and are rectified by V1, half of a 6H6 diode. From the i.f. transformer end of the 220,000-ohm diode load resistor, these pulses have a *negative* polarity to ground. The negative pulses are fed through the .0001-$\mu$f coupling capacitor to the control grids of the 6SN7 (V2 and V3). The common grids of the 6SN7 are returned to ground through a 560,000-ohm grid-return resistor. Note that the plate load resistor for V2 is actually the terminating or load resistor for the delay line. Ordinarily, the plate current for V2 would flow from the plate of V2, through the 22,000-ohm load resistor, back to the power supply. The I-R drop across the load resistor would also charge capacitors C, C1, C2, C3, and C4 of the delay line network, since these are shunted across the load resistance. When the grid of V2 receives the negative pulse, V2 becomes biased to plate current cutoff. When V2 stops conducting, the capacitors of the delay line discharge through the load resistor. It is interesting to note that these capacitors do not all discharge

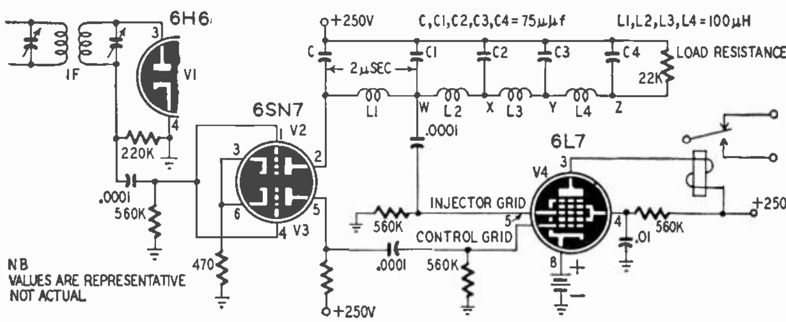



*Fig. 520—Representative delay line circuit used as a decoder. Action of the decoder depends upon pulse timing.*

in the same time. C, being furthest away from the load resistor, discharges first, since it will try to charge the other capacitors as they start to discharge. C is followed by C1, C2, C3, and finally C4.

Because C discharges first, it thus removes the bucking voltage it presented between point W and the supply voltage. Point W is the first to reach the supply voltage potential after the plate itself does. In this case point W reaches the supply potential 2 microseconds after the plate; point X 4 microseconds, point Y 6 microseconds, and point Z 8 microseconds later.

Now let's turn our attention to the pentagrid tube V4. This tube is so biased that both its grids (control grid and injector grid) must be positive at the same time before it will draw enough current to operate the relay in its plate circuit. With this in mind, consider V3, the second half of the 6SN7. The same instant the first pulse caused V2 to cease conducting, it also forced V3 to behave in the same way. This, of course, results in a rise in voltage at the plate of V3. This voltage rise is transferred to the control grid of V4, making it positive; but since the injector grid of V4 is not positive, the tube does not close the relay.

The second of the two pulses now arrives at the grids of V2 and V3. The effect on V3, as we have seen, results in a positive voltage being placed on the control grid of V4. Meanwhile the line, which started discharging with the first pulse, becomes equal at this instant to the supply potential at point W. This is equivalent to placing a positive pulse on the injector grid of V4. Since both grids are now positive at the same instant, the tube conducts and the relay closes. The plate circuit relay, in turn, can close a circuit to a latching relay, energizing it and forcing it to close and hold.

If a second relay tube similar to V4 were connected to point X on the line, then it would require pulses with a 4-microsecond spacing to give us a similar response. Such a relay tube would require pulses with a 4-microsecond spacing. It might be thought that our original relay tube V4 might conflict with additional relay tubes added to the circuit. We should remember, however, that relay tube V4 will conduct only upon reception of pulses 2 microseconds apart. A new relay tube placed at point X would require pulses 4 microseconds apart in order to operate.

In general, when V2 conducts, it starts a pulse down the delay line, so that it arrives at points W, X, Y, and Z at 2, 4, 6, and 8 microseconds, respectively, after starting. The 50-microsecond spacing between pulse pairs is for the purpose of allowing the tone to "clear" or settle before sending another command or repeating the first one.

## Counting Circuits

It is possible to decode codes of the numerical-sequence type by electronic means. With a circuit such as illustrated in Fig. 521, several numerical commands can be distinguished. In this circuit, each pulse is rectified by the diode and stored in capacitor C as a certain value of voltage. Each tube, connected to the

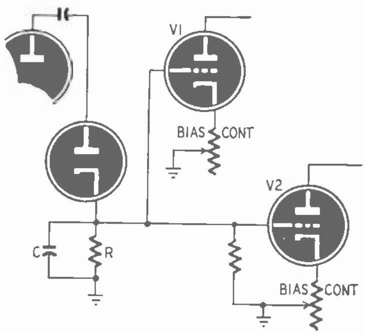



*Fig. 521—Counting circuit decoder.*

top portion of the capacitor, has a value of bias which differs from the bias of the other tubes. When two pulses are transmitted, V1 will have its bias raised above the cutoff point, and the tube will conduct. This flow of plate current could operate a relay in the plate circuit of the tube. Since the bias on V2 could be made greater than the bias on V1, it might be necessary to have three pulses in order to make V2 conduct. Additional tubes could be added as required.

Note that after a command (of two pulses, for example) has been transmitted, a pause is required long enough for the capacitor to discharge through its load resistor in order to allow the circuit to return to its static condition and be ready for the next command. Otherwise, if two pulses were followed quickly by two more, the circuit could not tell whether it was a two-or a four-pulse command. In this type of circuit latching relays should be used since the tube will not hold its relay closed continuously. Also, the number of relays that closes is directly proportional to the number of pulses transmitted.

## Amplitude-Detecting Circuits

It it feasible to use pulse amplitudes to convey information, just as it is possible to amplitude-modulate any radio signal. A decoder which decodes the amplitude of a pulse into a command function is illustrated in Fig. 522. It consists of several biased detectors V1 and V2. Since each tube has a relatively larger

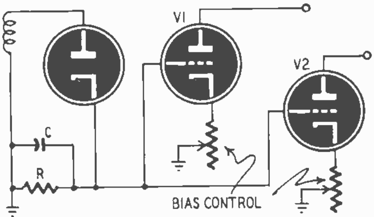



*Fig. 522—Pulse amplitude decoder.*

amount of bias, it would take a pulse of greater amplitude to cause each succeeding stage to operate. Notice here, as in the decoder for numerical sequences, that one, two, or more tubes may be made to conduct, but that we cannot have tube 4, for example, operating without having tubes 1, 2, and 3 operating also.

The circuits shown in Fig. 521 and Fig. 522 are the same. In Fig. 521, the time constant of the R-C combination ($T = R \times C$) is very large. This means that this circuit will hold a voltage level due to a given pulse long enough so that a second pulse can be added to it. Thus the voltage level increases according to the number of pulses transmitted.

The resistor R and capacitor C in Fig. 522, however, has such a very short time constant that it is the instantaneous amplitude of the pulse that determines the amplitude of the voltage across R and C, instead of the number of pulses applied to it.

## Gating Circuits

A gating circuit is used to decode signals of the pulse-presence–pulse-omission type. It may also be used to decode time-modulated or pulse-spacing codes.

An essential feature of a gating circuit is an integrator network. Basically, the integrator consists of a resistor and a capacitor in series, with a second resistor shunted across the capacitor, as illustrated in Fig. 523. When the switch is closed, the battery charges the capacitor; and since the current must flow through R1, it takes a definite amount of time to do so. This length of time depends directly upon the size of the resistor and the amount of capacitance.

If the switch is opened at the moment that the capacitor is charged, C1 will begin to discharge through R2. It takes a definite time for the capacitor to discharge. We can make use of this simple circuit to distinguish between a pulse which has a long time or which is wide, and a short time or narrow pulse by combining our integrator network with a diode, as shown in Fig. 525. The triode V3 has sufficient bias on its cathode to be normally cut off. The tube can be made to conduct, however, by placing on its grid a positive pulse having an amplitude sufficient to overcome the bias. Whenever the input triode V1 receives a negative pulse on its control grid, the decrease in plate current means less of a voltage drop

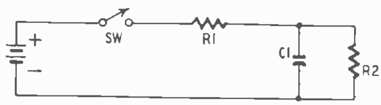



*Fig. 523—Integrating network.*

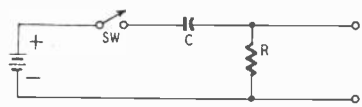



*Fig. 524—Differentiating network.*

across its plate load resistor R1. Consequently the potential on the plate of V1 increases. The result is a positive charge placed on the diode plate, through C1. The positive plate of the diode will attract electrons from its cathode. Since the cathode is returned to ground through R2, there is a flow of current up through R2 from ground. The effect of this current flow is to charge C2.

Since C2 acts like a short circuit until it does get some charge, it takes some time before a voltage appears across R2. If V1 produced only a short pulse, there would be no voltage drop across R2 and, as far as V3 is concerned, the short pulse produced by V1 would have no effect.

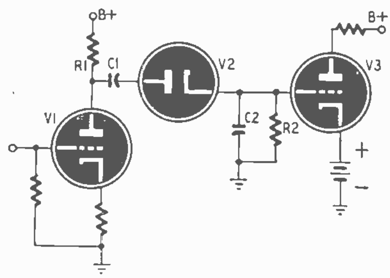



*Fig. 525—Integrator circuit used with diode.*

Let V1 produce a pulse much longer in time. Capacitor C2 does get a charge which builds up until the full possible voltage exists across it and R2. This voltage is positive with respect to ground and is of sufficient magnitude to override the bias on V3, causing it to conduct. In this manner V3 will recognize only long and not short pulses.

Our diode acts just like the resistance R1 in the circuit shown in Fig. 523. C1 prevents the application of the B-plus supply to the plate of the diode.

There is one more very important fact to consider. Because of the slow charging and discharging action of capacitor C2, the rectangular pulses fed into the integrator system appear triangular at the output.

Before we study a complete gating circuit making use of an integrator, let's go over another subsidiary gating circuit network known as a differentiator.

It is quite possible to have a circuit which produces a voltage only when the applied voltage is *changing*. If the voltage produced is in proportion to the *rate of change* of the applied voltage, the circuit is said to be a differentiator. A basic differentiator network appears in Fig. 524. If the switch is suddenly closed, current flows through resistor R to charge the capacitor. As soon as the capacitor has taken a charge, the flow of current stops. Naturally, a voltage appears across the resistor only so long as there is current flowing. The voltage across R is proportional to the *rate* at which the voltage across C changes. Such a circuit can be used to produce sharp trigger pulses for control purposes. Let's examine Fig. 526 to see how a differentiator is used in conjunction with a vacuum tube.

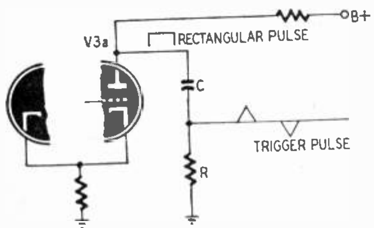



*Fig. 526—Differentiator used with vacuum tube. The tube is part of a multivibrator circuit. The differentiator is shorted when the tube conducts. The tube produces a rectangular pulse which is differentiated into a triangular trigger pulse.*

When a pulse appears in the output of V3a, due to a rise in voltage at the plate of the tube, it tries to charge capacitor C through R. C cannot be charged instantaneously; and, so, while current is flowing into it (this may take a millionth of a second), a voltage is built up across it which is positive with respect to ground. As soon as the capacitor is charged, the current flow through R stops. No voltage will appear across R even though the plate potential of V3a will have risen to a higher value. Although not shown in Fig. 526, V3a is actually part of a multivibrator circuit. The job of the multivibrator is to make V3a conduct, cut off, and then conduct again. While C was becoming charged, V3a was not conducting. When V3a begins to conduct once again, it short-circuits C and R and the capacitor discharges through the tube. This time, however, the flow of current is from the capacitor *down* through R, instead of from the power supply *up* through R: once again a voltage is produced across R, but this time the polarity with respect to ground is reversed. By this action, then, two trigger pulses are produced, one at the beginning and one at the end of the rectangular pulse, when the voltage at the plate of V3a is changing. We can use either the positive or the negative trigger pulse to control the operation of a succeeding tube.

The complete gating circuit, including an integrating and differentiating network, is shown in Fig. 527. The command pulse is always preceded by a marker pulse, designated No. 1 in Fig. 528. This is followed by a series of short pulses representing the code. When these pulses are received and sent to the decoder, V1 in the integrating network separates the wide marker pulse from the others. In this case, the marker is the only pulse that will cause a large voltage to appear across R1. When this voltage appears, it compels V2a to conduct, changing the charge on capacitor C1. Current then flows through R2 in such a direction that a negative voltage appears at the top of R2. The voltage drop across R2 forms a bias voltage for V3a having a value sufficient to cut off the flow of plate current through that tube. V3a will remain cut off until the capacitor can recharge.

Because of this action, a square pulse is generated at the output of V3a. This pulse has a width proportional to the time constant of C1 and R2. This pulse is then differentiated to produce the triggers shown in both Fig. 527 and Fig. 528.

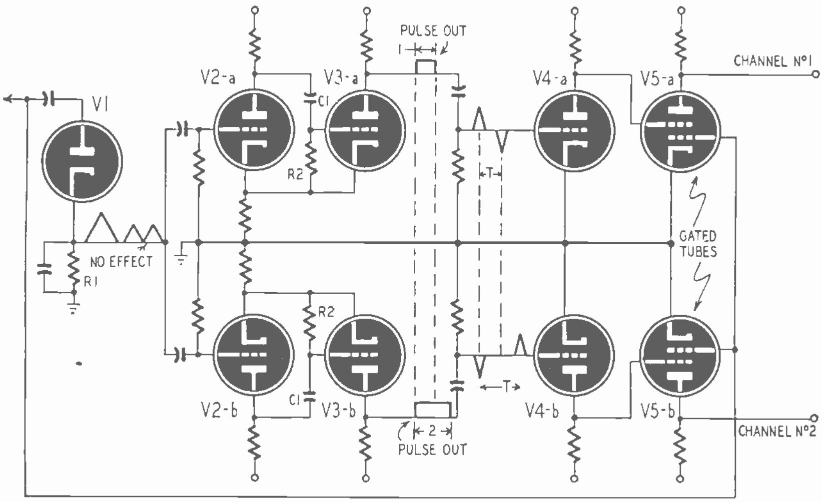



*Fig. 527—Complete gating circuit, including a differentiating and an integrating network.*

The triggers, positive and negative, are fed to V4a. The negative pulse forces V4a to cease conduction; the positive pulse has no effect. As the plate voltage on V4a rises, it also increases the screen voltage of V5a to which it is directly connected. If a signal pulse is transmitted now, V5a will conduct, passing the command on to channel 1. Since V5a is in the conducting state only while its screen is at high

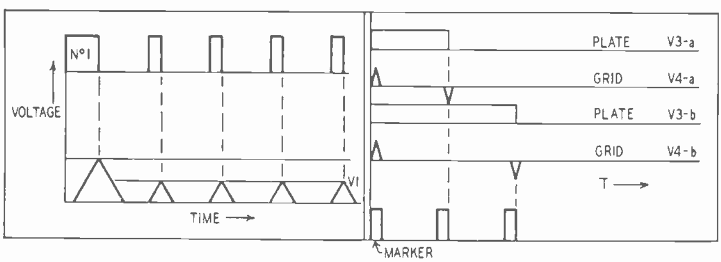



*Fig. 528—Timing of marker, rectangular, and triangular pulses.*

positive potential, the code pulse must come at that particular time if it is to be channelized. This is a definite time interval after the arrival of the marker signal.

The lower channel operates in the same manner; but since the length of the rectangular pulse from the plate of V3b is longer, V5b will become operative *after* V5a, the length of the time difference between them being determined by the difference in the time constants of the two circuits.

If a pulse code of the presence-omission type is sent, the pulses are channeled to the proper tubes in the output in sequence. If these output tubes V5a and V5b have self-locking relays in their plate circuits, a particular combination of pulses would cause either channel 1 or 2 to be placed in operation.

## Pulse-Rate Discriminators

The final decoder which we will consider is the discriminator type which can choose between different pulse rates. If a discriminator of the type mentioned earlier for decoding frequency commands is placed in the output of a receiver picking up pulses corresponding to the frequency of the L-C units, such a discriminator will produce an output in the same manner as for the variations in pulse rates. This is due to the fact that, when an L-C circuit is pulsed, the pulse is converted into a cycle through the charging and discharging of the capacitor and the build-up and decay of the magnetic field around the coil. Thus a pulse rate of 1,000 pulses per second becomes in effect a frequency of 1,000 cycles per second.

The preceding discussion has pictured some of the methods of decoding and evaluated their good and bad points. The type of decoder used depends upon the allowable size, weight, and degree of complexity the builder wishes.

Once a choice of decoder has been made, the next step is to decide upon the type of power control circuit to operate the actual motors or devices which are to respond to the commands.

# Chapter 6

## Power Control Circuits

POWER CONTROL CIRCUITS in radio or electronic control are those circuits which are operated by the decoder. They handle the power from the primary supply and govern its flow to motors or devices which are to be operated by the given commands.

Sometimes the decoder performs this function and sometimes it does not. Where a simple pulse sequence is used, as in control of model aircraft in which the stepper moves the fin directly, no power circuits are needed. In the use of tone-coded commands such as those for steering (one tone for left and one for right), additional power circuits may not be needed. However, with pulse codes in which one transmission channel is used to send a variety of commands, it might be desirable to give a command for one motor to start operating and have it continue to operate while other commands are being transmitted.

### Latching Relays

One of the most common types of power control circuits for such an application is the latching relay. This relay is so designed that it locks in the closed

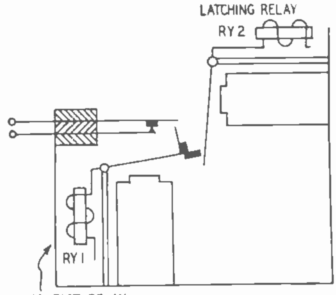



*Fig. 601—Mechanical latching relay.*

position when it receives a flow of power through its windings from the decoder. It remains locked until the next signal is sent to a second relay or winding in close proximity to the first, either electrically or physically, and which releases the first, either electrically or mechanically.

Latching relays may be of two types, electrical and mechanical. A mechanical latching relay is shown in Fig. 601. The armature of RY1 is equipped with contacts. RY2 is used for latching only. When the contact relay RY1 is energized, its armature is held down by the armature of the second relay. While RY1 is in this locking position, the latching relay RY2 is not energized. When the latching relay coil is energized, its armature moves far enough so that it releases the contact relay armature.

The second type of relay, shown in Fig. 602, is one which latches electrically. This merely requires a relay which has two poles and makes two contacts when energized. One set of these contacts completes the circuits to the power source, keeping the power flowing through the windings when the coded command ceases. The second set of contacts is used to have power flow to the motor (or other device) that is to be made operational.

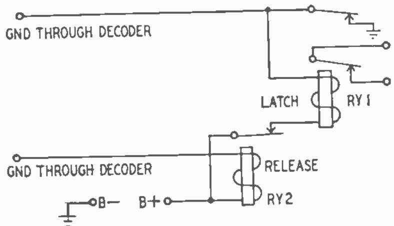



*Fig. 602—Electrical latching relay.*

The second relay is always connected to the first in such a manner that the power to the latching relay's coil flows through the normally closed contact of the release relay. When RY2 is energized, it breaks the circuit to the latching relay and allows it to release.

Of the two, the first requires no power from a power source to hold it shut; the second does. However, if a high-resistance relay is used for this function, the battery or supply drain may be small and within reason.

It is also possible to use steppers directly to control the flow of power to various devices. With these, the contacts can be wired to the activated device. The only circuit that is needed is one which prevents the passed-over contacts from becoming energized as the stepper arm moves. This circuit can be a relay which holds the common line open while the arm is in motion and closes it when the pulses cease.

## Reversing Relays

Reversing relays which can be used to control the flow of power are illustrated for different types of motors in Fig. 603. To reverse the rotation of a permanent-magnet motor (Fig. 603-A) it is necessary to change the polarity of the voltage to the motor terminals. A double-pole, double-throw relay can do this.

The armatures are connected to each end of the battery. When the armatures are against the normally closed (up) contacts, the top terminal of the motor has a plus polarity and the bottom, a minus one. When the relay is energized, the armatures pull down. Now the top motor terminal is negative, and the bottom positive. The motor reverses direction.

To reverse the direction of rotation of a split-field motor (Fig. 603-B) it is necessary only to energize the opposite half of the field winding. This type of motor usually has three out leads: one common, one for rotation one way, and the other for rotation in the opposite direction. A single relay as shown connects the armature through the normally closed contact of the relay to one half of the field winding. The armature is connected through a common lead to one end of the battery. The other end of the battery is connected to the center tap of the field. With the armature open, or resting against the normally closed contact, one half of the field is energized. When the armature is closed, it energizes the second half of the field, reversing the rotation of the motor.

To reverse the rotation of any d.c. shunt motor (Fig. 603-C) *either* the field leads *or* the armature leads must be reversed. In the diagram shown, the armature

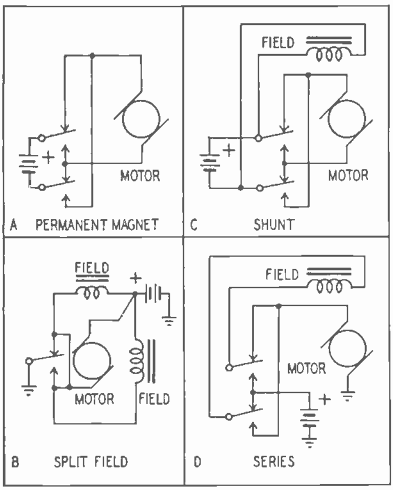



*Fig. 603—Reversing relays can control motor rotation.*

leads are reversed by a double-pole, double-throw relay, while the field remains constantly attached to the same battery terminals. With the relay not energized, the motor armature has plus on top and minus on the bottom. When the armatures of the relay pull down, the top terminal of the motor becomes attached to the negative side of the battery and the bottom to the plus side. The field, connected to the armature, does not have the direction of current flow through itself changed.

The series motor (Fig. 603-D), like a shunt motor, must have *either* the field leads *or* the armature leads reversed if a reversal of rotation is desired. In this diagram the field leads are reversed while the armature remains the same. With the relay in the normally open position, current flows through the armature of the motor to the top contact (normally closed) of the relay armature, then through the field, back to the relay bottom armature, and up to the plus side of the battery. When the relay is energized, the relay upper armature connects its side of the field to the battery plus, while the relay bottom armature connects its side of the field to the motor armature and through it to the battery minus. The direction of current flow through the field reverses and the motor changes its direction of rotation.

With ordinary relays which close with commands and remain closed as long as the command is transmitted, with delay relays, steppers, latching and reversing relays, we have the necessary arrangements to operate almost any control system. The methods illustrated have been of the electromechanical variety. Now let's consider electronic methods of controlling flow of power.

## Electronic Power Control

One of the electronic methods of handling a large amount of current is to use a thyratron-type tube, such as 2D21 or 884. The presence of gas in the tube allows the passage of a large amount of current when the tube is in the conducting state.

The current passed by these tubes is large enough to operate a motor directly. However, such tubes have one very distinct disadvantage: when the tube starts conducting, the grid loses control of the electron stream. This is particularly true in the larger size tubes. The only way that current flow can be stopped is to cut off the plate supply or make it negative, while the grid supply is negative. One

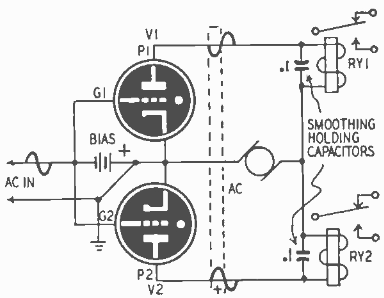



*Fig. 604—Power control using gas tubes.*

way in which the plate can be made positive for conduction purposes and negative so that the grid can get control is to apply a.c. to the plates. Thus the plates are positive half of the time and negative the other half. In this manner, the conduction of the tubes can be controlled by an a.c. signal on the grids.

If gas tubes have relays in their plate circuits, as shown in Fig. 604, these can be closed by changing the phase of an a.c. input signal. In this circuit, with no a.c. input to the grids, the grids are biased to cutoff by means of the bias battery. If an input signal is applied which has a magnitude large enough to overcome the bias on the positive alternation, then the grids of both tubes will be made positive simultaneously. If the phase of the a.c. input is such that it is the same as that applied to the plate by the a.c. supply, then the plate of V1 can be positive when its grid is positive; hence this tube will conduct. The phase is negative on the plate of V2; therefore this tube will not conduct.

As long as the input phase and magnitude are maintained, V1 continues to conduct in pulses, or each time that its plate is positive. V2 can never conduct while V1 is conducting, since both grids are made either positive or more negative *simultaneously* by the input signal. Reversing the phase of the input signal makes the grid of V2 positive when its plate is positive, and the plate of V1 positive when its grid is negative. The key here is that the grids are tied together, the plates are not. Depending upon the phasing of the input signal and the a.c. plate voltage, either RY1 or RY2 can be made to function. This situation is also applicable for ordinary tubes supplied with a.c. With gas tubes, however, due to their ability to pass a large amount of current, we have the advantage of controlling the flow of current through the windings of a bidirectional d.c. motor, without the use of relays.

The motor shown in Fig. 605 is a two-winding, split-phase unit. To run the motor, one winding is connected directly to the a.c. source (110 volts, 60 c.p.s.). The second winding is connected through a capacitor. The capacitor causes the phase in its side of the motor winding to lead that in the directly connected winding, and so the motor runs in one direction.

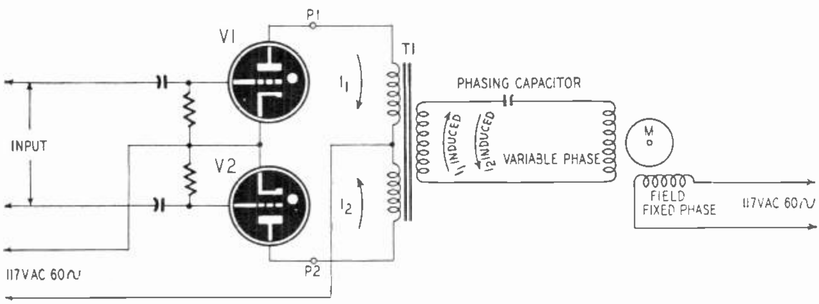



*Fig. 605—Bidirectional and speed control of a motor using push-pull thyratrons.*

If, instead of a capacitor, an inductance were placed in series with the second winding, a lagging phase would result and the motor would reverse its direction. Since the impedance of the motor is low, a matching transformer T1 is needed to match the motor winding to the tube plates. T1 has a push-pull input for connecting to the plates of V1 and V2 and the center tap connects to one side of the 110-volt line. If V1 conducts, current I1 will flow in pulses from the plate to the center tap. If current flows *down* in the input side of the transformer, it will flow *up* in the secondary; i.e., it will be 180 degrees out of phase with the input winding. In order for the motor to run, the phase to the controlled winding must lead or lag. Placing a capacitor in series will advance the phase of the secondary of the transformer nearly 90 degrees and the motor will run in one direction.

If the phase of the input signal is reversed, V2 conducts, while V1 does not. The current flow I2 through the primary is reversed. It now goes *up* to the center tap. This means that the output current will flow *down* and once again a 180-degree shift has taken place through the transformer. Since the phase of the input has changed by 180 degrees, this now makes the phase of the output 180 degrees different from the fixed-field phase. Here again the capacitor causes an advance of 90 degrees, which in this case is just enough to cause this variable phase to get 90 degrees behind the fixed-field phase, i.e., lag it by 90 degrees. This lag now causes a reversal of the motor's rotation.

If the input signal is small, the output is small and the motor runs slowly. If the input signal is large, the output is large and the motor runs fast. Thus we have both bidirectional and speed control of the motor by means of thyratrons.

## Saturable Reactors

A saturable reactor (Fig. 606) is a transformer operated near its limit of magnetic intensity. It has, in this case, an input, output, and control winding. The control winding is operated with d.c. When the control winding is not energized, the input transfers power to the output; but if the control winding has d.c. passing through it, it saturates the transformer core with magnetic lines of force.

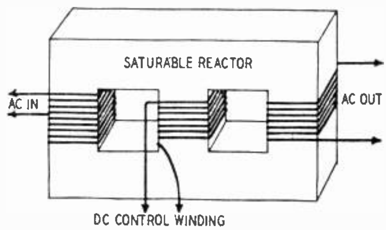



*Fig. 606—Saturable reactor type transformer.*

This condition means that a.c. supplied to the input can cause no flux change and thus cannot transfer power to the output. By controlling the current in the control winding, the amount of power transfer can also be controlled.

An example of this type of power control is the control of lighting in theaters. It may be used to govern the speed of an a.c. motor or, when used in a dual arrangement, may govern both direction of rotation and speed of rotation of a.c. motors.

# Chapter 7

## Servomotors

A SERVOMOTOR (*servo* from the Latin, meaning slave) is a motor which responds to some command. The final unit in radio or electronic control systems, it causes gears to turn, giving rotary motion by wheels or translational motion by an arm attached to a wheel.

A servomotor may be thought of as an electric motor, with or without gears. It may be a motor which merely moves back and forth like a meter hand as its input polarity is changed. This type does not revolve. It may be a relay and an escapement which furnishes mechanical power, or it may be a plunger-type solenoid. It could also be a pneumatic or hydraulic cylinder in which the flow of air or oil on each side of the plunger governs the direction and force applied by the arm.

All of these types may be familiar; some undoubtedly are. Their purpose is most certainly obvious. However, there are some circuits and applications of servomotors which may not be quite so apparent, as, for example, the use of limit switches and neutralizing switches.

### Limit Switches

A limit switch is, as the name implies, a switch which limits the motion of some mechanism moved by an electrical motor or device. If the arm, in Fig. 701, tries to move too far in either direction, it physically opens a switch. This is the limit switch and the circuit which is opened is the one which, when energized, originally caused the arm to move in that direction.

Limit switches are made of spring metal and are normally closed due to spring tension. When the arm moves or pushes against a limit switch, the switch is placed in the open position. When the arm moves away from the limit switch, the switch, because of spring tension, closes automatically. This allows the circuit to be complete once again so that the arm can be made to move back if so desired.

There are other means for opening a circuit when the limit of rotation or movement of a wheel or arm is reached. The limit switch might be a cam of some insulating material mounted on the shaft which holds the switch closed and allows the circuit to open when the limit of travel is reached. It might also be just a physical stop as in the case of a relay, solenoid, or a pneumatic or hydraulic cylinder.

One method of using a limit switch to govern the rotation of a wheel is shown in Fig. 702. Here the limit switch is a cam mounted on a gear shaft which is in turn geared to the wheel shaft. The rotation of the cam depends upon the gear reduction; it might be arranged to move, let us say, 180 degrees when the wheel turns 25 times, a 50-to-1 reduction. Note that this particular limit switch is normally open and is closed only upon contact with the cam.

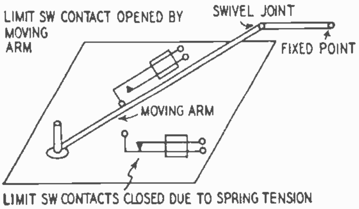



*Fig. 701—Limit switches operated through use of a moving arm.*

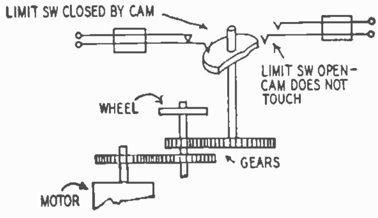



*Fig. 702—Limit switch closed by rotating cam.*

## Neutralizing Switches

A neutralizing or normalizing switch (in addition to limit switches) is found physically mounted on the servomotor itself. Its job is to cause the servomotor to return to some predetermined position (usually neutral) when the commands have ceased. Generally, a neutralizing switch consists of a pointer which moves with the arm of the servomotor and rides on a segment contact located on each side of the neutral position of the arm. (See Fig. 703.)

When the point R in the circuit is connected to ground (through a receiver relay, for example), RY2 will become energized. This connects one side of the servomotor (a permanent-magnet type) to ground through contact 1 of RY3, contact 1 of RY2, and the left limit switch.

One side of B2 is connected to ground. One side of the motor, therefore, is now connected to the battery. Notice that connection from the other side of B2 is made to contacts 2 and 3 of RY3; but since this relay is not energized, the armature (which connects to the other motor terminal) rests against contact 3. The motor is now connected to the battery in such a manner that terminal 1 is negative and terminal 2 positive. Thus, the motor rotates and the arm moves toward the left.

As the motor turns, the sliding contact geared to the grounded arm shaft also moves left up onto contact segment A. This segment is connected to the top armature of RY2. The arm continues to move until it physically opens the left limit switch. It stops then, because the connection from the motor to the battery is now broken.

The arm is now to the left, and has opened the left limit switch. The sliding contact is on A, RY2 is energized, the motor is not running.

Consider, now, that the connection from R to ground is broken, as would happen when the received command stops and the receiver relay connected to R opens. RY2 releases and the bottom armature breaks the connection to contact 1, but the top armature makes connection with contact 2. Notice that the sliding contact has grounded contact segment A on the plate, and, now, through the top armature and contact 2 of RY2 one side of RY3 is connected to ground. The minus side of B1 is also connected to ground.

Since plus of B1 is connected to RY3 winding, this relay is now energized. The upper armature of RY3 connects motor terminal 1 to the plus side of B2. The bottom armature connects motor terminal 2 to contact 4 of RY3 and then through the right limit switch to ground.

The permanent-magnet motor was originally made to rotate in one direction by having terminal 1 negative and terminal 2 positive. Since we have now reversed the polarity, the motor rotates in the opposite direction. As it rotates, the sliding arm moves toward the insulated center between contact segments A and B and the arm moves away from the left limit switch.

As soon as the sliding contact moves away from contact segment A, the circuit to RY3 is broken and the relay opens. Since RY2 is also open, the motor is completely disconnected from B2 and so stops rotation. The sliding contact has returned to neutral.

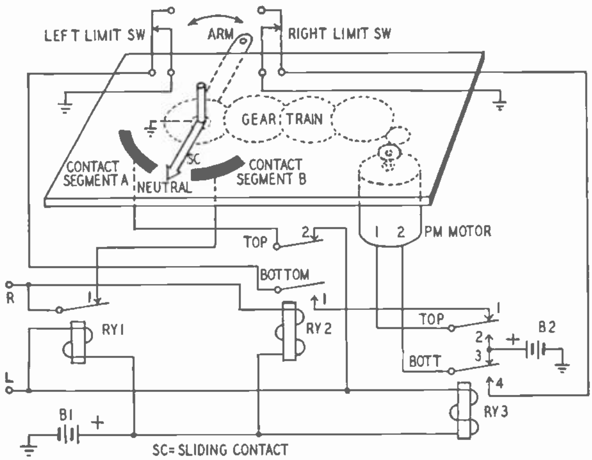



*Fig. 703—Neutralizing switch controlled through the use of a moving arm and a pair of limit switches.*

Now let us suppose that point L on the circuit diagram is connected to ground through a second receiver relay. This causes RY3 to be energized. The motor turns, the arm moving toward the right limit switch and the sliding arm toward segment B. Notice here that RY1 is also energized at the same time. This causes the circuit contact of segment B to be broken. The arm moves until it touches the right limit switch, opening it and breaking the circuit. The sliding contact rides up on segment B and remains in this position as long as point L is connected to ground.

When L is disconnected from ground, RY3 again connects the motor terminals to its 1 and 3 contacts. RY1 connects point R to ground through its contact 1 and also through the sliding contact on the segment B; so now RY2 becomes energized. When RY2 is energized, the motor moves the arm to the left until once again the sliding contact rides off segment B and breaks the circuit. RY2 then opens, breaking the circuit to the motor, and the sliding arm is in neutral again.

With this circuit, then, the arm can be made to move either to the right or left with a signal. When the signal stops, the arm automatically returns to neutral from either position.

A neutralizing switch is almost essential in control systems unless proportional control is used. It is extremely difficult to make a rudder move and then position it back to neutral accurately and quickly by commands. Either it "overshoots" or "undershoots" the neutral position and the jockeying necessary to get it exactly correct causes the controlled object, be it a boat, mobile unit, or plane, to maneuver erratically and sometimes even crack up. With the neutralizing switch, the rudder returns to neutral easily, quickly, and accurately. Fig. 704 is a photograph showing cam-type limit switches and neutralizing relays of a commercial servomotor.

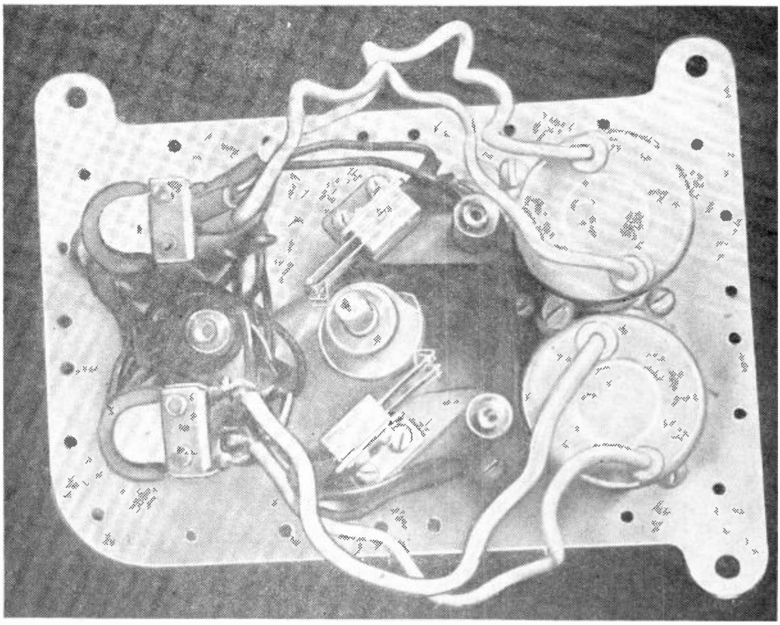


*Fig. 704—Cam-type limit switches and neutralizing relays. The relays are shown at the left; servomotors at the right.*

## Proportional Control

Proportional control means that the servomotor, in moving an arm, does not have to move it completely to the right or left, or in controlling the speed of a motor that the motor does not just run at full speed, half speed, or stop. Proportional control means that the arm may be deflected any amount — 1, 2, 3 degrees, etc., either way. This gives gradual steering. In the case of a motor, the speed may be any desired value from stop to full speed.

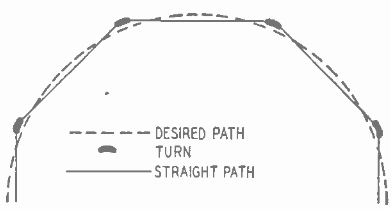
One of the simplest ways of illustrating proportional control is to visualize a motor with a rheostat in series with the power line. Here the amount of resistance in series governs the speed, the motor running at any speed from maximum to stop.

If a control system is such that the speed of a motor may be governed gradually or a steering arm moved gradually to any position and held there as long as desired, the system can be said to have proportional control.

When, in using a model airplane, it is desired to make a large turn, larger than would normally be executed if the rudder were held over to its maximum position for a long time, the procedure would be somewhat as follows:

First, the command for a turn is given, the rudder moves to its maximum position and stops; the plane starts to turn. The operator observes the amount of this turn and, when a small fraction of the turn is completed, sends a command for neutral rudder, causing the plane to straighten out. The next command would make the rudder deflect in the same direction, and again the plane would turn slightly before it was commanded to straighten out. This series of events continues until the desired large turn has been executed. The course would be such as shown in Fig. 705. Proportional control in this case is achieved by controlling the amount of *time* that the rudder is deflected for each segment of the turn.

*Fig. 705—The method for obtaining a partial or complete turn is shown in the illustration at the right. The desired flight path is achieved by controlling the amount of time that the rudder is deflected. Note that for most of the time neutral rudder is used.*




In a second case, suppose that, in addition to limit switches, a potentiometer were so arranged that the pointer of the potentiometer would move as the arm of a servomotor moves (and in the same direction). The total resistance of the potentiometer would, of course, remain fixed. The potentiometer is so wired that, when the arm of the potentiometer is at the middle position or neutral, the voltage between the pointer and ground is zero. An arrangement such as this is shown in Fig. 706.

The servomotor can be controlled by relays in the plate circuits of vacuum tubes, one for each direction of rotation. Both relay tubes have their grids tied together and receive a plus or minus signal from a discriminator in the receiver. The plus signal causes rotation one way, a minus signal rotation in the other direction. When the frequency sent to the decoder (the discriminator in this case) is varied above the resting frequency, this could result in a discriminator output voltage of approximately −1 volt. This negative 1 volt, acting as a bias voltage, would cause V1 to stop conduction. The plate voltage on V1 would become more positive and would also make the control grids of V2 and V3 more positive. The increase of plate current through V3 would close RY1. The resultant increase of plate current flow in V2 would close RY2. This completes the power circuit to the servomotor; consequently the servomotor begins to rotate.

Now if the potentiometer pointer is connected to the grids of the two tubes electrically through V1 as it moves with the arm, it establishes a voltage difference with respect to ground. Assume the direction of motion causes a plus voltage to be developed, and suppose this voltage reaches 1 volt when the arm has moved 2 degrees. If, then, this plus voltage cancels the incoming minus signal voltage, V2 will stop conducting, RY2 will open and the arm will remain at 2 degrees deflection. Sufficient current will still flow through V3 to keep RY1 closed.

Suppose a turn has been made and the command stops; that is, the signal frequency is returned to the resting value. The discriminator output becomes zero and there is present on the grid of V1 a positive voltage of 1 volt. This makes the plate of V1 less positive (or more negative). Since the plate of V1 is tied to the grid of V3, this has the effect of increasing the bias on V3 and the tube is driven to cutoff. As a result, RY1 returns to its normally closed position. The armature of RY1 is now connected to ground making the motor rotate in the opposite direction toward neutral. When the arm reaches neutral, the potentiometer pointer observes no voltage difference to ground. Since the discriminator also has no output, the motor stops and the arm rests at neutral. The bias voltage through the variable potentiometer ganged to the control arm must be of equal and opposite polarity to the control voltage developed in the discriminator.

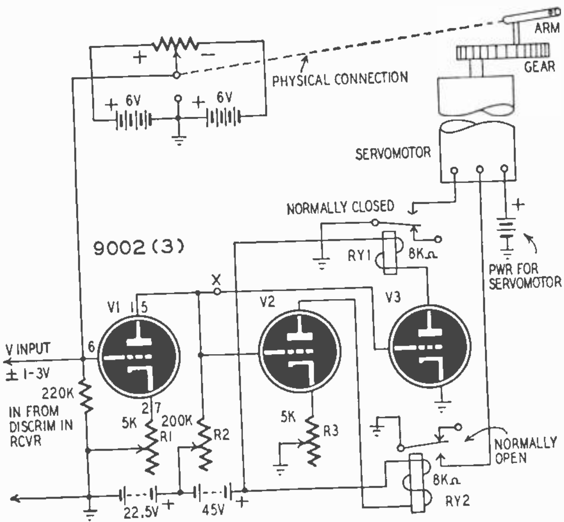



*Fig. 706—Circuit for proportional control. The amount of turn is proportional to the deviation in frequency.*

It is not necessary for the operator to observe the controlled object in this instance. He knows that when he increases the command frequency a turn will result, the amount of the turn being proportional to the amount by which he increases the command frequency. He knows also that a right turn results from increasing frequency and a left turn from decreasing frequency.

Getting back to Fig. 706, we note that RY2 is normally open, while RY1 is normally closed. V3 is operated with zero bias voltage on its grid when no signal comes from the discriminator; therefore V3 draws enough current to hold its relay normally closed. V2 is cathode-biased by R3 so its plate current is not high enough to energize its relay. A negative signal from the discriminator closes the motor circuit through RY2 and a positive signal can close the circuit through RY1.

The circuit shown in Fig. 706 is unique in that it is a direct-coupled amplifier. This means that the plate of the first tube is directly connected to the grid of the second. Notice that the minus side of the 22.5-volt battery connects to ground.

and that the plus side is tied to the variable load resistor R2. This battery has practically zero resistance through it. The amount of plate current drawn by V1 can be determined by regulating the cathode resistance R1 and the plate load resistance R2. The voltage drop across the plate load resistor is opposite in polarity to that of the battery. If the I-R drop across the plate load resistor is equal to the battery voltage, then the voltage measured from point X to ground will be zero (measured with a high-resistance voltmeter). In this way, both V2 and V3 will have zero bias on their grids. In adjusting the circuit, the voltage from point X to ground must be measured at the time that the load resistance and the cathode resistance of V1 are adjusted.

It is desirable that the full 67.5 volts be used as a plate supply for the 9002 relay tubes. As far as the plate circuits of the relay tubes are concerned, both the 22.5- and 45-volt batteries are in series from the bottom ends of the relays to ground. Since the cathodes of the 9002 relay tubes are also returned to ground and the other ends of the relay coils are attached to the plates, the tubes have 67.5 volts of battery supply. V2 has a variable cathode resistor which is used to adjust the tube until it draws so little current that the relay in its plate circuit is normally open.

# Chapter 8

## Receiver Construction

RECEIVERS USED in radio control may be as simple or as complex as desired. Where the controlled device must respond to many commands, the receiver may become elaborate. However, for functions such as forward, left, and right control, one tube receivers are very satisfactory.

### One-Tube Receivers

The simplest receivers for radio control are the Aerotrol and Goode, one-tube receivers in which the reception of a nonmodulated radio-frequency carrier operates a relay. The basic principles of both are the same. The circuit of the Aerotrol receiver appears in Fig. 801 and the Goode receiver in Fig. 802. The difference between the two receivers is in the method of obtaining the required plate current change necessary to operate a relay.

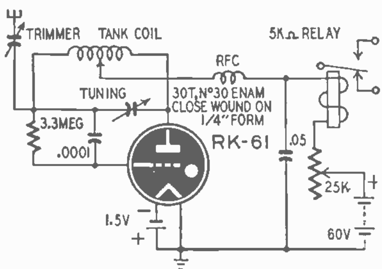



*Fig. 801—The Aerotrol one-tube receiver.*

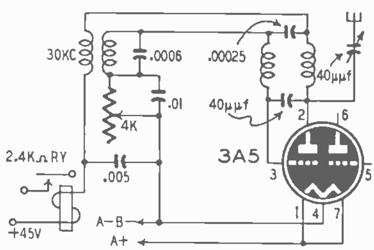



*Fig. 802—The Goode one-tube receiver.*

For reasons previously outlined, the Aerotrol circuit comprises a superregenerative receiver. When the circuit is in a condition of superregeneration, the plate current is low because the bias is high; when the circuit is not superregenerating, the bias decreases and the plate current rises to about 1.5 milliamperes. These two operating conditions take place upon the reception of the radio-frequency carrier; that is, the circuit is adjusted so that the tube is not superregenerating but is very close to that point. When the signal is tuned in, it makes the circuit go into the superregenerating state. This in turn decreases the plate current so that a relay in the plate circuit opens. A gas-filled triode is used in order to operate a relay by means of the tube plate current.

The Goode circuit uses a vacuum tube instead of a gas tube. The tube is arranged in the circuit so that it oscillates at two frequencies simultaneously, one governed by the tank circuit and the other by the quench circuit. The receiver is so adjusted that a signal from the transmitter results in an increase in the tube bias. Consequently, the tube plate current decreases, and the relay in the plate circuit opens.

Both of these receivers are of commercial design and may be purchased on the market.

## Goode Receiver Construction Notes

Constructing a Goode receiver circuit using a standard Sigma 4F relay, instead of the special one which comes with the set as purchased, produces disappointing results. This set is designed to work with a relay which will close with approximately 0.5 milliampere. Such relays are not readily available on the market. A modification enables the set to operate a standard Sigma 4F relay, making the set much less critical and much more easy to adjust.

Fig. 803 shows the necessary changes. The modification consists simply of

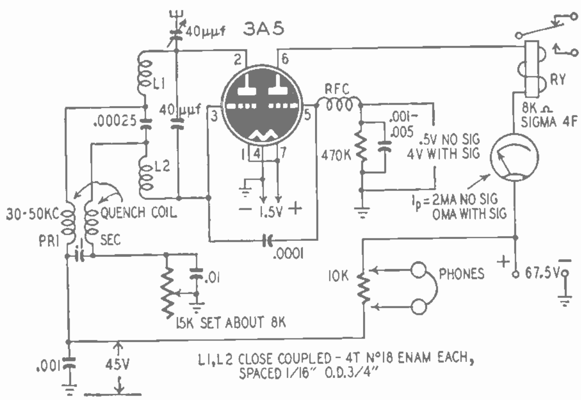



*Fig. 803—Modified Goode receiver using Sigma 4F relay.*

coupling the second half of the 3A5 tube to the superregenerative stage in such a manner that in the absence of signal the second half of the tube draws its rated current. This is about 2 milliamperes at 67.5 volts plate supply, and drops to zero when the signal is received.

The first half of the 3A5 works as a normal self-quenched superregenerative detector. When it is in the superregenerating condition, there is a certain amount of r.f. energy present in the tank circuit. This energy is coupled to the grid of the second half of the 3A5 tube by means of the 100-$\mu\mu f$ capacitor. Rectification of the signal takes place in the grid circuit of the second half of the 3A5, a negative grid voltage being developed across the 470,000-ohm resistor. The r.f. choke is necessary to prevent the short-circuiting of the r.f. energy in the tank circuit of the 3A5 to ground.

When a signal is received, it adds a small amount of energy into the tank circuit of the 3A5. This energy is amplified through the feedback action of the tube until it becomes a large value. The signal, having increased amplitude, is presented to the grid of the second half of the 3A5, increasing the bias on this half and decreasing the plate current to zero.

In operation, the first half of the 3A5 is made to superregenerate by adjusting the variable 15,000-ohm grid resistor and also by having correct connection to the quench coil. A pair of earphones connected as shown will make the hiss audible; if no hiss is heard, either the plate connection *or* the grid connection to the quench coil should be reversed. With the values of components shown, the variable grid resistor should be adjusted until the relay in the plate circuit of the second half of the 3A5 *just closes.* This means that, with the normal amount of r.f. energy present in the tank circuit, only a small amount of bias will be developed in the grid circuit of the second half of the tube (approximately ½ volt).

If a signal is tuned in, the additional energy increases the bias on the second half of the tube to about 4 volts, enough to drive the tube to plate current cutoff. In the absence of plate current, the relay opens. If the Sigma 4F relay is adjusted to close at about 1.5 milliamperes and to open at approximately 0.25 milliampere it will need no readjustment when placed in the circuit. The armature should be free, not sticky. The gap between armature and relay must be small for it to operate under these conditions.

Once the set is constructed and adjusted, almost any length antenna may be used so long as it is not resonant. A resonant antenna will make the superregenerative half of the tube cease operation. The set is not critical and there is no trouble with body capacitance. Long leads have no effect, nor do variations in the supply voltages. Four things should be remembered to make construction easy:

(1) Listen for the superregenerative hiss with earphones; reverse the quench coil (one side) if the hiss is not heard.

(2) Keep the two halves of the tank coil close together and make connections to the outer end of each with the plate and grid.

(3) Adjust the variable grid resistor to a value which causes the relay to close. Listen to be sure that the set is still superregenerating when this occurs.

(4) Increase the value of the 470,000-ohm resistor if the relay does not open with signal. However, if a meter is placed in the plate battery lead and a current change of 2 milliamperes is observed, do not change this resistor. Instead, adjust the relay both in gap and spring tension until it operates with this change.

The r.f. choke used may be any good high-frequency unit or a winding consisting of about 35 turns of No. 30 cotton-covered wire scramble-wound on a small 10-megohm resistor. Connect the winding ends to the resistor ends.

The quench coil is one of the most difficult parts of this circuit to obtain. A National OSR quench coil may be used. If this item cannot be obtained, use two flat single-pie 5-millihenry r.f. chokes for this component by bolting the two together. When this is done, care should be taken that the two windings run in the same direction. With a quench transformer of this type, the value of the 10,000-ohm plate resistor should be reduced to about 3,000 ohms when using a 67.5-volt battery for the plate supply. To check circuit operation, place a pair of 4,000-ohm earphones across the resistor (temporarily reducing it to 3,000).

The grid resistance is varied to determine if the circuit is superregenerating. If no hiss is heard, the connections to one choke should be reversed. Rotation of the grid resistor should produce the hiss when set at approximately center value.

The relay, if adjusted to pull at 1.5 milliamperes and release at about 0.25 milliampere, should not require further attention. To set the circuit in operating condition, the grid resistor should be rotated until the relay closes. *At this point the hiss of the superregenerative stage should still be audible,* although softer than before. Keying the transmitter should make the relay operate. Finally, replacing the 10,000-ohm resistor with a 3,000-ohm resistor completes the unit.

## Tone-Operated Receivers

Fig. 804 is an example of a receiver which works with a modulated signal. Because this receiver requires the presence of an audio tone to make the relay operate, it can be tuned in with an ordinary pair of earphones. This receiver can be adjusted easily and quickly, there being no necessity for the very critical adjustments which characterize one-tube sets.

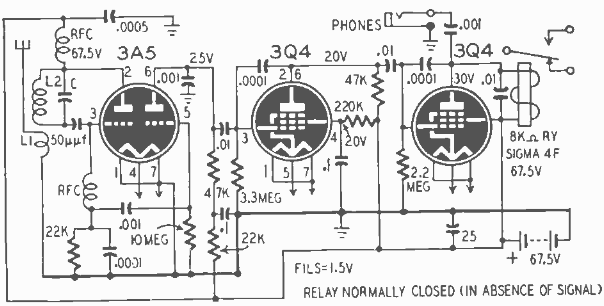



*Fig. 804—Tone-operated receiver using superregenerative detector.*

The receiver uses two 3Q4 tubes, standard battery pentodes, and one 3A5 dual-triode. One side of the 3A5 is wired as the superregenerative detector and the second half as the first audio. One 3Q4 is used as the second audio stage and the second 3Q4 is used as a relay tube.

When the audio tone is received and detected by the superregenerative stage, it is fed to the amplifiers which build it to a large voltage value. This voltage, presented to the grid of the relay tube, is sufficiently large so that rectification of the signal takes place between the grid and the filament. The direct current resulting from this rectification passes through the large grid resistor (2.2 megohms) of the relay stage. This produces a voltage drop of a value sufficient to bias the tube to plate current cutoff, thus opening the relay in the plate circuit. In the absence of the signal, the relay tube has no bias and conducts, the flow of plate current causing the relay to close.

The superregenerative stage is conventional except for the type of coupling used to the first audio stage. Since it was desired to have the receiver operate on the lowest value of plate voltage possible and also have the least weight, both plate-resistance and transformer coupling were ruled out. The audio section is a conventional resistance-coupled amplifier and includes feedback and bypass capacitors. These small value capacitors are used to bypass quench frequencies which would appear in the output along with the desired signal, and prevent the relay tube from drawing the maximum amount of current.

In testing this receiver, a pair of earphones should be used. These can be placed across the output and should make audible the familiar quenching hiss, a characteristic of superregenerative detectors. Next, using a high-resistance voltmeter (a v.t.v.m., if possible), measure the d.c. grid voltage from the grid of the relay stage to ground (across the 2.2-megohm grid resistor). This should not exceed 1.5 volts. If it is higher than this, increasing the size of the bypasses and the feedback capacitors will reduce it to this value. When a transmitted tone is tuned in, the voltage across the grid resistor should rise to 12 or 15 volts, the plate current change under these conditions being about 4 milliamperes. This receiver can operate an escapement directly. The photograph (Fig. 805) shows the

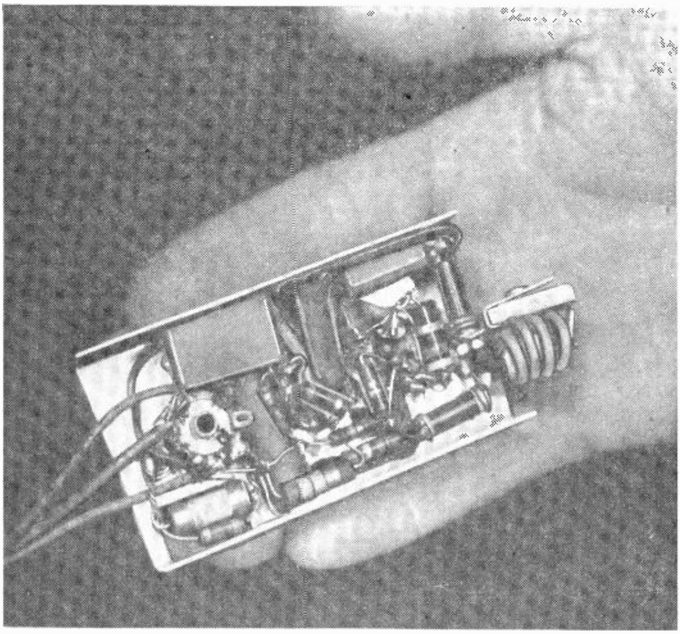


*Fig. 805—Wiring and parts layout for the three-tube receiver.*

wiring and parts layout of the three-tube receiver. Note the comparative size of the set.

A modification of this receiver is shown in Fig. 806. A 9002 used in the superregenerative stage gives considerably more sensitivity. Its disadvantage for model aircraft use is that a 6-volt A-supply must be used. However, for most applications it is small and easy to adjust. The receivers shown in Figs. 804 and 806 have a ground range of over 500 yards and an air range of about three times this value. Construction details for antenna and antenna transformer can be taken from the receiver illustrated in Fig. 808.

In Fig. 807 we have another receiver which differs slightly from the preceding types. In this unit the audio voltage is developed across the coil of an L-C bandpass filter. The relay tube in this unit conducts when a signal is received, instead of not conducting as in the previous cases. All of the remarks made earlier concerning bandpass filters apply to this unit.

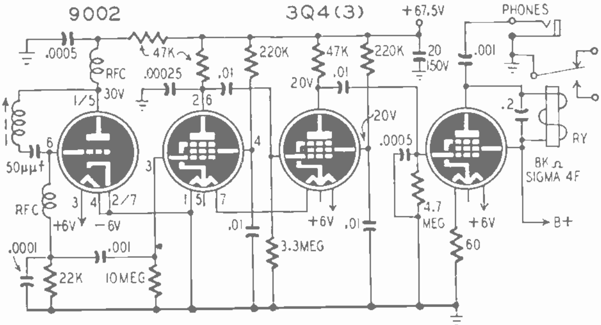



*Fig. 806—The use of a 9002 in the superregenerative stage increases the sensitivity.*

The 9003 relay stage is biased to cutoff by connecting its cathode to the positive side of the 6-volt A-supply. The first tube of the amplifier section is connected as a triode in order to eliminate microphonics. The Sigma relay coil in the plate circuit of the first 9002 is to provide an inductive load for the tube. This means that a low value of supply voltage can be used, since the d.c. resistance of

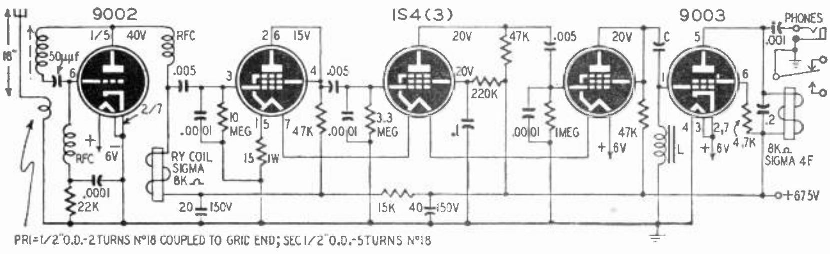



*Fig. 807—Tone-operated receiver using band-pass filter in grid circuit of relay tube.*

the relay coil is low. At the same time the coil presents a high impedance to the signal, allowing greater amplification. A Sigma relay coil was used, instead of a conventional choke, because it provides sufficient inductance and yet is small in size.

The secondary of the antenna coil consists of five turns of No. 18 wire wound on a form having an outside diameter of ½ inch. The wire may be plain enameled but double silk-covered wire is recommended. The coil is tuned by a polyiron slug.

An unusual feature of this circuit is the bypassing of the grid resistors of the 1S4 tubes. This is done to prevent r.f. generated by the 9002 from feeding through the stages. If the r.f. should get through, it would be rectified between the grids and filament, causing the audio stages to have more than the desired bias. More amplification is obtained by having the grid return resistors bypassed, eliminating any possible difficulties due to r.f., yet having very little effect on the audio tones. If the bias on the 9003 relay tube is excessive, the relay will not work. This can be cured by increasing the value of the 4,700-ohm screen resistor. The relay spring tension may also have to be adjusted.

A modification of the idea just presented is to use not one, but three, bandpass filters of the L-C type and three relay tubes, as shown in Fig. 808.

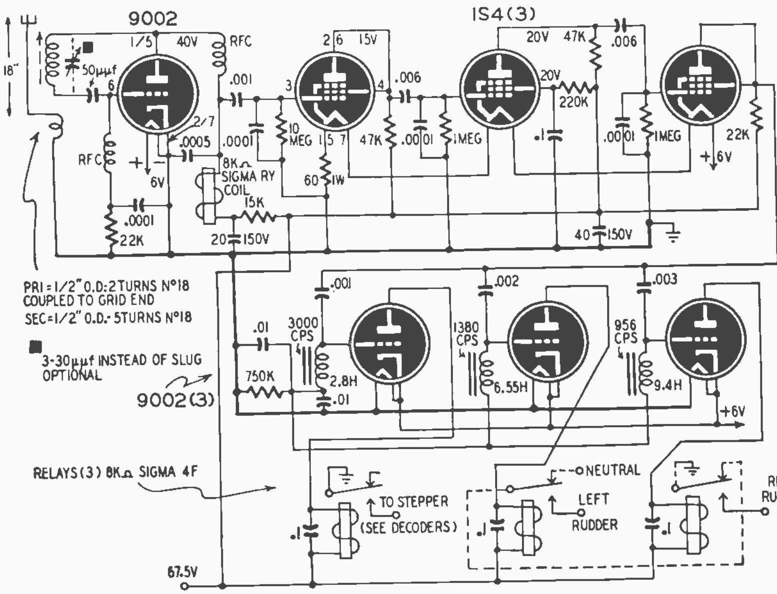



*Fig. 808—Tone-operated receiver using three band-pass filters and three relay tubes.*

The ground transmitter must be capable of producing three audio tones. As each tone is transmitted, it causes its respective relay to close. All three relays cannot be operated simultaneously, nor can any two be operated at the same time unless the tone separation is very great and unless the common grid resistor is removed from the L-C circuits. When one tube conducts, it develops a bias voltage across the common grid resistor. This bias holds the other two tubes cut off, preventing simultaneous operation. The capacitor across the resistor is necessary to allow the a.c. signal to return to ground easily. The photograph (Fig. 809) shows a topside view of the three- and five-tube tone-operated receivers. The escapements are to the left of the receivers. The cigarette in the foreground gives an idea of the size of these sets.

The receiver diagrammed in Fig. 810 is shown connected to the reed selector described in the section on "Construction of Coders and Decoders."

This receiver gave excellent results in numerous test flights when installed in a 7-foot Piper Cruiser. It uses a superregenerative detector and has two stages of audio, the first a high-gain 1S5 pentode and the second a power output battery-type 1S4. The output is fed directly to a vibrating-reed decoder through reed filters which are essential to correct operation.

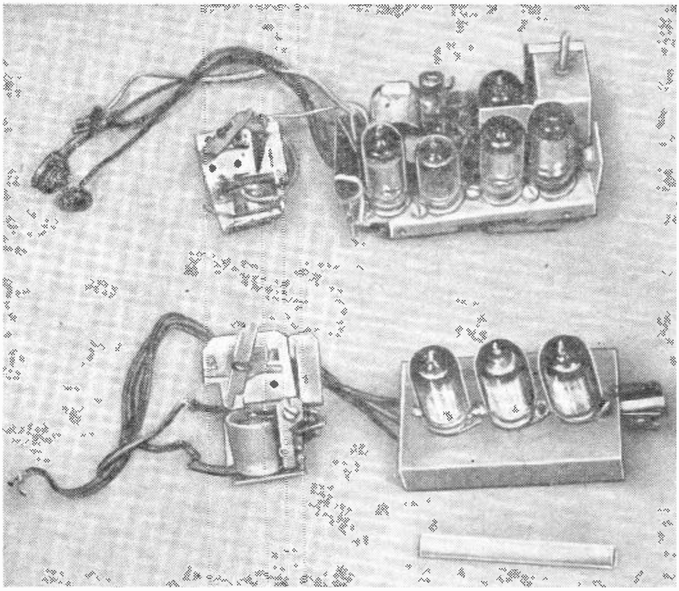


*Fig. 809—The three-tube and five-tube superregenerative receivers. The escapements are shown at the left. Cigarette in foreground gives idea of size.*

Construction details for a resonant-reed decoder are given on pages 85 and 86 of Chapter 10. Although three reed selectors are shown here, either more or less reeds can be used, depending upon individual requirements. The reed tones should be sufficiently separated in frequency so that there is no interaction between any of the reeds. Increasing the number of reeds in the receiver means that additional modulator tones must be supplied at the transmitter.

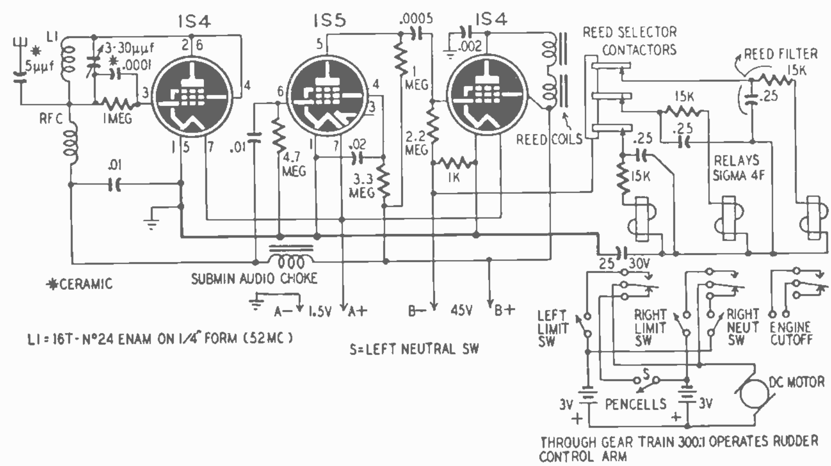



*Fig. 810—Receiver using three vibrating reeds as decoders. The reed coil forms the plate load for the 1S4.*

# Chapter 9

## Transmitter Construction

HERE ARE four transmitters which find use in connection with the receivers discussed in the previous chapter. The first type (Fig. 901) is a commercial unit, which can be used with both Aerotrol and Goode receivers. The transmitter employs a 3A5 tube. Capacitors C1 and C2 are used to determine the frequency of transmission. Capacitors C3 and C4 control feedback, and in adjustment should be rotated until the d.c. milliameter in the plate circuit reads its lowest value. These capacitors should then remain fixed. The tank coil is made of 10 turns of No. 18 solid copper wire, ½ inch outside diameter and spaced ⅛ inch between turns. The antenna coil is a single-turn loop of the same wire placed at the midpoint of the coil and spaced ⅛ inch from it. The antenna coil loops over the B-plus tap. The carrier is pulsed by breaking the B-plus or B-minus leads.

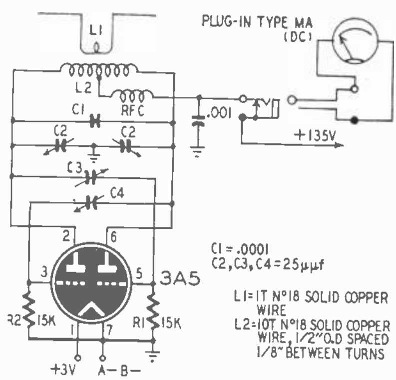



*Fig. 901—Simple transmitter for use with Aerotrol or Goode receivers.*

## Tone-Modulated Ultra-audion

A second type of transmitter, including a tone modulator, is shown in Fig. 902. Designed for use with the two tone receivers previously described, this transmitter employs a 6C4 as an oscillator and a 6K6 as the modulator-tone oscillator.

This conventional circuit is operated on a wavelength of 2 meters, with batteries as the A- and B-supplies, or, alternatively, a Vibropack having an output of 250 to 300 volts at 50 to 75 milliamperes.

The modulation transformer is connected in the unusual manner shown in order to get a high percentage of modulation. A superregenerative detector acts as a volume expansion unit when receiving signals with a high percentage of modulation. Keeping the modulation percentage high means increased operating range.

The 6K6 is used as the modulator because of the lower filament current required. With this tube connected as a triode, the plate resistance decreases and makes the match between the 6C4 and the 6K6 close to a 1-to-3 ratio. It is possible to use other tubes (6V6, 6L6, 6F6, 6C5), provided that the correct match is maintained. A 6C4 might be used if it provides sufficient audio power. Two watts of audio should be available and this tube is capable of that. The main requirement is that the modulation be near 100% since the output of superregenerative detectors goes up considerably between 80% and 100% modulation.

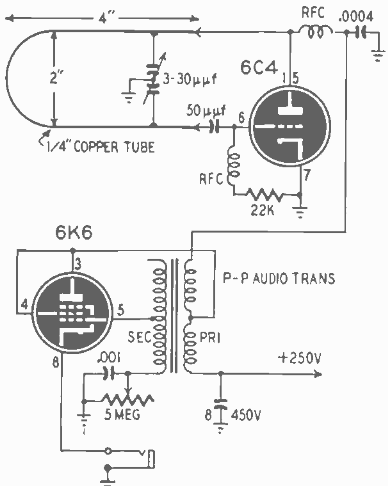



*Fig. 902—Transmitter including a tone modulator.*

The jack in the cathode of the 6K6 is to key the tone circuit. The bottom of the jack should go to ground. The 5-megohm potentiometer in the grid circuit controls the tone. Tone receivers which use a bandpass filter of the L-C or twin-T type require that the tone received correspond to the frequency of the filter. This adjustment is for the purpose of setting the audio frequency of the modulator to that of the bandpass filter. The tuning capacitor should be a split-stator type. The rotor may be grounded or left floating.

The antenna coil is identical in size and dimensions to the tank coil, except that it is inverted and of smaller wire or tubing. By inverted is meant that the loop is toward the open end of the tank coil. The ends of this connect to ground and to the antenna if the antenna is a quarter wave. If the antenna is a half-wave Hertz, the ground connection is omitted. The antenna coil should be spaced ½ inch from the tank coil. The photograph (Fig. 903) shows the physical layout and simplicity of parts of a tone-modulated ultra-audion transmitter. The tank circuit and antenna coil are clearly visible.

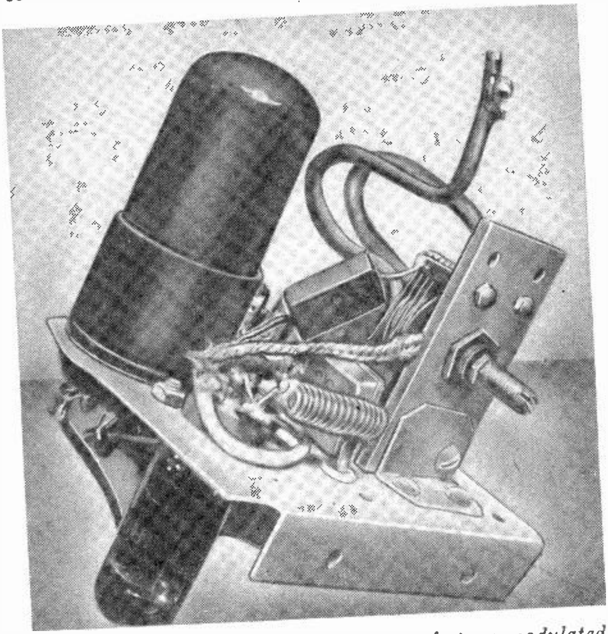


*Fig. 903—Compact physical layout of tone-modulated transmitter.*

## Antenna Adjustment

If you have a v.t.v.m. or high-resistance voltmeter which you can place across the grid resistor of the oscillator, you can couple an automobile whip antenna to the tank circuit through a one- or two-turn loop and then gradually vary the length of the whip, observing the meter. When the grid voltage drops to one-half of its non-loaded value, the coupling and length are approximately right for the transmitter. The whip makes a good quarter-wave antenna which is simple and practical.

## Push-pull Ultra-audion

This transmitter, shown in Fig. 904, uses a pair of 6C4's in push-pull. The transmitter operates in the 2-meter band and gives an output of about 4 to 5 watts when powered with a 300-volt Vibropack.

The circuit is used with a modified audio section to allow selection of any one of three different audio tones for transmission. The modulator consists of a 6A8 transition (negative-resistance) oscillator and three L-C circuits, any one of which may be connected into the operating position by closing the lead between one end of the tuned circuit and ground.

In order to get a high degree of modulation a conventional audio output transformer (push-pull 6V6's to voice coil) is connected in an autoformer circuit

This not only drops the voltage to the r.f. section slightly, but also gives the correct match for a single modulator tube.

The voltage stabilizing circuit on the tone banks is advisable because a drift of plate potential causes some drift in the frequency of the generated tone. A variation of more than 10% from the resonant frequency of the selective filter used in the receiver causes a large decrease in the output voltage to the relay tubes.

Fig. 905 shows the construction of the transmitter. The tone oscillators are below the r.f. section. Note the location of the tank coil and capacitor.

The proper way to adjust this transmitter to a three-tone receiver is somewhat laborious but pays big dividends in increased range and reliability. The re-

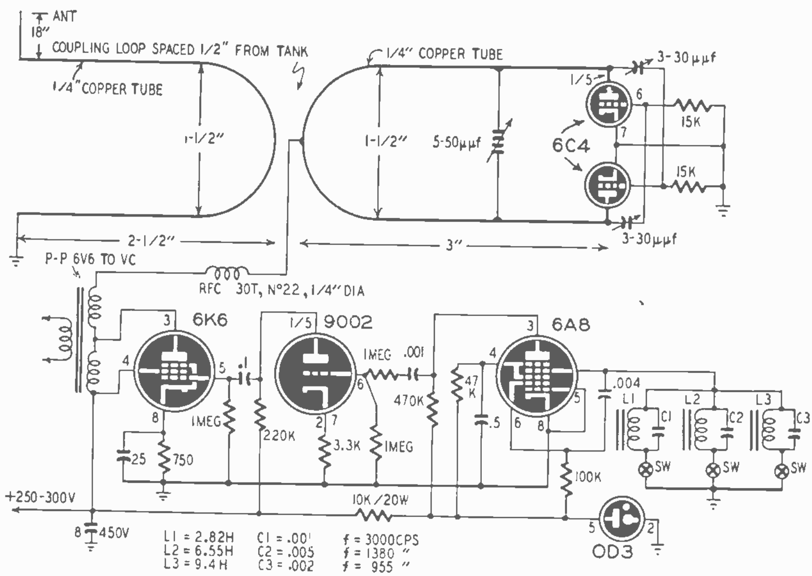



*Fig. 904—Tone-modulated transmitter using 6C4's in push-pull. The modulator is a transitron oscillator.*

ceiver is connected to its power source, and a scope (vertical axis) is connected across the choke part of the L-C circuit. The superregenerative tube is removed from its socket, and a signal from an audio oscillator is fed into the input of the audio section of the receiver, using the smallest signal that will produce a good output on the scope. The frequency of the audio oscillator is varied around the frequency at which the L-C circuit should be resonant. At resonance, an abrupt increase of the picture on the scope will occur. This will indicate the actual resonant frequency under operating conditions.

Each of the filters is thus checked for its resonant frequency and a note made of these readings, either on a card or on the dial of the audio oscillator itself. The transmitter should be connected and one of the tone circuits placed into operation by closing one of the switches. The scope vertical axis leads should be placed across the output of the modulator, between the plate of the 6K6 and ground.

The audio oscillator is fed into the horizontal plates of the scope and tuned to the reading corresponding to that of this particular filter. If the transmitter tone circuit is correct, an O should appear on the face of the scope. It may be slanted, but it definitely should be a line or circle. (See Fig. 906.) If it is not, the capacitance of the tone circuit should be increased or decreased until this does result; then the tone will be exactly right for the receiver filters. This technique should be followed for all the other tone circuits.

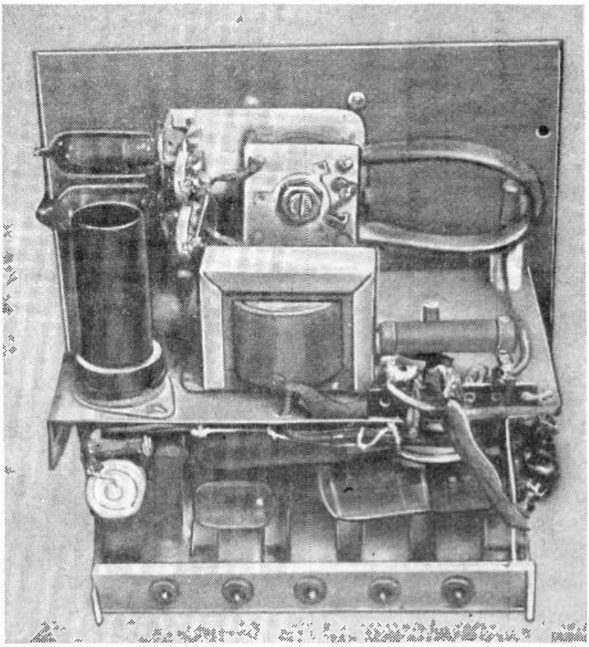


*Fig. 905—Parts layout for the tone-modulated transmitter using push-pull 6C4's.*

## Tone-Modulated Transmitter

This transmitter (Fig. 907) was designed to be used with a reed decoder. The modulator consists of a simple Hartley audio oscillator which generates tones whose frequency is adjustable by means of resistors R1, R2, and R3. Keying is accomplished by closing in each lead a switch which grounds the proper resistor for the tone selected and also places the screen voltage on the 1S4 oscillator tube at the same time.

The transmitter in Fig. 907 was used for the control of a model boat; however it can be used in connection with a model car or plane just as well. The tone-control circuit can be built into a separate box as indicated by the dashed lines. The double-pole double-throw lever switch can give either of two tones and was used for rudder control. Engine operation was secured by an engine control push-button switch. A three-reed decoder is necessary in the receiver when using this transmitter; one reed for each transmitted tone. Modulation of the 1T5 is accomplished through the use of two output transformers placed back to back. This gives a fairly good impedance match between the 1S4 and the 1T5. In this way a high percentage of modulation is obtained. Construction of the tank

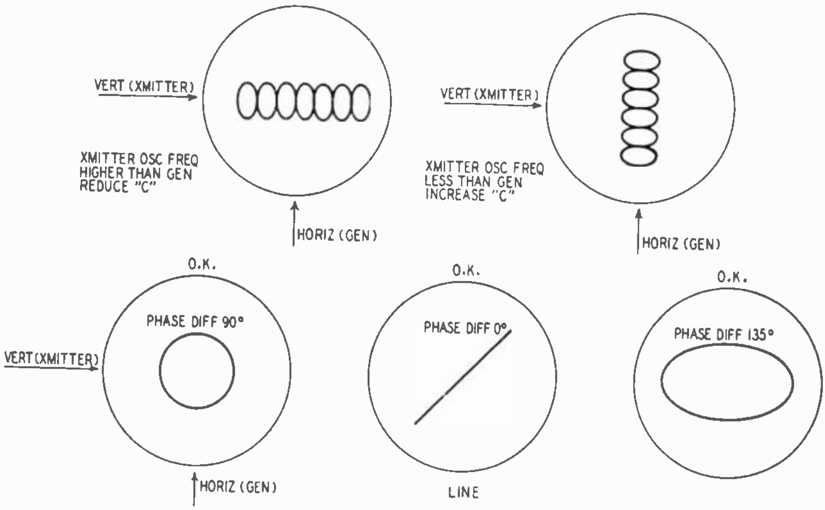



*Fig. 906—Lissajous figures obtained in checking frequency of tone modulators.*

circuit and antenna coil can follow that outlined for the other transmitters described in this chapter.

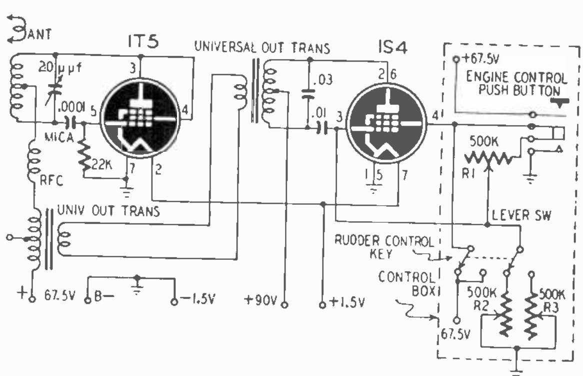



*Fig. 907—Transmitter designed for use with a reed decoder.*

# Chapter 10

## Construction of Coders and Decoders

A CODER is a device for controlling the output of a transmitter. The fundamental coder, of course, is a telegraph key or push button of the type used with door bells. Where more complete control of the transmitter is wanted (transmission of pulses varying in width or spacing, for example), it is necessary for the control operator to use some mechanical ingenuity and skill. The decoder in a receiver corresponds to the coder in the transmitter. The receiver picks up the signal, and sends it along to the decoder. The decoder, in response to the signal, causes some operation to be performed. This operation may be an action such as turning a plane to the left or right, or may be more complicated, as in the case of a model bus having front and rear lights, running lights, front and rear doors, reverse travel, horn, etc.

### Escapements

The escapement is one of the simplest types of decoders. If an electromagnet is mounted on a small plate, as illustrated in Fig. 1001-a, and to this magnet is fastened an arm which is free to pivot like a relay armature (Fig. 1001-b), this

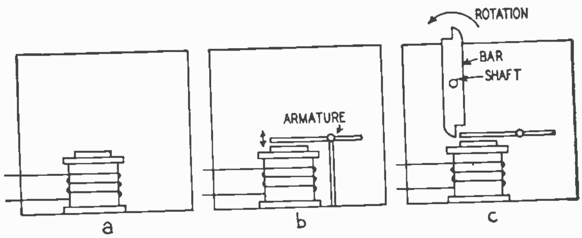



*Fig. 1001—Steps in building a simple escapement.*

arm can be used to stop the rotation of a bar when the magnet is not energized. It will pull down and allow the bar to rotate when the magnet is energized (Fig. 1001-c). The bar is fastened to a shaft and runs through a bearing on the base plate.

In practice, it is essential that there be some means of power to make the bar rotate. This is obtained by forming a hook on one end of the shaft through the bar, attaching a rubber band to the hook and twisting it until it has enough tension to rotate the bar, just as a rubber band rotates a model plane propeller. (See Fig. 1002.) If this magnet and bar are to be used as a decoder, some further refinement is necessary or the rubber band will unwind very fast when the magnet is energized and will be incapable of supplying power for any length of time.

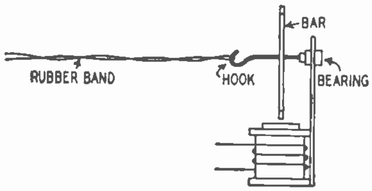



*Fig. 1002—Complete escapement. This is a side view.*

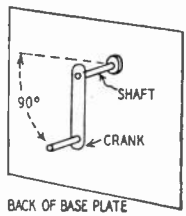



*Fig. 1003—Crankshaft.*

In a model plane, steering is accomplished by moving the rudder to the left for a left turn, to neutral for straight flight, and to the right for a right turn. These motions will be the only ones required and will be repeated over and over again as long as the plane is in the air.

Now examine Fig. 1003. Here is the first modification to the basic escapement. The base plate is turned over so that we are looking at it from the side where only the shaft protrudes from the metal. If this end of the shaft is bent into the form of a small crank, it will rotate from the vertical to the right with a 90-degree rotation of the shaft, from right to down with 90 degrees more rotation, from down to left in another 90 degrees, and back to the vertical in the last 90 degrees of rotation. This means that the crank moves through all these positions every revolution of the shaft.

Examine Fig. 1004. Here we have added an inverted U bent in the end of

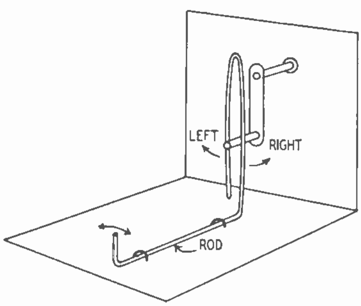



*Fig. 1004—Escapement linkage.*

a long rod. As the crank rotates the rod moves from rest position, to the right, back to the rest position, then left. The rotating action of the crank has been transformed into a back and forth motion of the rod. If the opposite end of the

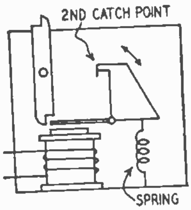



*Fig.* 1005—*Two catch points.*

rod is now bent, this part of the rod will move back and forth as the crank rotates and can be fastened to the rudder of the model plane to give left, right, or neutral position of the rudder. It is apparent that the only way that we can get this left, right, and neutral positioning of the rudder is to provide some means of stopping the bar every 90 degrees of rotation. This is accomplished by providing a second catch point on the magnet armature, as shown in Fig. 1005.

Now to review the whole operation. First, the rubber band is wound tight. The bar catches on the upraised portion of the magnet armature and holds. The crank on the back of the plate is so orientated that this position causes the rudder to point the far tip vertically. When the magnet is energized, this catch point pulls down and lets the bar rotate, but the second catch point has now moved into position, catching and holding the bar. The crank has moved 90 degrees left. The tip of the rod has also moved left. The bar will remain in this position as long as the magnet is energized.

When the current to the magnet stops, the second catch point moves back or pulls away due to the spring force on the armature, and the bar rotates another 90 degrees, its opposite end catching on the first catch point of the armature, just over the magnet. This is a second neutral position for the rudder. When the

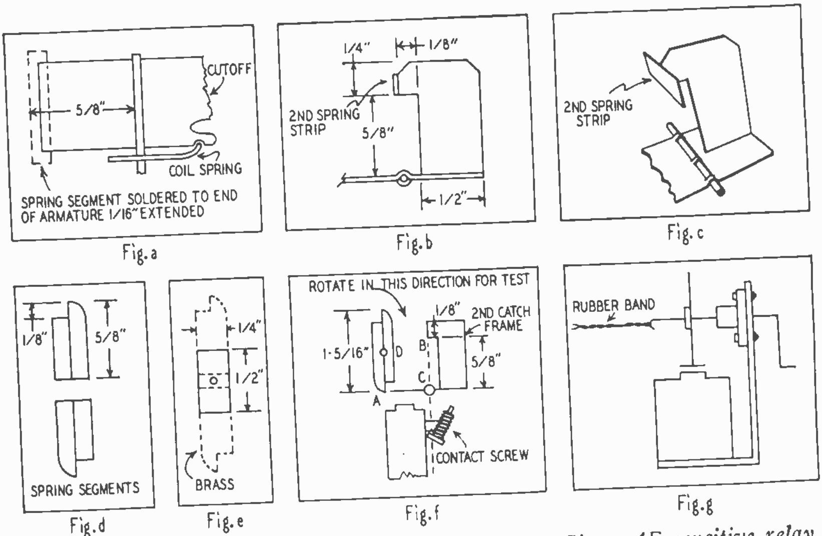



*Fig.* 1006—*Construction details of escapement using Sigma 4F sensitive relay.*

magnet is energized a second time, the bar again rotates 90 degrees, rests on catch point 2, and the crank is now in position for right rudder. De-energizing the magnet causes the bar to rotate the last 90 degrees back to the original neutral or starting position.

To construct this escapement, first procure a standard Sigma 4F sensitive relay of 8,000 ohms resistance. As it normally appears, this relay has an armature whose tension is controlled by a spring. One end of the armature is over the magnet, the other end is between two contacts mounted on a small Bakelite frame. The first step is to remove the two small screws which hold this Bakelite contact mounting plate to the metal frame of the relay. Remove one of these contacts by drilling out the rivet. Take this contact and solder it to the relay frame as illustrated in Fig. 1006. Any portion of the armature that extends beyond the contact screw can be cut off with tin shears. Glue a thin piece of tissue paper to the coil and bend it so that it rests between the armature and the magnet to prevent sticking of the armature when the relay is pulsed fast.

Cut a segment of a spring steel (from a small spring-wind toy) and file it until both sides are bright. Solder it into position on the end of the armature shaft as shown in Fig. 1006-a. To make the second catch point use a piece of

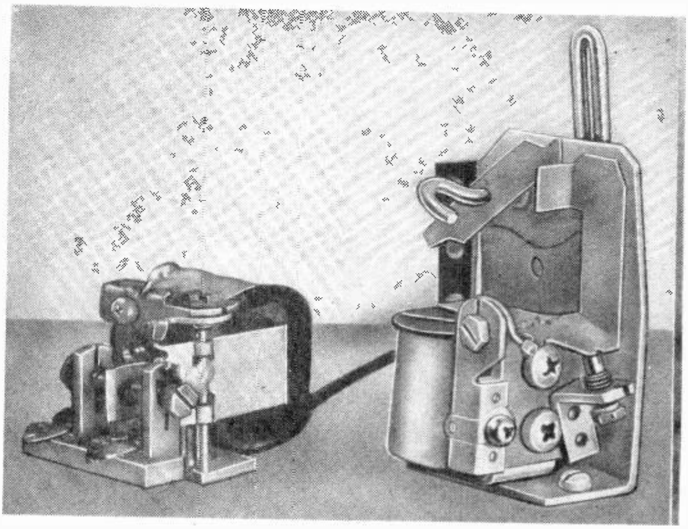


*Fig. 1007—Sigma 4F relay at left. Completed escapement shown at the right.*

medium heavy tin cut to the shape shown in Fig. 1006-b. A second spring strip is soldered to the top. It is then soldered to the armature as illustrated in Fig. 1006-c.

The shaft bar is constructed from a small piece of brass and two pieces of spring steel. Spring steel is used so that the metal will not bend under the snap of the rubber band and also to provide less friction. The two spring segments are cut as shown in Figs. 1006-d and 1006-e. Now the magnet portion and bar are ready to be mounted to the baseplate and, when assembled, should appear as in Fig. 1006-f. The distances between A, B, C, and D must form a perfect rectangle for best operation, the magnet furnishing a minimum amount of power to release the catch bar.

Some adjusting may be necessary. The contact screw will have to be adjusted so that the catch bar will engage the armature at point A when the magnet is *not* energized, and the second catch frame may have to be moved either close to the catch bar or away from it so that it will engage the catch bar when the magnet *is* energized. The magnet itself may have to be lowered so that it will release the bar when energized, and the spring tension on the armature may have to be adjusted so that it causes the second catch frame to pull away and release the catch bar when the magnet is nonenergized. To test the release clearances, rotate the catch bar backward. It should push down the armature at point A and pass by easily.

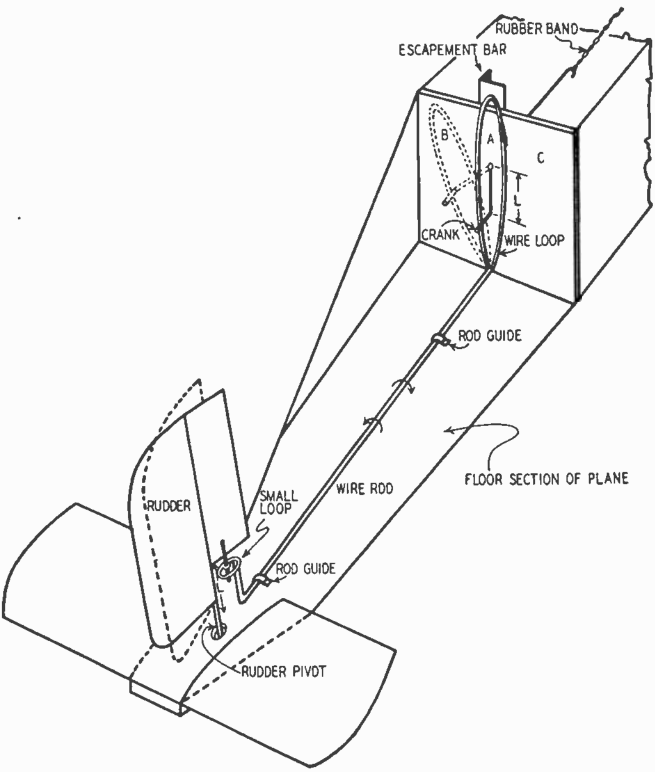



*Fig.* 1008—*Rudder control in model plane by means of an escapement.*

The final step is to provide the rubber-band hook and the crank as shown in Fig. 1006-g. This drawing also illustrates the long bearing which is desirable for the catch bar shaft. To test the unit, twist the rubber band and connect a 67.5-volt battery to the magnet, wiring it so that it can be energized by pushing a button or touching a wire. The catch bar should rotate 90 degrees and hold. Release the connection and the bar should move another 90 degrees and hold. Fig. 1007 illustrates the conversion of a standard Sigma 4F relay (left) to the escapement (right). The Sigma relay should be oriented 90 degrees counterclockwise to have the same orientation as the escapement magnet.

If the escapement does not work properly, check the following:

(1) Be sure that the armature pulls down far enough to release the bar.

(2) The spring tension and placement of catch frame 2 should be such that it releases when the magnet is not energized.

(3) Do not stretch the rubber band away so far that it causes binding in the bearing. The *twisting* action of the rubber band is desired, not the *pulling* strength. A good separation between the hook and the far end of the rubber band is about 8 inches for a standard 10-inch model plane.

(4) Be sure that the rubber-band tie point is straight away from the escapement and in line with the shaft.

(5) Be sure that the spring tension on the magnet armature is not so great that it prevents the relay from closing. Do not use any more tension than is needed.

(6) Lubricate the bearing.

Once adjusted, this escapement will give hours of service without further attention, and patience in adjustment will be well repaid.

Fig. 1008 shows the escapement in use in a model plane. The wire loop is moved from neutral position A to position B or C, depending upon the motion of the crank. The wire loop is fastened to a wire rod. The wire rod controls the position of the rudder, giving either neutral, left, or right rudder. L indicates the approximate length of the crank.

## Pulse-variation Coder

A coder of the pulse-variation type is illustrated in Fig. 1009. In this case

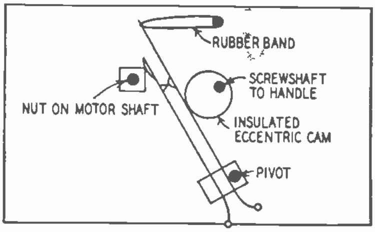



*Fig. 1009—A pulse-variation coder is shown in the illustration at the right. This coder can give long pulses (short spacing) or short pulses (long spacing). The eccentric cam controls pulse duration. Tension is obtained by means of a rubber band.*

the coder controls pulses of long duration and short spacing or short duration and long spacing, varying gradually from one to the other. The coder is simply a motor, geared down so that it turns an output shaft at about 15 revolutions per minute. On the shaft is placed a small four-point metal contact; this can be a large square nut.

On the motor frame, and pivoted so that it can be closed by moving it against the nut, is a set of contacts. These are so arranged that by turning a screw or moving a lever the contacts move down or away from the nut corners. When the nut is rotating, if the contacts are moved closer they are closed sooner and remain closed longer; thus a long pulse results. If they are moved away, just the tip of the nut closes them and a series of short pulses with long spacings result. It can be seen that there will be a point between these two limits where the pulses will have the same duration as the spacing. This coder is also pictured in Fig. 1010.

## Delay Decoder

This decoder is simply the receiver relay with a delay relay in addition, as illustrated in Fig. 1011. When the receiver relay closes with a signal from the transmitter, it causes the delay relay to be energized, and this in turn sends power to a drive motor. When the tone is pulsed, the receiver relay makes contact with the normally open contact and causes the steering relay to close. If the pulses transmitted are of equal spacing and duration, the steering relay will spend half its time on one contact and half on the other, causing the power sent to the motor

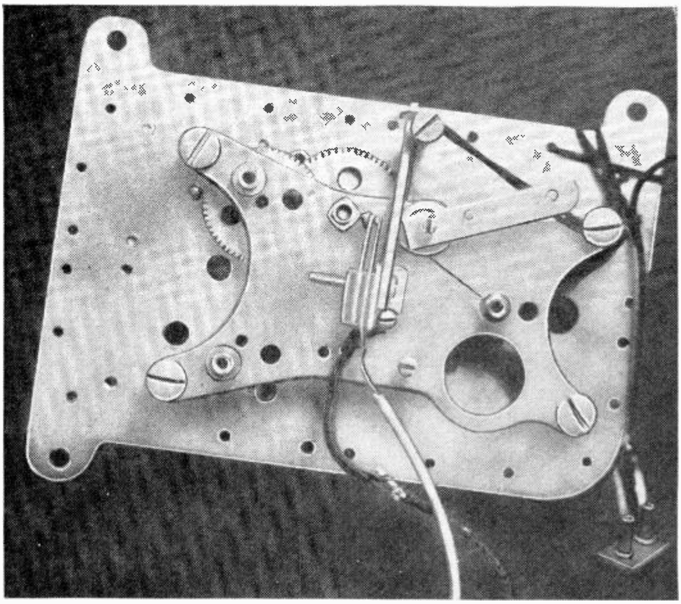


*Fig. 1010—Pulse-variation coder. Note that the tip of the nut closes the switch contacts.*

to be equal and opposite; thus no motion results. If, however, short pulses are transmitted, the steering relay spends more time on one contact than the other and the motor moves in one direction; if long pulses are transmitted, the motor reverses.

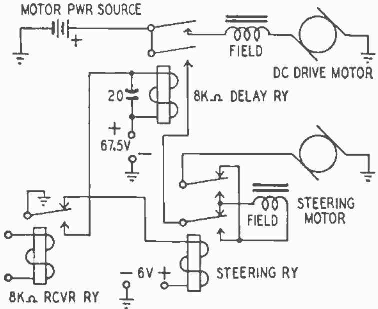



*Fig. 1011—Decoder using a delay relay.*

The common lead to the steering motor is fed to the battery through one of the contacts on the delay relay so that when it opens, due to signal stoppage, both the steering motor and the drive motor will be de-energized. The delay on the drive relay is necessary to hold it closed between pulses. A method of using this system in a model car is shown in Fig. 1012. The drive motor is geared to the rear axle. One of the rear wheels is fixed to the axle and turns with it. The other wheel rotates freely. Steering is done by a servo motor to which a rod is fixed. Rotation of the servo causes the rod to move either left or right, as shown, providing left or right turning action for the car.

One end of the 67.5-volt relay is permanently connected to B-plus. The other side of this relay is connected to a receiver relay. Closing of the receiver relay could connect the 67.5-volt relay winding to ground. The 67.5-volt relay energizes. This activates the delay relay, resulting in the delivery of power to the drive

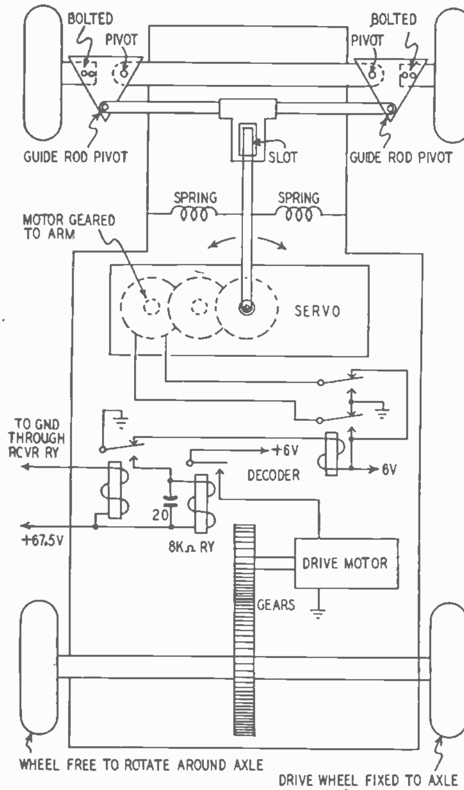



*Fig. 1012—Delay decoder used in model car.*

motor, and the car moves forward. The capacitor across the delay relay will hold its relay closed during the brief fraction of time between transmitted pulses. With a rapid succession of equal pulses the car drives forward. If the pulses are unequal in width, this will result in the armature of the 67.5-volt relay spending more time on one contact than the other. This, in turn, will control the length of time that the relay for the steering motor is energized. The steering motor operates at all times. If, however, the steering motor relay is in the up, or unenergized position, voltage of a certain polarity is applied to the steering motor. When the relay is down, the polarity to the motor is reversed. Steering is done by having the steering motor relay remain more in one position (unenergized, for example) than in another position (energized).

A modification of this system which also works with the same pulse code is as follows: The coder consists of a small d.c. motor geared down so that it will turn a contact arm at the rate of about 12 r.p.m. On the motor frame is arranged a set of contacts in the form illustrated in Fig. 1013. When one set of contacts is

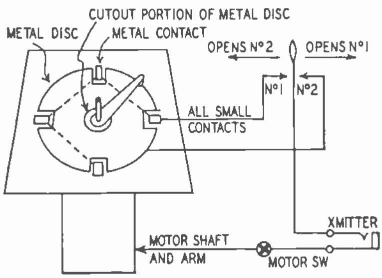



*Fig.* 1013—*Mechanical pulse-variation coder.*

opened by moving the control switch in one direction, short pulses are transmitted. When the control switch is moved in the opposite direction, long pulses are sent. With the switch in neutral, a continuous tone is transmitted, which may be cut off by opening the motor switch.

The contacts are constructed by notching a circular piece of metal at four equidistant points around its rim. In these notches, but insulated from the circle, are placed the four small contacts. As the pointer rides around the circle it makes contact continuously with both sets of contacts for a continuous tone. By breaking one or the other of the leads to the contacts, the pulses are emitted.

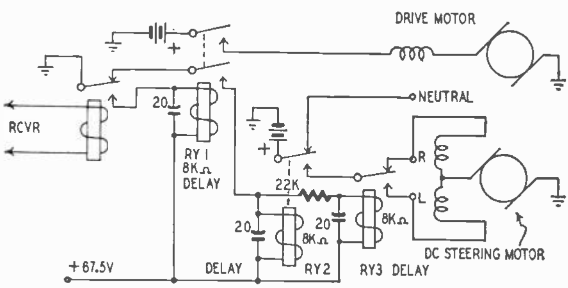



*Fig.* 1014—*Decoder for use with pulse-variation coder.*

The decoder section consists of three relays and three capacitors arranged as shown in Fig. 1014. When a pulse is received, the receiver relay becomes energized. This connects one side of the delay relay coil 1 to B-minus. Since the other side of the delay relay coil 1 is connected to B-plus, this means that this delay relay will become energized. Energizing this first delay relay connects the drive motor to a source of power causing the drive motor to turn. As pulses are transmitted, the 20-$\mu f$ capacitor holds this relay closed.

If short pulses are transmitted, the second delay relay is also operated and its capacitor charges instantly. Energizing RY2 connects the steering motor to power and also makes the rudder or wheels turn in one direction. When long pulses are transmitted, both delay RY2 and delay RY3 become energized. This results in rotation of the steering motor in the opposite direction.

If the pulses cease, but the tone or signal energizes the receiver relay, then both RY2 and RY3 return to neutral, or up position, closing the circuit to the steering neutralizing circuit and causing the rudder or wheels to return to neutral. When the signal is cut off, the receiver relay drops onto its back contact and energizes both RY2 and RY3. However, after a short delay (longer than that between pulses, however) RY1 opens and cuts off power to both the drive motor and the steering motor relays.

## Numerical-Sequence Coder and Decoder

We can also have a coder and decoder designed to operate with numerical sequence codes in which as many as 16 functions can be performed as commanded.

The coder is simply a telephone dial. This unit transmits two pulses for the number 1 on the dial, three for the number 2, etc.; hence it must be modified in order to send out the proper sequence of 1, 2, 3, 4, etc.

The first step is to take the dial and change the single set of contacts on the back so that they close instead of open when the cam hits. Drill a large finger hole below the 1 hole, half-way between it and the stop. This corrects the sequence so that the pulses are transmitted in the proper order.

Now the decoder: You can construct a power-driven stepper, although one purchased would work just as well. Construction details are presented for those who are experimentally minded.

Procure a *small* 6-volt motor and mount it on a plate, as shown in Fig. 1015. Add small gears so that the output shaft will turn at about 30 r.p.m. and has

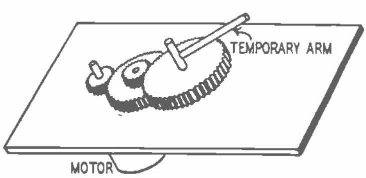



*Fig. 1015—Small motor mounted on plate.*

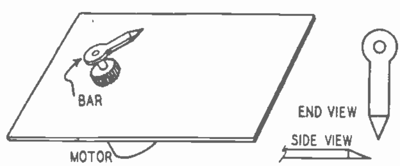



*Fig. 1016—Catch bar mounted on gear shaft.*

enough torque to move a pointer over a set of contacts. Attach an arm 2 inches long to this shaft by soldering a small piece of wire to it. This is sufficient for marking purposes. Now turn the drive motor one revolution and measure the distance the arm moves at its tip. It should move at least ⅜ inch. Lengthen or shorten the arm to achieve this. Solder a small bar to the motor shaft above the gear, as shown in Fig. 1016. On a small bracket just over the motor place a Sigma 8,000-ohm relay with small stops soldered to the ends of the armature (Fig. 1017). The relay is adjusted in height above the bar on the motor shaft so that the bar catches on the low side and holds; but when the low side of the armature is pulled up (by energizing the relay), the bar can then pass beneath it and catch on the other end of the armature.

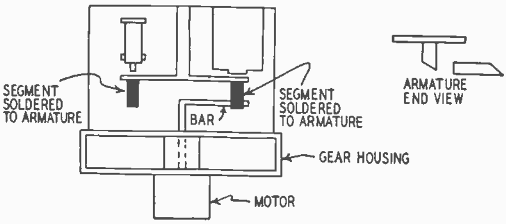



*Fig.* 1017—*Relay and gear box assembly.*

To test, energize the motor in the forward direction and connect the dial through a battery to the relay. As the dial is operated, the arm on the gear shaft steps around a distance corresponding to the number dialed, moving around ⅜ inch for each pulse. Now disconnect the battery and dial from the relay and reverse the power to the motor so that it turns in the opposite direction. It should spin around, forcing the relay armature up as it hits the slanted portion of each little contact soldered thereto. It should rotate in the reverse direction as long as power is applied. Make the spring tension on the relay as strong as possible and still have the relay operate with every pulse when energized with a battery.

Now mount a piece of Bakelite on the gear housing so that a series of contacts may be arranged with which an arm, driven by the last gear shaft, can make contact. A hole is drilled in the center of this insulated block and the last gear shaft is run through it. Mount the block in place with screws.

After the Bakelite has been mounted, the best way to arrive at the location of the contacts is to set the soldered arm at some starting position by rotating it backward and then pulling it forward until the bar on the motor shaft rests against the de-energized armature stop. Mark this point with a scribe or pencil. Hook up the battery and dial to the relay and energize the motor so that it will rotate in a forward direction. Step the arm around one step at a time by continuously dialing number 1 and mark each point where the arm comes to rest.

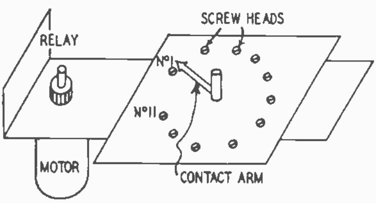



*Fig.* 1018—*Stepper plate and contact arm.*

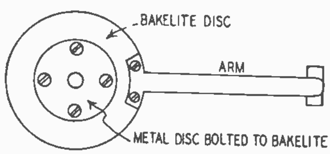



*Fig.* 1019—*Details for the construction of the stepper arm. The T strip is spring metal.*

Drill a small hole through each of these marks far enough in so that the arm passes over them. Insert 6/32 screws and bolt them tight with solder lugs on the underside. The Bakelite strip may have to be raised on spacers. Now step the arm around again. It should stop over each screw head. The plate should look like that in Fig. 1018.

The contact arm is made from three pieces of material, illustrated in Fig. 1019. One is a circular metal disc, the second a disc of Bakelite or other insulating material larger than the metal disc, and the third is a T-shaped strip of some springy material which is to be the arm itself. When these three are bolted together as shown in Fig. 1020, the arm is complete and the unit may be slipped over the shaft of the second gear and soldered in place. The screw heads should

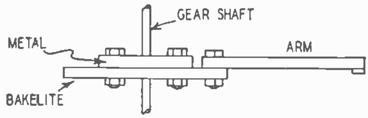



*Fig. 1020—Side view of contact arm.*

be filed down to about 1/16-inch clearance so that the arm does not have to ride up too high in rotation. When the relay is dialed, the arm should step to each contact and stop. The contact end of the arm must not short-circuit between two contacts as it moves.

It is now advisable to make two mechanical stops. These are simply bolts passed through holes on the last gear and so arranged that they make contact with another bolt attached to the frame, when the arm is at position 1 and also at position 11. Incidentally, only 10 contacts should be mounted, the number 1 space being left clear to provide a noncontact rest point for the arm.

The theory behind automatic reversing is that, if the motor is energized through a delay relay, this relay causes continuous rotation forward as long as pulses come without too great spacing and, when a long break between pulses exists, it drops out and energizes the reversing relay of the motor.

Five relays are necessary: two 6-volt types; one 8,000-ohm double-pole, double-throw; an isolation relay; and a motor physical stop relay. The two 6-volt relays and the 8,000-ohm double-pole, double-throw relay are mounted to the underside of the gear housing. The double-pole, double-throw relay must have one set of contacts so spaced that they will close before the other set. They are wired as shown in Fig. 1021.

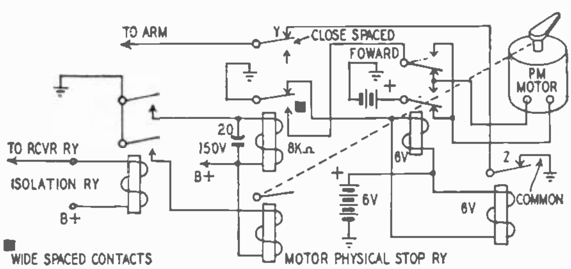



*Fig. 1021—Relay system for numerical-sequence decoder.*

When the pulses are transmitted, they cause both the motor physical stop relay and the 8,000-ohm double-pole, double-throw relay to become energized.

As this latter activates, it closes the circuit to the motor. The motor rotates in the forward direction. The d.p.d.t. relay opens the common line through its second set of contacts. The arm then steps around to the desired position over "cold" contacts.

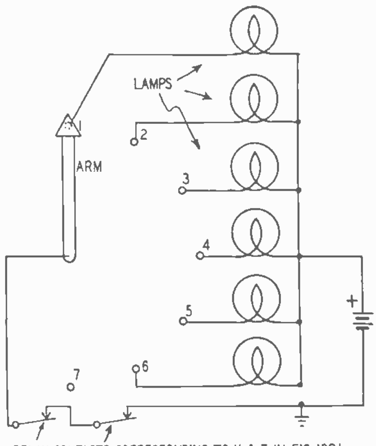



*Fig. 1022—Test unit for numerical-sequence coder.*

At the end of the pulse train, the double-pole, double-throw relay de-energizes, the upper armature of the 8,000-ohm relay touches point Y, and, since the common-line contacts are the closest spaced, it causes current to flow through the common line and out through the contact upon which the arm rests. When the wider spaced ones close (opening of the lower armature), both the motor reversing relay and the second 6-volt relay become energized. The motor relay makes the arm rotate

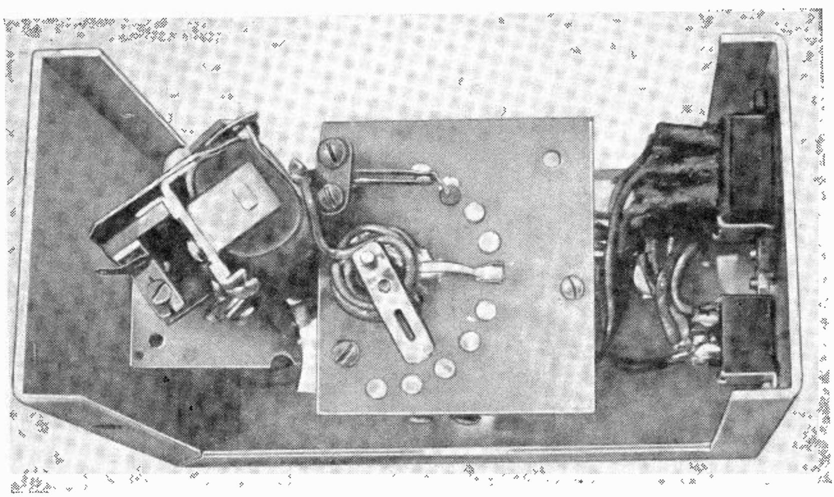


*Fig. 1023—Top view of numerical-sequence decoder, showing contact arm assembly.*

back to the start position, and the second 6-volt relay again breaks the common line so that the contacts remain "cold" as the arm passes backward over them.

If, at the starting point of the arm, an electrical limit switch is placed so that the arm opens its contacts when it is in the start position, and this set of contacts is in series with the reversing relay and the second 6-volt relay, the arm will open the switch and de-energize both the motor and the relays when it gets back to the neutral position.

As a final test of the unit, a series of flashlight bulbs may be connected to the contacts, as shown in Fig. 1022. Dialing the various numbers causes the arm to step around and flash the particular lights corresponding to the numbers dialed. No other light should flash when the arm moves either forward or backward. The two relay contacts shown in the illustration in series with the stepper correspond to those labeled Y and Z in Fig. 1021. They are shown here to illustrate how the arm is kept from making connection to the battery when it is in motion. Fig. 1023 is a top view of the numerical-sequence decoder, showing contact arm, relay, and motor "off" switch which is operated by the arm.

## Multiple Control Stepper

This stepper can be used by connecting electrical latch and release relays to the various contacts so that different functions are performed. In some cases,

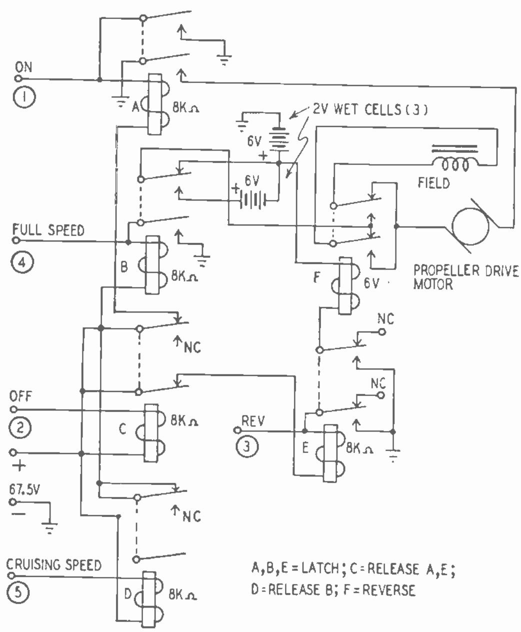



*Fig.* 1024—*Motor control circuit for model boat.*

two or more latch relays have a common release relay which makes possible more functions than would be obtainable by simply using every other contact for a release relay.

In the following schematics are illustrated those power control circuits used in remote control of a boat. These circuits connect to the stepper contacts in the order shown, and allow the following functions to be performed:

(1) Motor on cruising speed;
(2) Motor full speed;
(3) Motor reverse, full, or half speed;
(4) Motor stop;
(5) From full to half speed (cruising);
(6) Lifeboat down;
(7) Lifeboat up;
(8) Cabin and searchlight on;
(9) Cabin and searchlight off, running and below deck lights on;
(10) Anchor winch down;
(11) Anchor winch up.

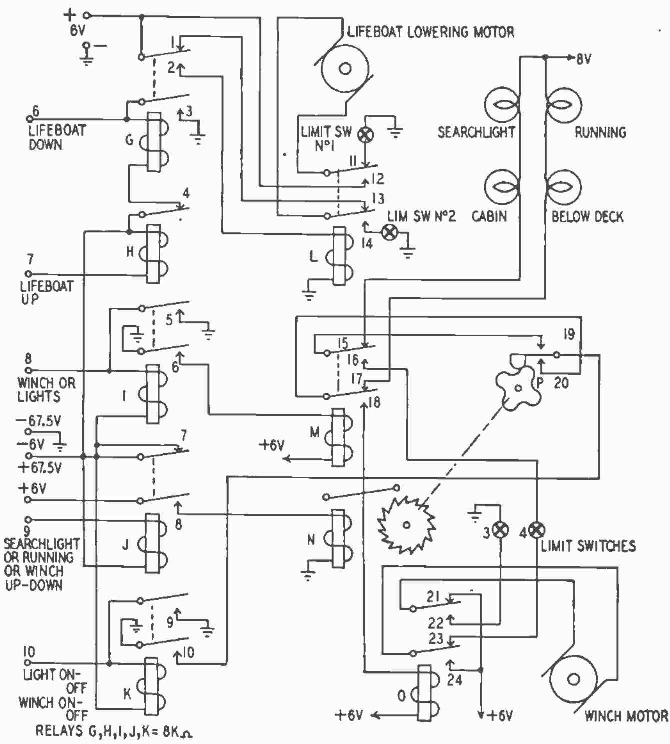



*Fig.* 1025—*Circuit for control of lights, winch, and lifeboat.*

The functions of steering, left, right, and neutral rudder are accomplished directly from the receiver. The first schematic (Fig. 1024), is that of the motor control circuits. It consists of latching, release, and reversing relays. With this circuit the propeller drive motor can be set at cruising speed, full speed, or reverse.

In the circuit (Fig. 1025), for control of lights, winch, and lifeboat there is some interaction which should be noted.

When relay G is energized, it latches and results in relay L becoming energized. This routes the power through contacts 2, 12, and 14, causing the lifeboat lowering motor to rotate until it opens limit switch 2. This places the lifeboat in the water and it rides free of the arm. When relay H is energized, it releases relay G, relay L opens and power is routed to the lifeboat-lowering motor through contacts 1, 13, and 11 so that a reverse polarity is applied to the brushes. The motor lifts the arm up until it reaches limit switch 1 and opens it. This disconnects power to the lifeboat motor.

The lower side of relay K connects to the top contact of relay J and through that contact to B plus. Relay J is a double-pole, double-throw relay so wired that it uses one normally open and one normally closed contact.

When relay K is energized, it will turn on either the searchlight (and cabin lights) or the running lights (and below deck lights), depending upon the position of the ratchet arm of relay N. The ratchet of relay N physically controls the positioning of the arm of switch P. Energizing relay J shifts the arm to the opposite set of lights and also releases relay K so that it has to be energized again to turn on the new set of lights.

To operate the winch, relay J must close to release K. When relay J is open again, relay I is energized and causes the contacts of the arm to be shifted to the winch motor control circuit, instead of the light banks. When relay I is energized, it puts relay M to work. With relay M on, searchlight, cabin, running, and below deck lights are turned off. Switch P is now used to operate the winch motor instead of the lights. Energizing relay K gives rotation of the winch motor unless the arm contact of switch P is on the wrong side. This would mean that the winch motor has opened its "in" limit switch and thus cannot be energized in this direction. To have the motor rotate in the opposite ("out") direction, relay J must be energized again. Relay N will also energize, and its armature will push the ratchet. The ratchet will move switch P to a new position. This places the arm of switch P on the correct contact, at the same time releasing relays I and K so that both of these now need to be re-energized. Relay J is open. Relay I is first energized, and then K. The winch motor runs out the anchor until again stopped by its "out" limit switch. To bring the anchor in again, dial the numbers 9, 8, 10 in that order, energizing relays J, I, and K, respectively. Dialing 9 once more cuts off the holding relays and places the circuit in the "ready for out" signal again.

## Resonant-Reed Decoder

Specifically designed for use in model aircraft, this decoder is based on the theory of the resonant-reed type of frequency-selective device. Fig. 1026 shows the arrangement whereby a pair of coils, connected to the receiver like a loudspeaker, cause the reeds to vibrate from the receiver's output. The three reeds shown are secured at one end to a "bridge." Although the reeds in the illustration are identical, notches in the bridge give the effect of different reed lengths. One, and only one certain tone will make the reeds vibrate sufficiently to touch the contactor located above it. Such vibration of a reed will rapidly open and close a circuit through the reed and contactor, and may be made to hold a sensitive relay closed as long as the vibration continues, since each sensitive relay is equipped with a small delay-in-opening capacitor.

As each individual tone is transmitted, the reed corresponding to that tone vibrates, making the sensitive delay relay close and hold closed as long as the tone is transmitted. Either servomotors (electric motors or relays) may be connected to, and activated by, the sensitive relay.

One way to adjust this unit after it has been constructed is to use an audio oscillator. The output of the oscillator can be coupled to the coil of the decoder

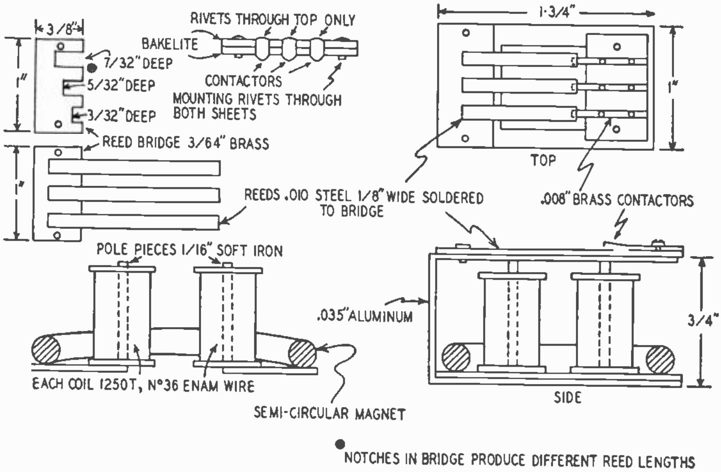


*Fig. 1026—Details for construction of resonant-reed decoder.*

and to flashlight cells in series with a battery connected through the contactor and reed terminals. The output of the audio oscillator can then be varied. As the resonant frequency of each reed is approached, it will vibrate with a large amplitude. When the vibrating reed strikes its particular contactor, the circuit will close and the light will go on. The frequencies of the different reeds can be determined in this manner. At the same time this also indicates the proper tones to transmit.

## Pulse-Rate Decoder

The decoder consists of a servomotor (or actuator) which rotates approximately 90 degrees each way from center when energized, the direction of rotation

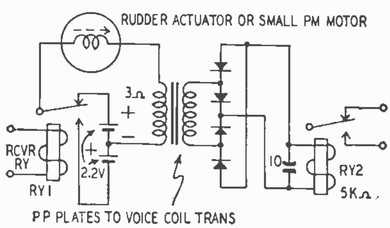


*Fig. 1027—Pulse-rate decoder.*

depending upon the polarity of the applied voltage. Think of it as identical to a small meter movement which, instead of having the coil mounted on the armature and moving in a permanent-magnet field, has the field contain the coil and the armature constructed from small permanent magnets.

The circuit is shown in Fig. 1027. When a slow pulse rate is applied, the rudder actuator will receive current, first in one direction, then the other. This is due to the connection of the two batteries. If the pulse time and spacing between pulses are equal, the servomotor does not move but vibrates slightly about the neutral position. If the signal is tuned off, the armature of RY1 falls on the back contact, causing the servomotor to move in one direction. If the signal is not pulsed, the relay armature closes and the servomotor moves in the opposite direction.

Notice the transformer connected in series with this line to the rudder actuator. Since a transformer must have pulses or a.c. applied to it to produce a voltage in its secondary, a constant signal or no signal will produce zero output. Examine the secondary. A copper-oxide rectifier is connected to this winding, and its output (which will always be d.c.) is connected to RY2 shunted by a 10-$\mu f$ capacitor. When slow pulses of equal duration spacing are transmitted, the output of the transformer is small. The capacitor becomes charged but discharges through the relay coil between pulses, and as a result does not have sufficient current to close the relay. Thus, by sending slow (two-per-second) pulses the rudder actuator remains at neutral, and the effect of the second relay RY2 is as though it were not in the circuit.

If, however, the pulse rate is increased to approximately six pulses per second, the capacitor does not have time to discharge between pulses and builds up a voltage. As soon as this voltage reaches a high enough value, it can drive a current of sufficient strength through the relay to close it and hold it closed as long as the fast pulse rate continues. Since this fast pulse rate can still be of equal pulses and spacings, the rudder actuator remains at neutral. By increasing and decreasing the pulse rate, RY2 can be closed and opened. It can operate a motor or stepper, if desired.

The pulser can be a simple motor-driven arm, riding over a set of contacts so arranged that their spacing and length is the same and having a switch to short all contacts together or to open the circuit to the transmitter for left and right operation. A rheostat in the motor circuit will give the increased pulse rate.

## Stepper-Decoder

The decoder in Fig. 1028 illustrates a method of using the escapement relay for a stepper-decoder. By using a four-arm catch bar (two cross-arms) instead

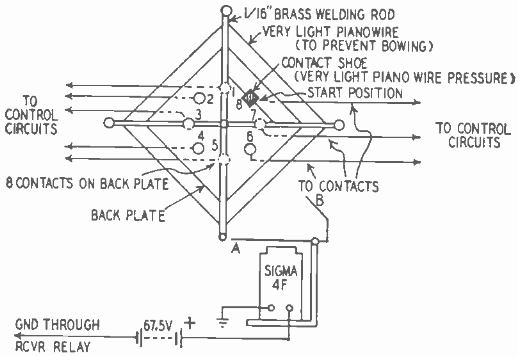



*Fig. 1028—The illustration at the right shows how to construct a stepper-decoder using an escapement. The stepper moves 45 degrees every time the relay is energized or released. In this way 8 stop points are obtained. The catch bar must be built as shown in order to catch on the extended cross-arms of the stepper. The contact shoe can be a small piece of spring metal.*

of a two, as previously illustrated, eight stop points are obtained. If a contact shoe is placed on the rotating bar section, it will make contact with each of eight "fixed" points as it is stepped around through one cycle. When the Sigma 4F relay is not energized, one arm of the bar will catch on the escapement at point A. When the relay releases, the arm will move 45 degrees and catch on point B. The contact shoe will move from position 8, as shown, to position 1. This stepper-decoder could be mounted on a shaft turned by a twisted rubber band.

If the rotating contact point rapidly steps over the fixed contacts, the control circuits connected to these points will receive energization. However, the resulting current would be only momentary and not long enough to produce any effect. The contact it finally does come to rest upon will result in physical motion. While this might seem a disadvantage, a moment's thought will reveal that in steering (a model car, for example) the wheels are first turned in the proper direction. The drive motor then energizes so that the car will go in that direction until it reaches the desired distance. The wheels are then made to change, with the drive motor off, and again the car goes either forward or in reverse.

## Coder for Model Car

Perhaps the most significant part of this unit is the coder, illustrated in Fig. 1029, which allows the selection of the desired function by merely depressing a key. When this is done, the proper pulse sequence is automatically transmitted, making the decoder step around to the correct contact pin. Since the coder is motor-powered, this operation is performed at fast speed and is almost the equivalent of direct tone control of each function.

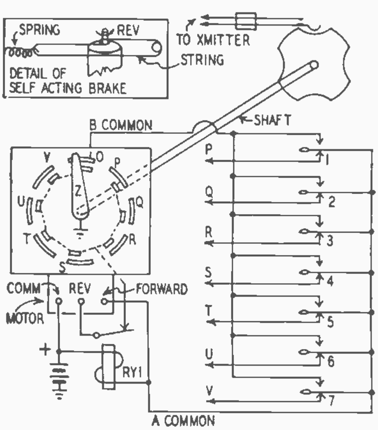



*Fig. 1029—Coder for model car.*

The normal or resting position of the coder arm Z is at point O. The neutral position of the single-pole, double-throw switches is located so that the A common line is connected to each of the contacts 1, 2, 3, 4, 5, 6, and 7. Now consider what happens when contact 3 is broken, for example.

When 3 is pushed over against the B common line, the motor is energized in a forward direction through the resting contact at O. Since the bar segments P and Q are connected to the A common line, the arm, in passing over them, still makes contact with the battery, giving forward rotation. The arm now rides up on the segment R which corresponds to the third switch position and which is the desired stop point. If key 3 is held against the B common line, circuit tracing will indicate that contact R is not connected to any point except ground. The motor-battery circuit is broken, the motor no longer being driven forward. While the motor rotates forward, RY1 energizes and holds open the battery connection to the small motor-reversing contacts. As soon as forward rotation of the motor stops, due to opening of the forward battery circuit, this relay de-energizes and causes the small segments to become "hot" so that, when the circuit is completed by having the arm Z come in contact with them, the motor reverses.

These segments are small; and as the arm hits, it reverses and backs off far enough to break the contact, although, due to the self-acting string brake, cannot get back to the small segment located near the forward bar Q. Thus, the arm rapidly travels around to R, reverses, and stops, still in contact with R whose circuit is broken by switch 3.

If contact 3 is closed by allowing the switch to return to its normal position, the circuit is again completed through the segment R. The motor will run in a forward direction, and the relay, becoming energized, breaks all the reversing connections. When the arm finally comes around to position O (this contact is connected to the B common), there is no connection to B common by any switch. The forward movement circuit of the motor is broken, the relay de-energizes, the reverse segments are made hot, and the arm stops as before on segment O. It is then ready again for another movement from this position when another key is depressed.

Rotating arm Z is mechanically geared to the motor. The shaft which is attached to the rotating arm is also attached to the pulsing disc. Thus, as the arm rotates, the disc rotates the same amount, sending out just the right number of pulses to make the stepper move (in the case just illustrated) to contact 3. When contact 3 of the coder is returned to normal, the right sequence is transmitted to make the stepper contact return to its start position.

The self-acting brake consists of a string wound around the shaft so that the shaft in rotation in one direction causes the string to tighten. This increased friction acts like a brake. When the shaft rotates in the opposite direction, it unwinds the string and thus moves easily. The spring adjusts the tension to get the desired amount of braking action.

## Pulse-Presence Pulse-Omission Coder and Decoder

This coder and decoder is the motor-driven commutator type. Its operation is based on the pulse-presence pulse-omission type of coding, which in this case is inverted; that is, the pulse is actually the absence of signal instead of the presence of signal. This means that if four pulses were transmitted in a given time interval, the carrier or tone would be broken four times during that time interval and remain off each time for a period corresponding to the desired pulse width. The reason for this arrangement is that it requires less movement of the decoder relay, increasing the speed of operation.

This unit has two distinct characteristics. First, its speed of operation is such that it almost corresponds to direct, instantaneous control of the desired funcions; and second, the coder is so constructed that depressing of a lever automatically causes the desired sequence or code to be transmitted. In this case four "operating" switches or levers are employed. Each one, when depressed by itself, constitutes a command. Any two depressed together constitute further commands. Any three may be depressed, or all four—thus it is possible to control as high as 16 functions with the four keys.

The coder is made up of a small PM motor which is geared to a shaft so that it turns between one and four revolutions per second. The greater the speed, the more difficult the synchronization. The motor and gear train are mounted to the contact block as illustrated in Fig. 1030. The contact face may be a small square of Bakelite mounted on spacers above the metal top plate of the gear housing.

A circle ½ inch in radius is drawn with the shaft hole as the center. The arm is constructed from a small piece of spring metal and a small piece of Bakelite. These are bolted together and the metal circle is lightly soldered to the shaft holding the arm in place.

The next step is to mount the normally closed limit switches S1 and S2 along one side and so placed that the Bakelite portion of the arm will open them as it goes by but that the contact part of the arm does not touch them in passing. This can be tested by rotating the arm manually.

The starting position of the arm, the position to which it will always return, is labeled X in the drawing, and this should be located next. Its position is governed by the placement of S1 and should be such that when the contact point of the arm is at X, the forward tip of the Bakelite strip just opens limit switch S1.

Now the first contact segment R1 can be placed. It should begin not more than ⅛ inch from the tip of the contact point when the latter is at X. R1 is roughly ½ inch long and can be made by drilling two small holes through the face plate and running a wire through them, pulling it tight and twisting the ends together on the underside.

The position of contact R2 is such that the insulated part of the arm just opens switch S2 when the contact tip of the arm is at position Y, approximately ⅛ inch from the beginning of contact R2. The other end of R2 is then ¼ to ½ inch away from this point. The distance between R1 and R2 should now be such that the contact tip when at position X does not make connection with either. At the same time there should be a gap of at least ⅛ inch on each side of the tip. Relocation of switches S1 and S2 might be required to make this possible.

The balance of the contact segments can now be located evenly spaced around the periphery of the circle as shown. Contact 4 should not come close enough to position Y to connect with the arm tip when the arm tip is at this position. A ¼ inch should be allowed here. Lines may now be run from segments 1, 2, 3, and 4 to the lever-type switches L1, L2, L3, and L4. The other sides of these lever switches should be connected together as shown.

In operation, switch Lx must function whenever any of the other lever switches is operated. This will require mounting Lx in line and so connecting it mechanically that it operates with the others. Another method is the use of a double-pole, double-throw switch for each one of the operating switches L1, L2, L3, and L4—all of one set of contacts connected in parallel to form Lx and the other sets of contacts wired as shown for the operating section.

The motor leads are connected to the contacts of a reversing relay. One set of these contacts is directly connected to one side of the battery. The second set is connected through a 5-ohm rheostat to the common line which runs up to limit switch S1, through S1 to switch S2, through S2 to the opposite side of the battery. This means that, for the motor to run, both S1 and S2 must be closed. Notice also that the switch Lx is so wired that it closes or shorts out S2 when in the up position, and shorts out S1 when in the down position. Since the arm itself has opened S1, as shown, the battery circuit to the motor is broken and the motor does not rotate the arm.

When Lx is pushed to the down position, it shorts switch S1. The battery line to the motor is closed and the arm whips around until the Bakelite portion opens S2. Although the power to the motor is cut off, the speed of the arm carries it past position Y, and the metal part of the arm rides up on contact R2. In tracing the circuit from the reversing relay back to contact R2, through the motor shaft to the arm of RY1 we notice that the upper contact of RY1 is connected to the plus side of the battery, and the bottom contact to the minus side of the battery. The coil of this relay is connected directly to the plus side of the battery while the other end of the coil contacts the minus side by means of the line running through S1 and S2.

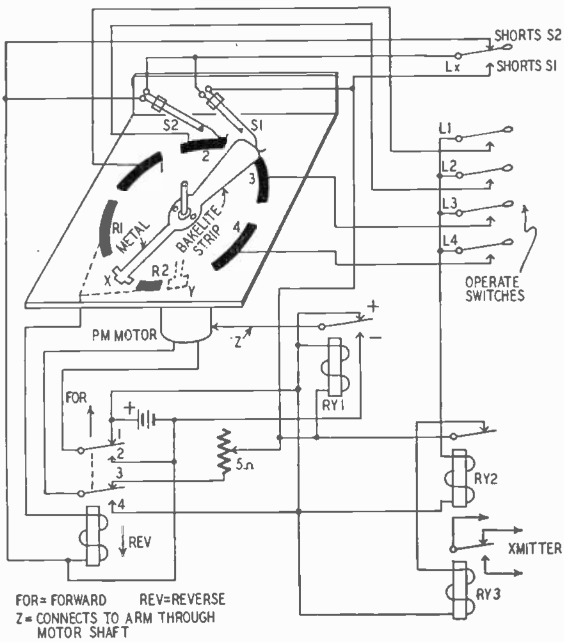



*Fig. 1030—Pulse-presence pulse-omission coder.*

When the Bakelite portion of the arm opens S2 (and holds it open as the contact tip rides up on segment R2) since S2 is not shorted by Lx, the line to RY1 and the minus side of the battery is opened; RY1 is de-energized and makes connection from the plus side of the battery to the metal arm tip. The tip connects the plus side of the battery to one side of the reversing relay. Since the other side is always connected to minus, the reversing relay energizes. This connects the motor to the battery through contacts 2 and 4, and the arm backs off segment R2. If it backs off too far, it allows S2 to close. The motor will then run forward, and thus the arm has to stop at position Y. It will remain there as long as Lx is depressed.

When Lx is moved up, its contacts short out limit switch S2. Power is applied to the motor through contacts 1 and 3 of the reversing relay and at the same instant causes RY1 to become energized. The arm rides up on segment R2; but now, the arm, instead of connecting the coil of the reversing relay to the plus side of the battery, connects it to the minus side. Because the opposite side of this coil is also connected to the minus side of the battery, the reverse relay does not operate and the arm moves over it to position X or up on contact R1.

Since the Bakelite portion of the arm has opened S1 as the metal tip rides up on segment R1, RY1 de-energizes again and the same positioning action takes place as before for position Y. Thus it can be seen that whenever the switch Lx is depressed, the arm spins around to position Y and stops; when Lx is pushed up, the arm again returns to its start position X.

Now let's examine the purpose of the other lever switches, and also RY2, and RY3. RY3 is connected directly to the plus side of the battery and to its minus side through the normally closed contact of RY2 and limit switches S1 and S2. Thus RY3 is open or de-energized whenever S1 or S2 or the normally closed contacts of RY2 are opened. When RY3 is de-energized, no signal is sent from the transmitter. Now consider the coil connections of RY2. One side is connected to battery plus, and the other side of the coil ties to the bars of the "operate" switches. The bottom contacts of the operate switches are connected respectively to segments 1, 2, 3, and 4.

Consider what happens when L1 is depressed, remembering that Lx also makes connection with its bottom contact at the same instant. The arm starts to rotate, and at the same instant, RY3 is energized, and the transmitter sends out a signal. As the metal arm passes over segment 1 (since RY1 is energized) the circuit to the battery is complete for RY2. One side of RY2 is directly connected to the battery, the other side being connected through lever switch L1, the segment, the metal arm, and the bottom contact of RY1. The circuit to RY3 is broken for the length of time that the arm is on segment 1. The transmitter signal is off for this period. It comes on again as the arm passes over 2, 3, and 4, and goes off when S2 is opened and remains off as long as the arm stays in this position. When L1 and Lx are released, RY3 is again energized until the arm reaches position X when it causes S1 to open.

If the spacing of the segments 1, 2, 3, and 4 is correct, depressing all of the operate switches simultaneously will make RY2 operate as each segment is passed over and open when the spaces between the segments are passed over. The spaces should be wide enough so that this does happen, but no wider than necessary.

Now let's see how the decoder uses this information of signal-no-signal so that various functions such as steering, etc., are performed. Examine Fig. 1031. The physical arrangement of the decoder is identical to that of the coder. In practical construction get two identical motors to rotate the arms, and use exactly the same gear train and the same amount of battery voltage to each motor. This is necessary because both arms must rotate in nearly exact synchronism.

There is one primary difference in the placing of the function segments on the decoder. Segments 1, 2, 3, and 4, should in this case be of narrow width, whereas on the coder they are as wide as possible. The reason for this is if the arms should differ slightly in position, the desired pulse signal will be transmitted as the decoder arm goes over the proper segment. The location of switches S1 and S2 and segments R1 and R2 should be identical to those on the coder. The rotating arms of the coder and decoder should be of exactly the same dimensions and, as far as possible, the same weight.

Notice too, that on the decoder there is a contact segment located at position Y. This is the "operate" segment. Routing of power through points A and B is accomplished when the metal arm rides up on segment Y, grounding the segment. When a lever key is depressed on the coder, its arm starts to rotate, as previously described. At the same instant, the decoder arm starts rotation. If the two arms are synchronized, both will pass over their respective segments at the same instant. If the coder causes a signal to be sent out, a circuit is completed through one of the decoder contact segments, which in turn would energize a latching relay, such as RY3, for example. When the coder and decoder arms arrive at position Y, the transmitter signal is such that the decoder again receives a signal which results in the connection of point B to segment Y through the contact and armature of RY2. This causes power to be supplied to the terminals at A and B, and thus, the circuit which has been set up becomes energized.

When the coder lever is released, both arms return to start position X. The decoder automatically breaks the circuit to the latching relays (in this case, RY3)

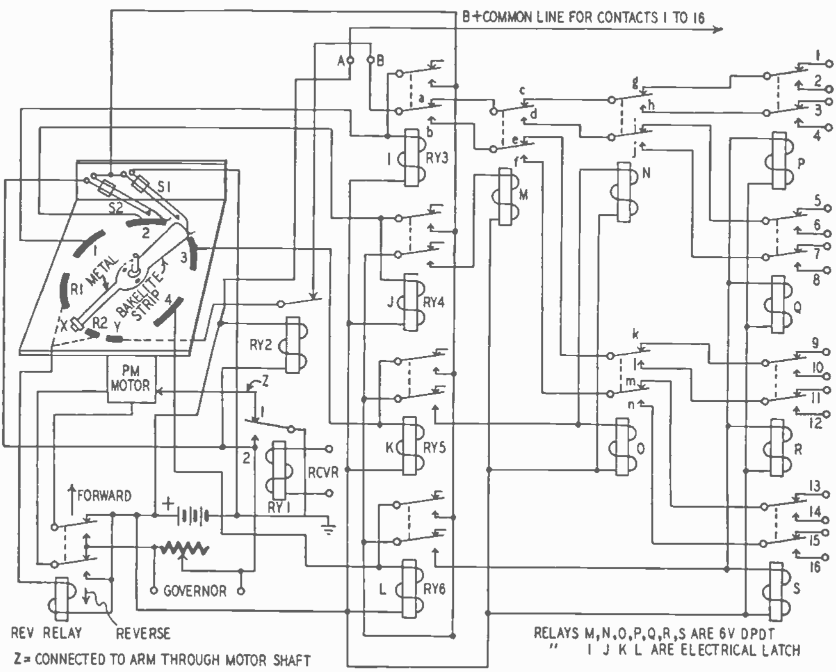



*Fig. 1031—The decoder routs power through points A and B. Speed of rotation of the decoder arm can be controlled by a governor.*

and makes the "setting up" circuit return to a neutral condition, ready for another combination.

It can be seen that the two arms are synchronized during every revolution, both starting from the same point each time. The two rheostats shown on both circuits are for the purpose of establishing synchronization in case there is a slight difference in speeds.

Now let's examine the decoder receiver relay, RY1. As soon as the coder starts to move, the transmitter sends out a signal making the armature of the receiver relay close to contact 2. This shorts out limit switch S2 and connects the motor to battery minus through the governor rheostat. Since the plus side of the battery is already connected to the motor, the arm moves forward. At the same instant, RY2 is energized, opening the "operate" circuit.

Notice that the latching relays, RY3, RY4, RY5, and RY6, are connected directly to the plus side of the battery and that the opposite ends of their coils are connected to segments 1, 2, 3, and 4. If the receiver relay falls on the back or normally open contact due to a break in the transmitter signal (as the arm passes over segment 1, for example), the segment becomes connected to the minus side of the battery through the metal arm. This completes the circuit from the latching relay to the battery, and consequently the latching relay becomes energized.

As soon as the latching relay closes, it completes the circuit to the minus side of the battery through the bottom contact of its upper armature and through limit switch S1. Thus, it holds closed as the arm moves on.

If no other pulses are sent, that is, if the transmitter signal is not broken again, the metal arm spins around to position Y where it stops. When the coder arm is in this position, the transmitter signal is always broken and so the circuit is again complete in the decoder from the arm to the minus side of the battery.

As the coder arm is returned to position X by releasing the operating lever, the decoder arm returns to position X by the same operation. This opens S1, stopping the motor and simultaneously breaking the circuit to the latching relays. Point A is connected to B plus. Point A is also a common B plus bus for contacts 1 to 16 of relays P, Q, R, and S. To operate some external circuit, points 1 to 16 of these relays must be connected to B minus. If, for example, we wanted to use contact 9 of relay R, power could be routed as follows: The receiving relay would close, supplying power to the PM motor. The moving metal arm would touch segment 1, grounding it. This would cause RY3 to energize and latch. When the arm reaches point Y, this segment is then connected to B minus through the metal arm. B minus is thus connected to point B through the armature of RY2. B minus is routed through b of relay 3, through e of relay M, through k of relay O, over to point 9 of relay R. Some external circuit, connected to B plus through the common B plus bus, is now also connected to B minus. The external circuit or device becomes energized.

The action of switches S1 and S2 and contact segments R1 and R2 is the same for motor operation and arm positioning as described for the coder. The chart, Table 10-1 details how power input to A and B is routed for various com-

TABLE 10-1—Relay and latch combinations for use with Fig. 1031.

*Power input to A and B routed as follows for various combinations*

| | | | | | |
|---|---|---|---|---|---|
| Relay I alone | = b, e, k, | 9 | Relays J, K | = a, d, j, | 7 |
| " J alone | = a, d, i, | 5 | " J, L | = a, d, i, | 6 |
| " K alone | = a, c, h, | 3 | " K, L | = a, c, h, | 4 |
| " L alone | = a, c, g, | 2 | " I, J, K | = b, f, n, | 15 |
| Relays I, J | = b, f, m, | 13 | " J, K, L | = a, d, j, | 8 |
| " I, K | = b, e, l, | 11 | " I, K, L | = b, e, l, | 12 |
| " I, L | = b, e, k, | 10 | " I, J, K, L | = b, f, n, | 16 |
| | | | None closed | = a, c, g, | 1 |

NOTE: The Combination is set up as the arm rotates and then energizes when the arm stops on operate segment Y.

binations. In tracing the circuits using this chart, note that the latching relays control the 6 volt d.p.d.t. relays. For example, closing of latching relay, RY4, also results in the closing of relay M.

This unit allows almost instantaneous operation of the controlled functions, depending upon the speed of the arm's rotation. One model, such as described, was used to steer and control a model boat, and another with a greater number of contact segments was built for use in a model plane. The number of controlled operations being $2^{\text{(number of contact segments)}}$ for the plane it was possible to have $2^{12}$ controlled operations.

In order to assist in synchronization, a governor may be added to the decoder unit. It isn't necessary at the transmitter point because the operator can adjust the rheostat if needed. One governor which has been used successfully is shown in Fig. 1032. A small hollow sleeve soldered to the motor shaft above the arm

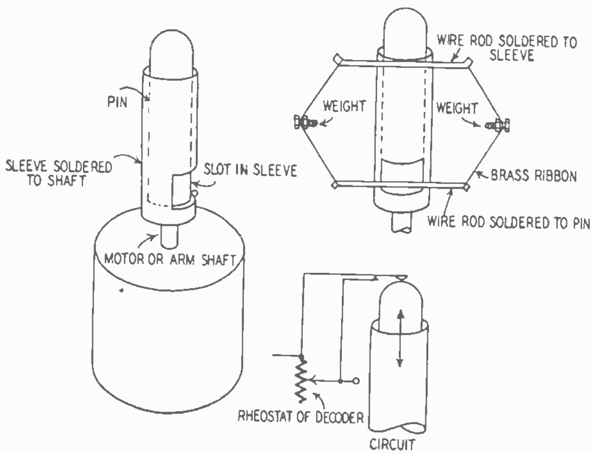



*Fig. 1032—This governor is connected to the rheostat of the decoder shown in Fig. 1031.*

has a cut in it near the base, as shown. A small pin is inserted and to the end (visible through the slot) a small stiff wire (welding rod) is soldered. Fasten a second piece of this rod to the top of the hollow sleeve. Between the two, when the pin is in the extreme down position, connect two small thin ribbons of brass bent in a semicircle, and in the center of each drill a hole to allow placement of a small weight (a nut and bolt). Just over the governor on the decoder frame, mount a small switch in such a manner that, as the pin moves up in the sleeve, it causes the contacts to open.

If the speed of the motor is too great, centrifugal force makes the weights fly out, pulls up the pin, opens the switch, and slows down the motor.

# Chapter 11

## Complete Control Systems

In all the preceding chapters, the various sections that comprise control systems have been considered. From the material presented, a complete control system could be built, the simplicity or complexity depending entirely upon the wishes of the builder.

Two complete systems are presented in this chapter. One is simple, the other rather complicated. Build them as they are, or modify them as you wish. Although both systems show radio control of a toy motor vehicle, the same ideas and principles can be applied to almost any other object...plane, boat, etc.

The procedure for setting up a radio control system consists of the following steps:

(1) List the functions to be performed;

(2) Decide on a code to represent each function;

(3) Choose a decoder that will have the ability to recognize the code and control the flow of power;

(4) Decide whether a lever is to be pushed, a switch closed, or a dial turned to cause the code to be transmitted;

(5) Make a choice of transmitter and receiver.

### Radio Control System for Toy Truck

To keep the system as simple as possible, the number of functions were held down to two.

(1) Steering (most important)

(2) Method of stopping drive motor (desirable)

The simplest code that can be used is carrier on-carrier off. We can use the carrier to give us movement of our steering wheel. The simplest type of decoder that has the ability to recognize whether the carrier is on or off, and still has the ability to control the flow of power in both cases, is a simple single-pole, double-throw relay operated by the carrier signal. Since the unit is to be small and we want short-range operation, a single modulated oscillator and a super-regenerative receiver can be selected for the communications link. Considering the receiver, it is easier to have a relay operate with a tone, than with an unmodulated r.f. signal. Tone and carrier could be simultaneously cut off to save batteries.

## Steering Mechanism

Steering of the toy truck involves at least three movements of the front wheels — left, neutral, and right. The steering device can be a small motor, geared down to about 30 r.p.m. The rotary motion of the motor is converted to mechanical motion by means of a linkage. To stop the wheels in any desired position, all that is necessary is to have the motor stop turning.

The steering section for this model is constructed by referring to Fig. 1101. Bend a tin or aluminum plate into a square trough, ¾″ wide, and then trim as shown. Its length will be governed by the size of the motor in which it is to be mounted. It is fitted into place inside the hood, and then the location of the shaft holes marked as determined by the position of the front wheels.

The length of the shaft itself is determined by the size of the motor hood. The shaft will act as a pivot for the axle. Once the length of the shaft has been decided upon, an "L" is bent into one end, the other end inserted through the bearing holes, and a washer is soldered on each side to prevent the shaft from pushing up or dropping out. Note that the shaft is centered on the axle.

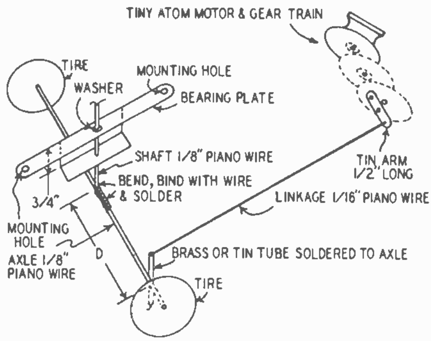



*Fig. 1101—Steering mechanism for the toy truck.*

The axle is made from ⅛″ piano wire. The wheels may be obtained from any model car or airplane shop. They are rubber tired and have the required size of hole in the center. The axle, cut to the proper length, is then bound to the "L" of the shaft with soft wire, and the joint is soldered. A small brass or tin tube is soldered in place to the axle shaft at a distance "D" from the center. This distance is determined by the amount of wheel displacement desired. The purpose of the tube is to allow the linkage to pivot easily.

The linkage itself is nothing more than a 1/16″ piece of piano wire, or other stiff wire bent into the desired shape. Its length will be fixed by the distance of the motor and gear train from the axle.

The tiny Atom motor and gear train are then mounted in place and a tin arm is soldered to the shaft of the last gear of the motor. The linkage passes through a hole in the gear tip. Washers should be used to keep the linkage from falling out of place, but these should not be so tight as to cause the shaft to bind.

If the motor is energized, the front axle will move back and forth as the arm goes around. If the gearing is such that the arm moves at a slow speed, it will be possible to stop the wheels in any desired position by stopping the motor. The arrangement for connecting the mechanical linkage to the gear of the steering motor is shown pictorially in Fig. 1102.

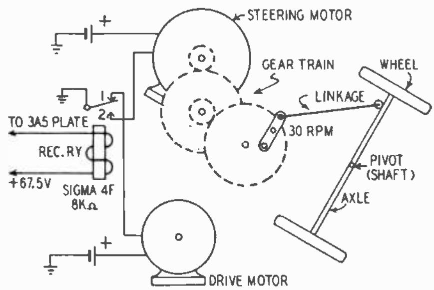



*Fig. 1102—Details of the axle to gear linkage.*

## Drive Motor Section

Our decoder is a single-pole, double-throw relay. One contact is used for controlling the operation of the steering motor. We can use the other one to control the drive motor. Thus, when the transmitter switch is off, the drive motor will run. When the relay is energized, the drive motor will stop, and the steering motor will run. How would this affect the operation? We can consider this as a good feature since it prevents movement of the truck until the steering wheels are in exactly the correct position. It is also possible to stop the truck by merely closing the switch, thus energizing the relay. The steering wheels would move back and forth continuously, but the truck would not move.

## Receiver

Since it would be much better to have our decoder relay operate with an audio signal (any tone) than with unmodulated r.f., we can use a simple detector, an audio amplifier, and a relay stage. The receiver is shown in Fig. 1103. There is no tuning capacitor across coil L1 since the coil is physically adjusted until it resonates in the center of the six meter band. The audio output from the superregenerative stage is taken from across the grid resistance, since in a superregenerative stage the bias follows the modulation of the r.f. signal. Quenching is obtained by capacitor C2 across R1.

The two audio stages, the second half of the first 3A5 and the first half of the second 3A5 are conventional, except for the plate to ground bypass on the first audio. This is to bypass the quench voltage from the superregenerative stage.

The capacitor, C8, from plate to grid of the relay stage, is for the purpose of bypassing, or degenerating any quench voltage that gets through. The grid resistor of the relay stage is returned to B plus to make the tube draw the required current. When the audio signal is applied to this stage, rectification between the grid and filament develops a bias voltage across the grid resistor

This voltage cuts off the plate current, and the plate circuit relay opens. The receiver, mounted in the toy truck, is shown in Fig. 1104.

## Transmitter

The transmitter in this case merely fulfills the requirements set forth by the receiver and decoder. It must transmit some audio tone, and have a point for

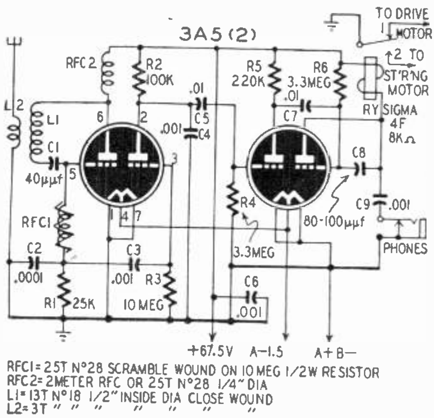



*Fig. 1103—Superregenerative receiver using a pair of 3A5's. If set does not superregenerate, increase C2 and substitute 2.5 mh choke for RFC1. For model plane use, increase R2 and R5 to 470,000 ohms for greater stability.*

connection to the coder. The transmitter is shown in Fig. 1105. The transmitter consists of a 3Q4 hooked up as a triode in an ultra-audion oscillator. A second

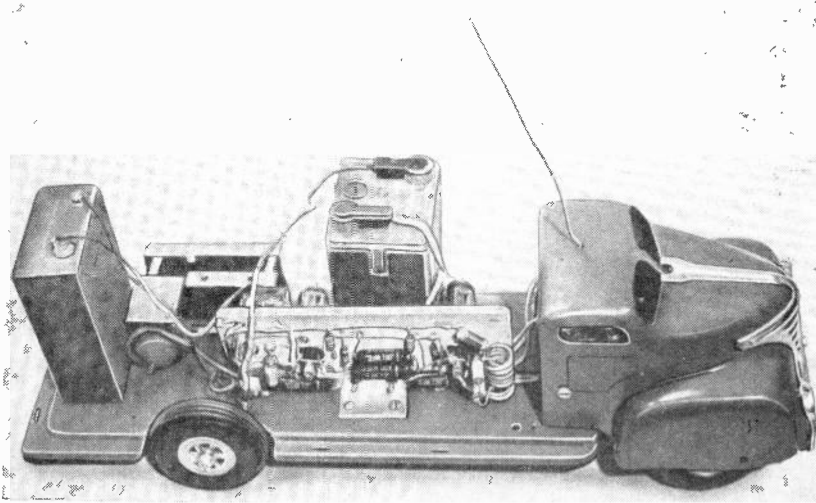


*Fig. 1104—The receiver, batteries, and motor are mounted on the truck frame.*

3Q4 is hooked up as a Hartley audio oscillator. The transformer, T1, serves as both the audio oscillator coil and the modulation transformer. The switch (or coder) is connected in the B plus lead.

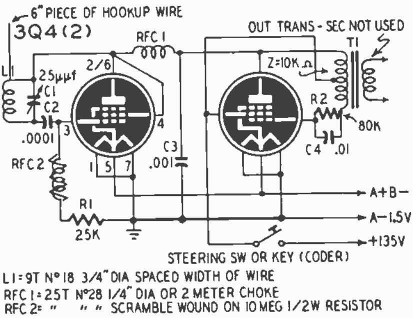



*Fig.* 1105—*The transmitter is modulated by a single tone.*

## Adjustments

Adjustment of the receiver is simple. The earphones are plugged in, and the familiar quench hiss is heard. If no hiss is heard, try another 3A5 — some oscillate more easily than others. With a wavemeter closely coupled to L1, a cessation of hiss, or a pop, will be noted when the wavemeter tunes to the receiver frequency. Reading the calibrated dial of the wavemeter will indicate the frequency. If the frequency is too high, squeeze the turns of coil L1 closer together. If the frequency is too low, spread the turns apart.

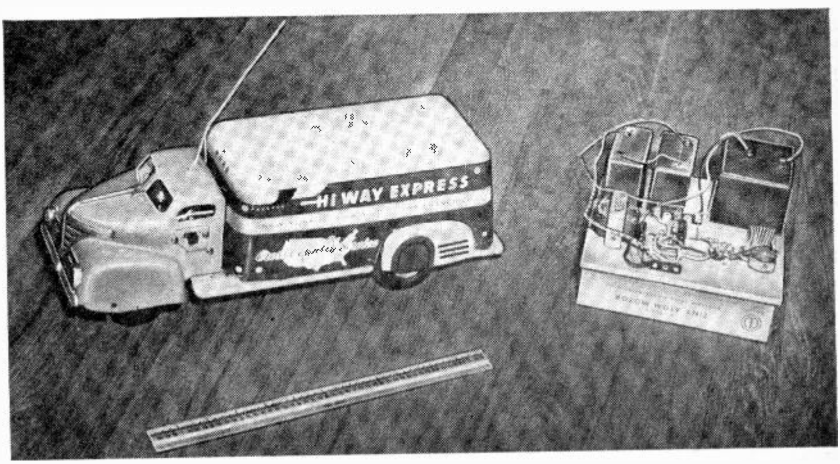



*Fig.* 1106—*The transmitter is shown at the right. The receiver is concealed in the truck at the left.*

The relay in the plate circuit of the relay stage is set so it just closes when the receiver is turned on. It should be possible to push the armature away from the pole piece and when released, it will be pulled back. The armature should be spaced about 1/32" from the pole in the energized position and *should not* touch the pole.

To determine whether the r.f. section of the transmitter is oscillating, connect a voltmeter having a sensitivity of at least 5,000 ohms per volt across grid resistor R1. If a d.c. voltage is present, the stage is oscillating. Since the receiver has been set to the correct frequency with the wavemeter, it is only necessary to tune the transmitter to the receiver. Pressing down on the transmitter key should operate the receiver relay. The complete transmitter is pictured in Fig. 1106. Note the comparative size of the transmitter and the truck. The wire protruding from the roof of the truck is the receiving antenna.

While the transmitter is capable of operating the receiver for a distance of 25 feet without an antenna, a small piece of wire approximately 6 feet in length, attached to C1, will give operation up to a hundred feet. If a regular doublet, or similar transmitter antenna is used, the operating range is greatly increased.

## Radio-Controlled Bus

This description of a radio-controlled bus was taken from an article written by M. Gordon Moses for Radio-Electronics Magazine.

This control system was developed for use in a model bus, but can be applied to almost any project where there is sufficient space and where weight is not an important factor. The control system, installed in a model bus 22 inches long and 9 inches high, enables it to perform many of the operations of a full-

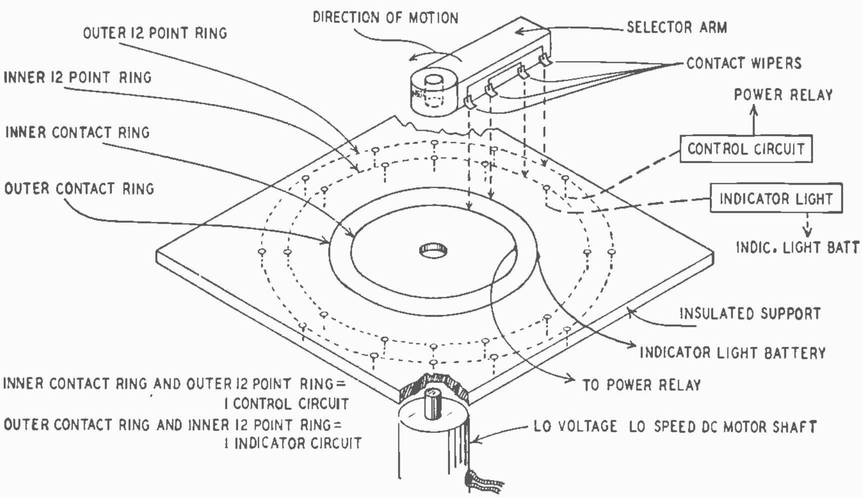



*Fig. 1107—Construction details for motor-driven, two-circuit, 12-point selector switch.*

size bus. The operator can start, stop, reverse, turn the vehicle right or left, open and close the doors, operate the windshield wiper and stop signals, and turn lights on and off—all by radio.

The vehicle was assembled from a kit, such as is available at most hobby shops, for a *working-model* bus. Seats and other interior fittings were left out to provide space for the control mechanism.

## The Control Circuit

The control system consists of a transmitter and receiver. The transmitter and receiver may be selected from among those described in this book. The receiver can be a one-tube superregenerator using a gas tube and a sensitive relay in the plate circuit. The transmitter can be equally simple; a one or two-tube transmitter is adequate. The operating wavelength is in the six-meter band.

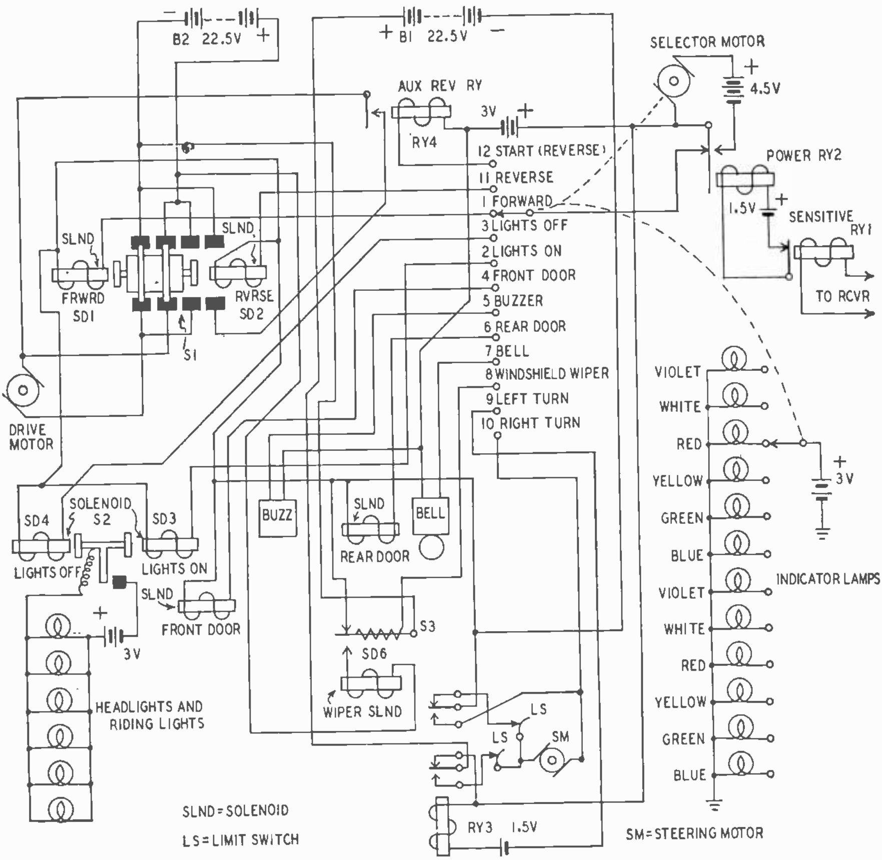



*Fig.* 1108—*Master control diagram. Solenoids and relays in this circuit are controlled by the receiver output.*

The heart of the control system is a special, motor-driven, two-circuit, 12-point selector switch. Its contacts are arranged in concentric circles. The movable arms are on a piece of insulated material mounted on the shaft of the motor. Concentric circles and wiping contacts provide a continuous circuit to the arms of the switch. The switch is shown in Fig. 1107. The outer ring and the inner circle of contacts control colored indicator lights atop the bus so the operator can tell the position of the switch arm. The inner ring and the outer circle of contacts handle the various controls.

The master control circuit is shown in Fig. 1108. When the transmitter key is closed, the plate current of the tube in the receiver decreases and the sensitive relay RY1 closes the circuit to the power relay RY2. This completes the circuit to the selector motor, which continues to turn as long as the transmitting key is pressed. The operator knows the position of the rotating selector switch by watching the lamp indicators atop the bus. If the selector is stopped in the FORWARD position, solenoid SD1 pulls the forward-reverse switch S1 to the forward position, connecting the battery B2 to the driving motor so that it propels

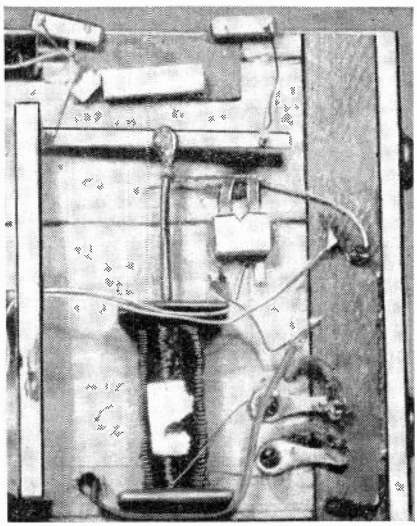


*Fig.* 1109—*Mechanism for opening the door.*

the bus forward. The motor is connected to the rear axle with 1-to-1 gears. The bus will continue to run forward until the selector is turned to REVERSE.

Setting the selector at LIGHTS ON causes solenoid SD3 to pull S2 toward it, closing the circuit between the 3-volt battery, the headlights, and running lights. When the selector is stopped at LIGHTS OFF, SD4 pulls S2 toward itself, opening the light circuit. To perform other operations with the lights on, allow the selector to pass over LIGHTS OFF without stopping. This is possible because the current to operate the solenoids is taken from B1 through the normally closed contacts on RY2.

The doors are opened independently by solenoids and closed by return springs when the selector is moved to another position. When either door is opened, the return spring contacts two metal strips and closes the circuit to the stop- and well-light circuits. The lights go out when the doors close. The construction of the door-opening mechanism is shown in Fig. 1109.

A bell and buzzer simulating the "getting-off" signals that passengers give the driver are powered by a 3-volt battery. The circuit is completed through RY2 when the selector switch comes to rest on BELL or BUZZER.

The windshield wiper uses a solenoid SD6, a return spring, and a thermostatic switch S3 to provide a slow reciprocating action. Current from B1 heats the bimetallic element, causing it to bend and open the heating circuit and close the circuit between the solenoid and the battery. SD6 pulls the windshield wiper in one direction. When the bimetallic element cools, it again closes the circuit to the heating element and the spring returns the wiper to its normal position. The cycle repeats as long as the selector is set on WINDSHIELD WIPER.

Steering is controlled by a 22.5-volt motor geared to the front axle as shown

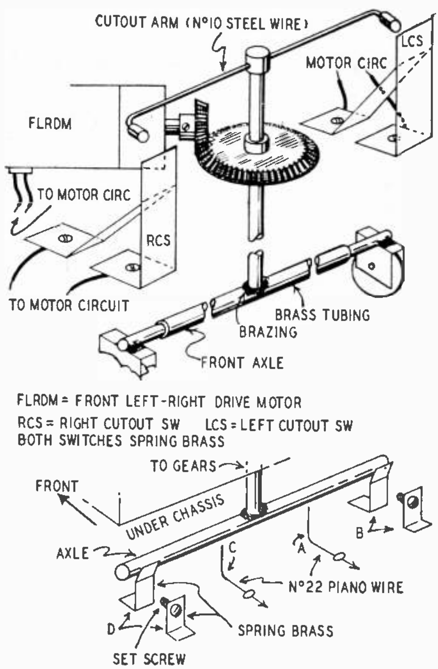



*Fig. 1110—Details for building steering mechanism.*

in Fig. 1110. When the axle is turned approximately 30 degrees to right or left the steering motor is cut off by limit switches. The wheels can be stopped in any intermediate position by moving the selector to a new position before the circuit is opened by the limit switches. The circuit is wired through RY3 so the motor normally turns to the right. RY3 reverses the circuit for a left turn.

Turn indicators are connected to blink when a turn is being made. Fig. 1111 shows the connections to the blinker circuit. When the wheels are turned to the right, the motor circuit is closed through the axle and contact A. Switch B closes the circuit to the right-hand indicators. This circuit is completed intermittently by the commutator and contacts E-E′. During a left-hand turn, the motor circuit is completed through the axle and C and the indicator circuit through D. The circuit is opened and closed by the commutator and contacts G-G′.

Two operations are required to reverse the bus: Set the selector to REVERSE. This causes SD2 to pull S1 toward it, reversing the connections between the driving motor and B2. In this position the circuit to the motor is completed through the auxiliary reversing relay RY4. Moving the selector to REVERSE-START closes RY4 and completes the circuit to the motor. The bus is stopped by moving the selector to an intermediate position.

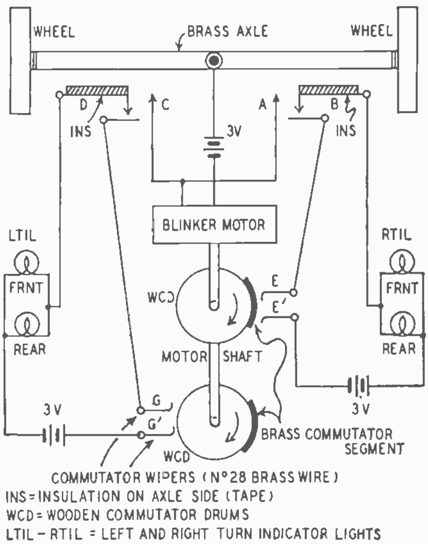



*Fig. 1111—Wiring of the turn-indicator circuit.*

Many of the problems of construction are left to the ingenuity of the individual builder because of the particular problems of each project. Two types of solenoids were used in this model. Both types are wound with No. 28 enameled magnet wire on 3/32-inch inside diameter aluminum tubing. The door-operating solenoids are 1½ inches long with enough wire added to give an over-all diameter of ½ inch. Those used to operate the windshield wiper, lights, and reversing switch are ⅝ inch long and wound to an over-all diameter of ⅜ inch. The cores are made of 1/16-inch soft iron rod. Steel machine screws are inserted in one end of the aluminum forms to adjust the pull of the solenoids.

A similar control system can be worked out by wired remote control, and the operator can control the power relay by inserting long flexible leads running to the operating position. Closing the circuit to RY2 by wire will give the same results as radio control.

# Chapter 12

## Hints and Adjustments

Once a transmitter, receiver, coder, and decoder have been constructed, the next step is to "iron out the bugs." Looking back at the construction section, the most logical place to start is with the receiver.

The first rule is: Examine and study the receiver circuit diagram until you are well acquainted with the theory and method of operation. By now we know that the gas-tube type of receiver operates as a superregenerative detector when receiving a signal, but actually is not superregenerating when the signal is off. Since the signal is radio frequency, it will be inaudible; hence we must use test instruments to determine if the unit is functioning properly.

In this case, and in the cases to follow, the minimum test equipment required will be a volt-ohmmeter and a milliameter. The latter might be incorporated as part of the test unit and should have ranges from 1 milliampere to as high as 100 milliamperes or more. It is best for the tests that have to be run to have a meter that will measure 5, 50, 250, and 500 volts a.c. and d.c.; 10, 50, and 500 ohms low scale; and a high-ohm scale having a range of 1,000 ohms to 1 megohm. The milliameter should read 1, 10, 50, and 100 milliamperes.

We should also have a good pair of high-impedance earphones, several small brown-bead 6-volt lights (150-ma type), and a few 6-volt batteries. With this amount of test equipment, most of the checks can be made quite readily.

### Trouble-Shooting RK-61 (RK-62) Receivers

The best check to make is to test the plate current by connecting the milliameter in series with the B-battery supply. Switch the meter to a high scale (50 ma) first. If the meter does not indicate, reduce the scale to 5 ma. The precaution of always using a higher scale than that desired protects the meter in the event that something is radically wrong. In this case we can connect the earphones in series with the B-plus lead. If the plate current is low, we should be able to hear in the earphones the familiar hiss characteristic of a superregenerating stage. If the stage is not superregenerating, the plate current should be approximately 1½ milliamperes and the plate relay should close. Suppose it doesn't? Adjust the relay spring tension until the relay pulls in at this value of current. A common cause of trouble with relays (when used in a job such as this) is that the armature binds. Be sure that the armature is free in its pivots, and that the distance between the pole piece and the armature is not so great that the magnetization of the coil fails to pull in the relay. The gap should be the smallest possible and still allow a good break when the circuit is de-energized.

The next check is to find out whether the relay releases when the stage is superregenerating. One of the simplest ways to do this is to increase the value of plate voltage slightly by having a variable resistance in series with the meter, earphones, and battery. Adjustment of the variable resistance can produce the required operating condition if the other portions of the circuit are correct. Varying the resistor should make the plate current drop and also enable us to hear the hiss in the earphones, if we listen carefully. If the maximum voltage recommended by the manufacturer (45 volts) does not produce this condition, then the circuit must be examined further. Two things can be at fault: first, the coil and capacitor may not have the correct ratio. Generally speaking, the coil should have a large value of inductance and the capacitor opened wide (minimum mesh), a small value of capacitance. The choke may not be good, or the grid resistance might be too large. Experimenting with these components will locate the fault.

With the meter indicating ohms, a test for continuity can be made through the choke. When checking, be sure to disconnect the item under test from the circuit; otherwise we might get a reading through some other circuit associated with this component. A variable resistance in the grid circuit will allow adjustment of this portion, and measurement of the value left in the circuit when the correct operation is obtained permits replacing the variable resistance with a fixed value.

When the stage is checked, vary the resistance in the plate circuit, causing an increase and decrease of plate voltage to the tube. This should result in superregeneration and nonsuperregeneration, enabling the relay to operate. The final adjustment is as close to the superregenerating state as possible, but definitely leaving the tube in the nonsuperregenerating condition. Operating batteries over periods of time will reduce their voltage; the adjustments have been made for the value at hand. We can expect to have to re-adjust the circuit periodically.

Coupling of the antenna to the receiver is generally done by means of a small loop of wire located close to the tank circuit. If the antenna is exactly the resonant length for the frequency involved, it will take power from the tank circuit, making it difficult for the stage to superregenerate at all. This is the reason that the tests mentioned previously should be made with the antenna disconnected. We would then know that the receiver is working and that any trouble (if experienced) could be attributed to the antenna.

If the tube is operated at a very critical point, such that the reception of a very small amount of energy from a transmitter can cause it to change state, the effect of metal objects, or even the human body, can also cause this change of state. Keeping the antenna clear is a good rule to follow.

## RK-61 (RK-62) Receiver Adjustment

Here are some instructions for the RK-61 (RK-62) type receiver that are the result of considerable experience. Individual experience and practice may call for slight revision here and there but, on the whole, they should serve to greatly increase the reliability of the receiver for the average user.

Assuming that the receiver has been installed and connected properly, the operator should practice and become thoroughly familiar with the following ten-point check list. Once a receiver is adjusted properly and known to be in good condition, only items 3, 4, and maybe 5, will need a repeat check in the field.

(1) Voltage check,
(2) Relay adjustment,
(3) Idling plate current,
(4) Transmitter tuning,
(5) Receiver antenna coupling,
(6) Antenna length,
(7) Receiver tuning,
(8) Meter wobble,
(9) Receiver response,
(10) Vibration.

These check items are listed in the approximate order in which they can be made on a new receiver installation. Actually, they are made more or less simultaneously since they are interrelated and interdependent. Also, they take much less time to do than to read.

(1) *Voltage check.* The RK-61 (RK-62) receiver works best when A-voltage is not less than 1.4 and B-voltage is above 45. The B-voltage is obtainable with a small size 67½-volt battery (RCA 457). A 25,000-ohm potentiometer in series with this higher value of voltage is recommended to permit accurate adjustment.

(2) *Relay adjustment.* Always check the relay adjustment on a new receiver. Once made, this adjustment seldom needs repeating unless a crash landing warrants it. The Sigma relay is easier to adjust than the Kurman (which is used in Aerotrol) because it is more rigid and has screws for contact and spring adjustment. The armature of any relay should never touch the iron pole piece of the coil because sticking will result. The Sigma relay armature should be adjusted so that at 1.5 ma light can just be seen between the armature and the pole. It is good practice on the Kurman relay to glue one or two thicknesses of tissue paper over the iron pole of the coil. This spacer is not necessary on the Sigma because of its extra rigidity. Detailed instructions for relay adjustment are not given here because experience shows that the operation must be understood rather than memorized for best results.

After the armature-to-pole gap is adjusted, there are two points to understand: (a) the contact spacing is used to adjust the relay sensitivity or pull-in-to-drop-out range on the meter scale, and (b) the spring tension is used to adjust the point of relay operation on the meter scale. The relay can be completely adjusted without the use of a transmitter if the recommended 25,000-ohm potentiometer is used. Slowly swing the plate current with the potentiometer and note the pull-in-to-drop-out range on the meter. This should be about 0.1 ma. If it is much more, the contacts are spaced too far apart. Use only the "live" contact to bring them closer together since the "dead" contact (on the Sigma relay) has been set to control the armature gap. If the range is too small, move the contacts further apart. If the relay operation is difficult to hear, use the noise of the control escapement. Now adjust the spring tension to bring the operating range to the proper place on the meter scale. This should be around 0.8 to 0.9 ma. Increasing the spring tension will raise the operating point, while decreasing spring tension will lower it. Use very little spring adjustment; if too much is required, the contact spacing may need readjustment to maintain the 0.1-ma operating range.

(3) *Idling plate current.* This check is very common for the receiver, and, of course, should be done in the field before each flight. An idling current of 1.1 to 1.3 ma increases tube life; 1.1 is preferred and can be used with the Sigma relay without fear of vibration effects. The Kurman relay should be operated at 1.2 ma. In using the potentiometer be careful not to turn it the wrong way, as each surge of high current means that much shorter tube life.

(4) *Transmitter tuning.* Information on transmitter tuning is covered further on in this chapter under the heading of Transmitter Hints.

(5) *Receiver antenna coupling.* Set the transmitter up in an open area or on the flying field with antenna connected. Have a friend stand by to operate it. Set the ship on the ground at least 100 feet away (20 normal steps) and off the end of the antenna to avoid too strong a signal. Place the meter in the receiver circuit, turn the receiver on, and call for transmitter on. Swing the antenna coupling capacitor for minimum plate current reading on the receiver. This may or may not be lower than that obtained previously. Now rotate the capacitor back until the plate current just barely starts to rise. This is considered the optimum setting for a new tube. An aging tube will require more antenna coupling than this, or enough to stop meter wobble as described under check item 8.

(6) *Antenna length.* When a new receiver is installed, the antenna length should be as recommended by the manufacturer. The best length may vary according to the arrangement of wiring in the airplane and the age of the tube. With the ship still at least 100 feet off the end of the transmitter antenna, try 4 inches more, and then 4 inches less antenna and repeat item 5. The best antenna length is the one that will give the lowest plate current reading (signal on) with the least antenna coupling of step 5. The antenna coupling adjustment is far more convenient than antenna length adjustment and they accomplish almost the same thing. However, increasing the antenna coupling raises the minimum plate current reading available with signal. To avoid too much of this, the antenna length adjustment must be resorted to, especially as the tube gets older. Generally speaking, the older the tube, the greater antenna length required. The antenna seldom needs lengthening in the field because step 5 is usually sufficient to get by for the day.

(7) *Receiver tuning.* Still with the receiver away from the transmitter and with signal on, here is a simple way to check receiver tuning. A polystyrene screwdriver is needed. Polystyrene is a very good insulator of r.f. current and should be used in preference to other plastic materials or wood. Place the screwdriver between the two end loops of the receiver tuned circuit coil, and spread these loops apart very slightly. This raises the operating frequency of the receiver. If the transmitter was previously tuned to the receiver, the receiver meter will show an increase. If it does not or if it reads less, the transmitter frequency is too high. Either retune the transmitter or spread the receiver coils a little more until the meter stays down. Don't do too much coil spreading as this affects the receiver in other ways and may require the recheck of items 5 and 6. To lower the receiver frequency, push the top of the end loop of the tuned circuit coil so that it bends in very slightly. Observe as before—if the meter goes down, the transmitter frequency is too low. In this test, care should be taken to keep the hands well away from the ship as body capacitance might confuse the action.

(8) *Meter wobble.* Wobbling of the meter pointer while the receiver is idling at or near 1.1 ma indicates fluctuating plate current and, since the meter cannot follow all of this plate current change, the amount of change is even greater than indicated. The condition can become bad enough in flight to trip the relay. Meter wobble is an indication of tube aging; new tubes should not show meter wobble. At the first sign of meter wobble, increase the antenna coupling capacitance enough to stop it. With further aging of the tube, a point will be reached where further antenna coupling will cause erratic and improper receiver operation. The plate current may go down on signal and never come up, or it may never go down on signal at all. At this point, increase the antenna length several inches (by trial and error) and at the same time reduce antenna coupling as in item 5. If the above procedure completely eliminates meter wobble, it is still safe to operate at 1.1-ma idling current. A point will be reached in tube life where this procedure will not completely stop meter wobble. We must then use an idling current that is progressively higher until the wobble stops. As high as 1.6 ma or even more can be used to prevent the plate current fluctuations from reaching the relay operating point. At this stage, the 60-volt B-battery is capable of producing safe tube operation. The tube life at this point is well beyond the stated 8 to 10 hours. Finally a point is reached where all the extra attention required is well worth the price of a new tube.

(9) *Receiver response.* Finally, have a friend send rapid pulses. The receiver should follow. If it misses a few, better leave it alone. However, if response is too slow, more antenna coupling capacitance may be required. Repeat items 5 or 6 or both carefully and improvement is certain.

(10) *Vibration.* This test is actually the last test that is done before launching the model. With the engine running, hold the ship off the ground while a friend sends signals. If the control chatters through more positions than signals are sent for, then either a wire connection is loose or the receiver is mounted so rigidly that the relay armature vibrates. This latter is very unusual. If the control still chatters through positions with the receiver off and servo (control) power off, the engine is shaking the ship too hard. More spring tension will be required on the escapement armature. At any rate, don't launch that ship until it is right. A ship in the hand is worth two in the next county.

## Goode (or Beacon) Receiver Adjustment

When using the Goode (or Beacon) receiver in a model plane, the following adjustments are recommended:

Set the fuselage away from any large metal objects. With the Beacon receiver, the plate current meter should have very short leads (less than 1 inch) for best results. Long meter leads act like antennas and may alter the settings when the meter is removed from the circuit. Adjust the antenna length according to the instructions to obtain optimum sensitivity. Keying the antennaless transmitter should cause the receiver's 6-ma idling current to drop to about 3.5 ma. Be sure to use fresh batteries and check them *under load* with a voltmeter. The B-battery should measure between 45 and 36 volts and the A between 1.5 and 1.1 volts. The escapement battery under load should read between 3.0 and 2.4 volts. After recording the two plate current values noted above, set the relay contacts. Insert a 10,000-ohm variable resistor in series with the meter and adjust it to obtain the plate current values desired for the relay setting. Setting "in" 1 milliampere from each edge is a convenient rule. Thus, for the above currents, the relay should close at 4.5 ma and open at 5 ma. Now remove the meter and resistor and observe the over-all operation while keying the transmitter. This completes the indoor tests and we adjourn to the backyard.

Sometimes with too long a receiver antenna the set "loads" when the model is placed on the ground. The result is poor sensitivity or no operation. Try the following with an antennaless transmitter. With a helper on each wing tip, lift the model 5 feet above the ground, keying the transmitter continually. This may "unload" the set if the receiver antenna is too short and causes the relay not to restore from the contact position. Thus we have two quick checks on the antenna length.

Next, with the model on the ground, run the engine at different speeds and, while keying, watch for proper rudder operation. Look for skipping rudder positions when not keying. Although not common, if skipping should occur, it is easy to localize the trouble. Turn off the receiver switch and see if the escapement continues to skip. If it does, propeller unbalance because of excessive vibration may be responsible. If skipping does not continue, then the trouble is probably at the contacts of the sensitive relay, indicating that the receiver mounting rubbers are too stiff or that the relay contact is set too close to the idling current. In any event, don't take a step toward the field until the skip is completely eliminated; a steadily skipping rudder can give a long straight flight.

If space is available, also make the distance check at home. With the help of a ham, set up your transmitter with its antenna in a clear area. With a helper wheeling the model away and while keying the transmitter, determine the operational limits of the frequency setting knob on the transmitter up to a distance of 500 feet. Set the knob halfway between your limit marks, adjusting the frequency of the transmitter to the center of the band to avoid out-of-band operation. Now pack the car—you're ready for the field!

## Transmitter Hints

For those not experienced in tuning a transmitter, this presents a big problem. There are two general rules applicable to transmitters: Keep the coil and capacitor values as similar as possible for the two tank circuits, receiving and transmitting. For example, assume that the receiver has a tank circuit consisting of a coil of six turns and a capacitance of 15 $\mu\mu f$ (as evidenced by having a 30-$\mu\mu f$ tuning capacitor approximately half enmeshed). Suppose this tunes to the 6-meter band which is the recommended wavelength for the operation of one-tube sets. In the transmitter a coil of the same size and capacitor of the same size will tune to almost the same wavelength. Actually, there will be a slight difference in wavelength due to wiring and the use of different types of tubes. A slight readjustment of the tuning capacitor can remedy this.

Transmitter coils should use a somewhat larger diameter wire than that used in the receiver. The transmitter coil can be spread apart, thus reducing its inductance so it will "hit" the receiver frequency. One of the best ways to arrive at the size coil and capacitors to use is to consult the *Radio Amateur's Handbook.* Find a receiver and transmitter circuit which operates on the desired frequencies, and then from that circuit data get the size coil and capacitor to use. Coil and capacitor combinations to fit almost any physical arrangement can be chosen.

Another method is to use a "Lightning Coil-Condenser Calculator," such as is distributed by Allied Radio, Shure Manufacturing Company, and others. These slide-rule-type calculators come with complete operating instructions.

One sure way to find out whether or not the transmitter is operating is to measure the d.c. voltage across the grid resistance when the circuit is turned on. This d.c. voltage is the oscillator bias voltage. If a value of voltage is read (minus with respect to ground), the transmitter tube is oscillating. If possible a meter having a sensitivity of about 10,000 ohms per volt should be used for this measurement. The measured bias voltage will vary from 1 volt d.c. to as high as 25, depending on the particular transmitter used.

A second way to determine if the transmitter is operating is to take a light bulb (6 volt, 150 ma) and solder it to a small loop of wire roughly 3 inches in diameter. If this is held near the tank circuit of a transmitter, a glow in the bulb will indicate oscillation. A small neon bulb or glow-tube can also be used. Just hold the neon bulb between your fingers and bring it close to the tank coil. If the transmitter is oscillating, the neon bulb will light. Small neon bulbs make very sensitive oscillation indicators. Be careful! The tank has high voltage on it—d.c. *and* r.f.

The four things most generally found at fault in transmitters are: (1) tank circuit not tuned to the correct frequency; (2) grid resistance too high or not high enough; (3) grid capacitance too small — a good average value is around 100 $\mu\mu f$; and (4) plate or filament voltage too low.

To be sure that operation is on the correct frequency, a wave meter (available on the market) can be used, or the frequency can be measured by means of Lecher wires (described in detail in *The Radio Amateur's Handbook*).

## Tone-Operated Receivers

The first general rule in constructing receivers is to keep all components associated with each tube as close to that tube as possible. Ideally, this would result in a series of small groupings of resistors and capacitors around each tube base. The superregenerative stage should be isolated by metal shielding whenever possible. Run the output lead to the audio section through a small hole in the shield.

To get at the root of trouble in these sets measure the d.c. voltage between each plate and ground, and also screen to ground. The voltage should be approximately 15 to 20. The screen voltage should be equal to, or less than, the plate voltage; but the screen should never be higher than the plate, except for the relay tube. Measure across each tube filament. The voltage for a 3Q4 should be about 3 volts, series connection; 1.5 volts shunt. Of course, the 9002 and 9003 will have a higher value (6 volts).

If these checks are satisfactory, clip on the earphones and touch the grid of the last audio stage with a small screwdriver. A definite click should be heard. Advance to the next to the last stage and repeat—the click should be louder. Follow through to the first audio stage, where touching the grid should either cause a howl or a very loud click. If possible, use an audio oscillator instead of a screwdriver. The signal should increase as we progress toward the first stage. If the grid of any stage does not produce a click or signal, carefully check plate and filament voltages, test the tube, and examine all connections to be sure they are correctly made and to the correct pins or components.

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