Radio Control for Beginners

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BERNARD BABANI BP79

Radio Control for Beginners

■ The aim of this book is to provide a practical introduction to radio control for newcomers to this fascinating hobby. A number of constructional projects are included and in many cases complete board layouts are given to help the beginner who is inexperienced in electronic construction techniques to simply and successfully build up the circuits.

■ The text commences with types of RC systems and licencing requirements as well as dealing with allowable frequencies and power of transmission. The construction of a field strength meter is then covered, as this is extremely useful in setting up correctly a RC transmitter and receiver.

■ Copious details are then given of transmitting equipment which the reader can easily and inexpensively build, this then leads on to the detailed construction of various types of receivers. The book concludes by explaining the various electro-mechanical methods of achieving actual movement of the controls of the model.

■ An invaluable addition to the library of both electronic hobbyists and model makers alike.

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by

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Controlling a Model

The principle of radio control will become clear from Figure 1. Here, it is assumed that a model boat is to be guided at a distance by the manipulation of a push switch or button. Such an arrangement is in fact a practical one, and suitable for small or simple models, where complex circuits are not wanted.

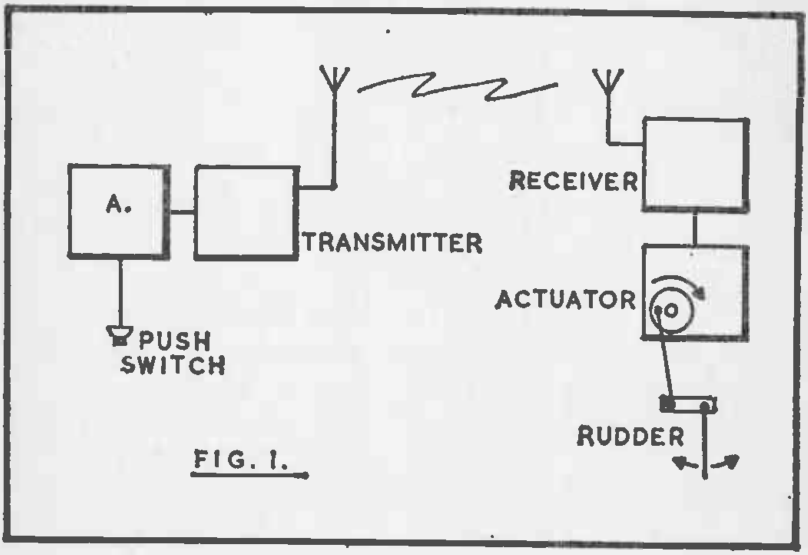


FIG. 1.

Operating the push button switches on unit A, which is in fact part of the transmitter. In many transmitters this brings on an audio tone, which is radiated by modulating the radio carrier wave. With extremely simple circuits controlled by the carrier wave, the push button may switch on and off the transmitter, no audio tone being generated. Others may be so arranged that audio tone and carrier wave operate together so that the carrier is never radiated except in a modulated condition.

If an unmodulated wave is being transmitted, it can be detected with a suitable field strength or indicating wavemeter, as shown later. This proves the transmitter is working.

Should a tone modulated wave be transmitted, then this can also be detected by similar means, and the audio tone can be heard with headphones. This can be convenient, as it shows that the transmitter is operating, and that the tone is present also.

The push switch, circuitry A, and transmitter, can occupy one quite small case, and run from a dry battery supply. A telescopic aerial extending to a few feet will generally be fitted. With the aerial roughly vertical, signals are radiated with one or less similar strength in all directions.

A convenient aerial on the model picks up the radiated signal. Here, the aerial may depend on the type or style of model, or range required. For some models a short vertical rod aerial is ideal, and quite appropriate. Sometimes the aerial is hidden, as when running a wire up a mast.

The receiver is most generally a transistorised superhet, because of the reliability and sensitivity obtained. Such receivers are also sufficiently selective to allow several model control enthusiasts to operate together, on slightly different frequencies. Simpler types of receivers are also used on occasion. These may respond to any signals in the band, so are only suitable for solo or isolated use.

A signal from the receiver passes to the actuator. In Figure 1 this is a straightforward electro-mechanical device in which a crank is made to rotate, thus swinging the boat rudder from side to side, by means of a connecting link. The actuator, in simple form, may have only four positions. Typically, these would be:

1. Straight ahead

2. Port

3. Straight ahead

4. Starboard.

Since rotation of the actuator crank provides two straight ahead positions, one of these might be used to stop the propulsion motor, or reverse it. Or this might be used for half-speed sailing. Any of the four positions can be reached by pressing the push button, and they would then provide:

1. Straight ahead

2. Port

3. Stop (or sail astern, or ahead half-speed)

4. Starboard.

The degree of control which can be provided in a model ranges from the very simple (say steering only) to the very complex, with operation of rudder, motor speed, motor direction, etc. Some systems can be started in simple form, and added to as wished.

Single Channel

The method shown in Figure 1 employs a single channel of communication between the transmitter and receiver. This is by means of the radio carrier wave; or by placing modulation on a carrier wave continuously present. This can if wished, be likened to a single connection from unit A to the actuator.

One benefit of single channel working is that the transmitting and receiving equipment may be of the simplest types. With a suitable actuator, satisfactory control of the model may be obtained.

Where it becomes difficult or almost impossible to obtain the required degree of control of the model by means of a single channel then multi-channel control is used instead.

Multi-Channel

Here, two or more channels of communication are established between the transmitter and model. This can be done by using dissimilar audio tones. Thus, for two channels, the transmitter radio wave could be modulated by either a high tone, or a lower tone. At the receiver, suitable circuits can select high or low tones, and result in individual control of two actuators. Two channels would allow, as example, steering by one tone, and control of the propulsion motor by the other tone.

Relatively simple multi-channel equipment may have three tones, for three channels. It is practical to employ more tones than three, for additional channels. As more tones are used, additional stability in their means of generation grows necessary, and more care is needed in separating near tones at the receiver.

Other Methods

Other means of obtaining control of the model can be used, and one of these employs the mark-space ratio of a signal. An example of the way in which this operates will become clear from Figure 2.

Here, the actuator is shown as having an electro-magnet coil, with core linked to an arm attached to the rudder. A spring tends to pull the core out of the electro-magnet, so that the rudder would take up position C. If the coil received current to pull the core completely in, the rudder would move to B. Should current in the coil be strong enough to hold the core in a half-way position, as shown, the rudder would be at A.

Difficulties arise in varying the strength of a steady current to accomplish this. But a similar result can be obtained if the current is interrupted rapidly, and the length of time it is "on" and "off" is adjusted.

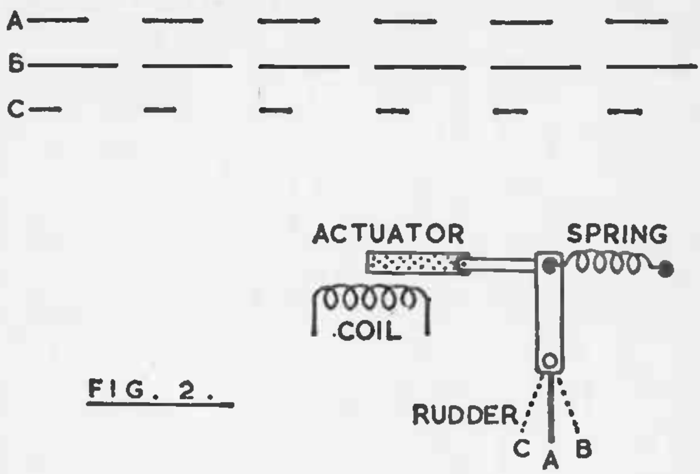


FIG. 2.

At A, on and off intervals are of the same length, so the rudder stays as shown for position A. At B, the on or mark signal is longer so the average power of the magnet is greater, drawing the core in, and the rudder moves to B. At C, the on period is short, and the spaces or off periods are long, so the power in the coil is small, and the rudder moves to C.

The pulses A, B or C are provided by an oscillator or other means, so that the rudder does not swing from side to side with each on and off interval, as the frequency is too high. A steady change of on and off periods can be arranged, from almost fully on, to almost fully off, so that the rudder can be made to take up any intermediate positions. If the lengths of signals such as A, B and C depend on the position of a "tiller" on the transmitter, then the rudder will follow its movement, and more realistic control is obtained.

It is worth noting that the same transmitter and receiver can often be used with a wide range of operating methods – various steering and other devices can be connected to the transmitter, and actuators to suit fitted in the model. This is useful for home-built models, where a transmitter and receiver can be retained, even when the methods of control are changed or developed.

Licence Conditions

Users of model control equipment need to avoid interference to other services, and there are regulations governing power, frequency, and other factors, to help assure this is so. Fortunately these are easily met, so that all operation is completely legal.

The licence (1980) is £2.80 for 5 years on issue, and also for 5 years on renewal. It allows the licence holder to establish and use a station for the purpose of controlling a model vehicle, vessel or aircraft, by means of radio. This covers both sets of equipment – that for the transmitter, and that used for reception in the model.

The station must operate within the permitted frequency bands. These are 26.96 MHz to 27.28 MHz, and 458.5 MHz to 459.5 MHz. Of these two bands, the 27 MHz range is almost exclusively used, for both ready-made and home-built equipment.

Only permitted classes of emission may be radiated. These will generally be an audio tone, or various combination of tones, used to carry information. Some types of simple equipment can be operated with no tone. The radiated signal is then equivalent to that of a radio station during a silent interval – only the unmodulated radio carrier wave is present.

Transmitting equipment is crystal controlled. The crystal is able to oscillate at a particular chosen frequency, and this controls the frequency of the transmitted signal. By this means, it is easy to make sure the signal is in the permitted band.

It is necessary to use a satisfactory method of stabilising the frequency of the transmitter. This is to prevent it drifting out of the permitted band, as example, and crystal control automatically takes care of this point.

Operation of the station is only to be by the licence holder, or under his supervision by a person he has authorised. Spark sending equipment (which can easily cause interference) is not allowed. The station shall be available for inspection by an authorised person. It shall be used in such a way as not to cause avoidable interference.

The maximum effective radiated power must not exceed 1.5 watts for the 27 MHz band, or 0.5 watt for the 459 MHz band. This is easily assured, and substantially less power will often be used. With the transmitters described and aerials shown, the ERP (effective radiated power) will be under 1.5W. Should any need ever arise to find the ERP for other circumstances, it is the mean radio frequency power multiplied by the gain of the aerial in the horizontal plane.

Means should be available to determine or show that the sending equipment is operating in the permitted band. With crystal control, this is readily achieved.

None of these regulations would appear to present any particular difficulty. Exact and full information should be obtained from the Home Office, Radio Regulatory Department, Radio Regulatory Division, Waterloo Bridge House, Waterloo Road, London, SE1 8UA, with a request for an application form for a Model Control Licence.

Field Strength Meter/Monitor

This instrument is of considerable aid when adjusting a home-built transmitter. It will give an indication of the radio frequency energy present in oscillator or other coils, so that stages can be tuned correctly. By plugging in a short telescopic aerial, it can be used as an indicator of the radiated field strength of the transmitter, as an aid to tuning up for best range. It will also take headphones or an earphone, so that the presence of audio tones can be checked.

Figure 3 shows the circuit, and L1 is tuned to resonance by VC1. The signal voltage developed is rectified by diode D1, and read on the meter M1. Best adjustment of the transmitter corresponds to the greatest meter reading. If no reading is obtained, the transmitter is not operating.

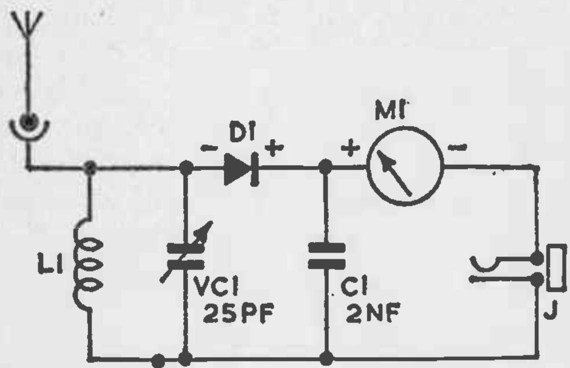


FIG. 3.

The jack socket J is normally closed (to complete the meter circuit) but 2k or similar phones can be plugged in here, when the presence of an audio tone is to be checked.

Where the instrument is to be used to compare radiated signal strength, the aerial is plugged into a socket provided.

Figure 4 shows construction in a sloping front metal case 4 x 4 x 4 in (102 x 102 x 102 mm). L1 consists of 15 turns of 24 swg enamelled wire, side by side on a former 7/16th in or 11 mm in diameter. Secure the turns with clear Bostik. The coil projects outside the case, so that the instrument can be placed near an oscillator or other coil where RF is to be checked. Bolts through the coil feet secure it, and one of these provides one connection, and also takes a lead to the rotor tag of VC1. Place sleeving on the other coil lead, and

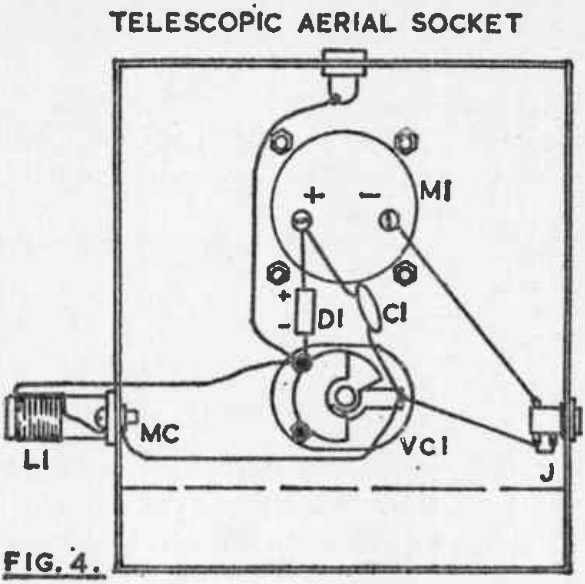


FIG. 4.

run it through a hole to the fixed plates tag of VC1.

A 50 μA meter is suggested, but 100 μA or even 250 μA may be fitted, with some reduction in sensitivity. D1 can be any detector type point contact diode. The value of C1 is unimportant. A 3.5 mm jack socket is convenient. Note that it must complete circuit when no plug is inserted.

An insulated socket is fitted to the top of the case for the aerial. A plug to suit is soldered to the aerial, which can be about 22 in when extended (the exact length is not important here).

It should be found that 27 MHz is tuned with VC1 about two-thirds closed, with no aerial; or about one-third closed, when the aerial is fitted. Should VC1 prove to be fully open or fully closed, adjust the turns on L1 to avoid this.

When testing for oscillation and similar purposes, as if setting a transmitter (Tx) up for the first time, energy is picked up by

L1, which is placed within a few inches of the source of RF. Subsequently, adjust the distance of L1 from the Tx coil, to avoid too large a reading on M1. No aerial is required.

When making tests which involve checking for actual radiated RF energy, fit the aerial and extend it, and re-tune VC1. The instrument may then be placed at some small distance, depending on the transmitter power and efficiency. Adjustments at the Tx will be directed towards obtaining the greatest reading on M1.

Transmitter: RF

The radio frequency section of the transmitter (Figure 5) can be used with a modulator providing a single tone, for single channel; or with more than one tone, for multi-channel. It can also be used with other forms of control.

Tr1 is the oscillator, whose frequency is controlled by the crystal. R1 and R2 set base working conditions, and emitter bias by R3 helps stabilise operation, and assist ready starting of the oscillator. The crystal frequency will lie in the permitted 27 MHz band, as explained. A frequency is listed, but it is not necessary to use this channel. With inexpensive equipment for isolated use, the crystal may be soldered in. However, it is preferable to fit a miniature holder, and use a crystal to suit, as the crystal can then be easily changed to shift frequency, should this ever be needed.

Coil L1, with C1 in parallel, is broadly tuned to the working frequency. An adjustable core is convenient for this purpose. L2 couples to the base of Tr2, which is the power amplifier. Tr2 is used without bias, and base current is obtained from the drive furnished by L2. C5 grounds the emitter for RF purposes only, so that tone modulation can be applied to the emitter at E.

The PA tank coil L3 is tuned to resonance by the trimmer T1. Tr2 collector is tapped on this coil, and also a connection for

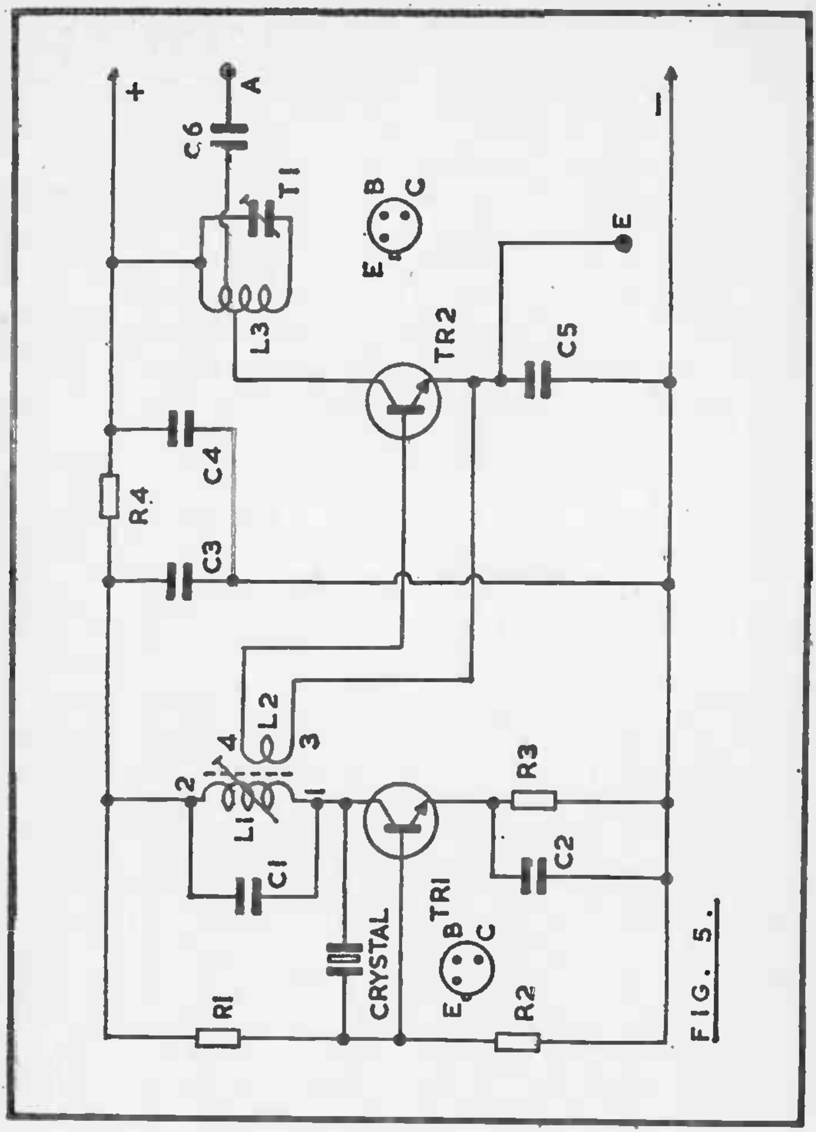


FIG. 5.

C6, which feeds the transmitter aerial at A. The latter is generally an extending telescopic aerial, so that the whole can be held in the hand.

Power can be from a 9v battery, or from two 6v packs, to obtain 12v. This section can be assembled and tested by itself, before building any tone generating circuits.

Inductors

These are shown in Figure 6. L1/L2 use a 5 mm diameter former 15 mm long, with high-frequency grade core. Both windings are 32 swg enamelled wire. Leave a little wire at 1, and wind eighteen turns side by side to point 2. Start L2 at point 3, and wind five turns in the same direction, finishing at 4. A slight space appears in Figure 6 to clarify connections, but L2 is against L1 with no space. Also take ends 1 and 2 away towards Tr1 (referring to the board layout) and ends 3 and 4 away towards Tr2. Cement the turns in place with a few touches of adhesive (such as clear Bostik).

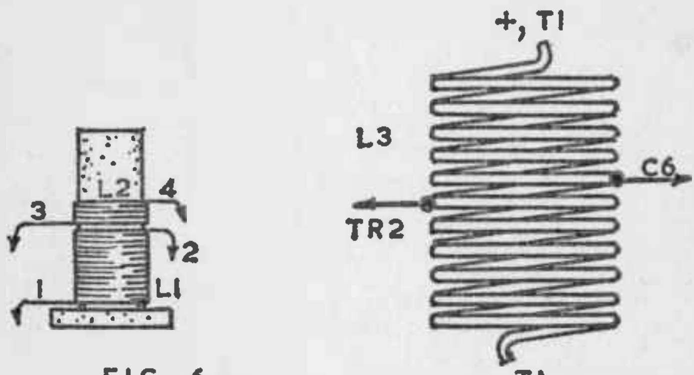


FIG. 6.

L3 is self-supporting, and 18 swg wire is convenient, tinned copper, or enamelled. The inside diameter is 15 mm, and the coil is 22 mm long, and has eleven turns.

Straighten the wire, and wind the turns side by side on some object of suitable size, adding an extra turn each end. Remove the object and if necessary spearate the turns slightly, either by stretching the coil, or by running a small tool or other item round and round between turns. The ends can then be shaped and cut so that each projects straight for about ¼ in (5 or 6 mm). The tap for C6 will be soldered four and three-quarter turns from the positive end, and the tap for Tr2 collector a half-turn further round, as shown.

Slight changes in diameter, etc., are in order for L1/L2, and L3, provided these can be tuned to resonance in the way explained. A small increase in coil diameter (e.g., as for L1/L2) would usually make necessary a slight reduction in the number of turns. Smaller diameters may make necessary more turns.

Board Layout

Figure 7 shows components for the RF section, the board being large enough (22 x 15 holes) to accommodate a tone generator. Holes are enlarged for the crystal holder. L1/L2 former is a push fit in a hole, and is also fixed with adhesive.

In most places the wire ends of resistors and capacitors will reach to the required points. Bend these over, cut to a suitable length, and solder. Wires may be arranged so that insulated sleeving is not required.

Scrape insulation from the ends of L1 and L2, take these down through the holes shown, cut to length and solder.

Transistor leads can be seen from Figure 5. When soldering these do not 'cook' the joints – remove the iron immediately the solder is seen to flow and make the proper connection.

Pins inserted in the board, or stiff vertical wires, can be used as mounting points for L3. Tap on Tr2 collector and C6 as in Figure 6. Tr2 and its sink must be just clear of contact with the coil. T1 is also just away from the coil, with top plates tag taken to the positive line. Another pin at A will anchor a lead for the aerial.

All leads need to be reasonably short and direct in this section. Convenient junction points for external positive and negative leads are at C4.

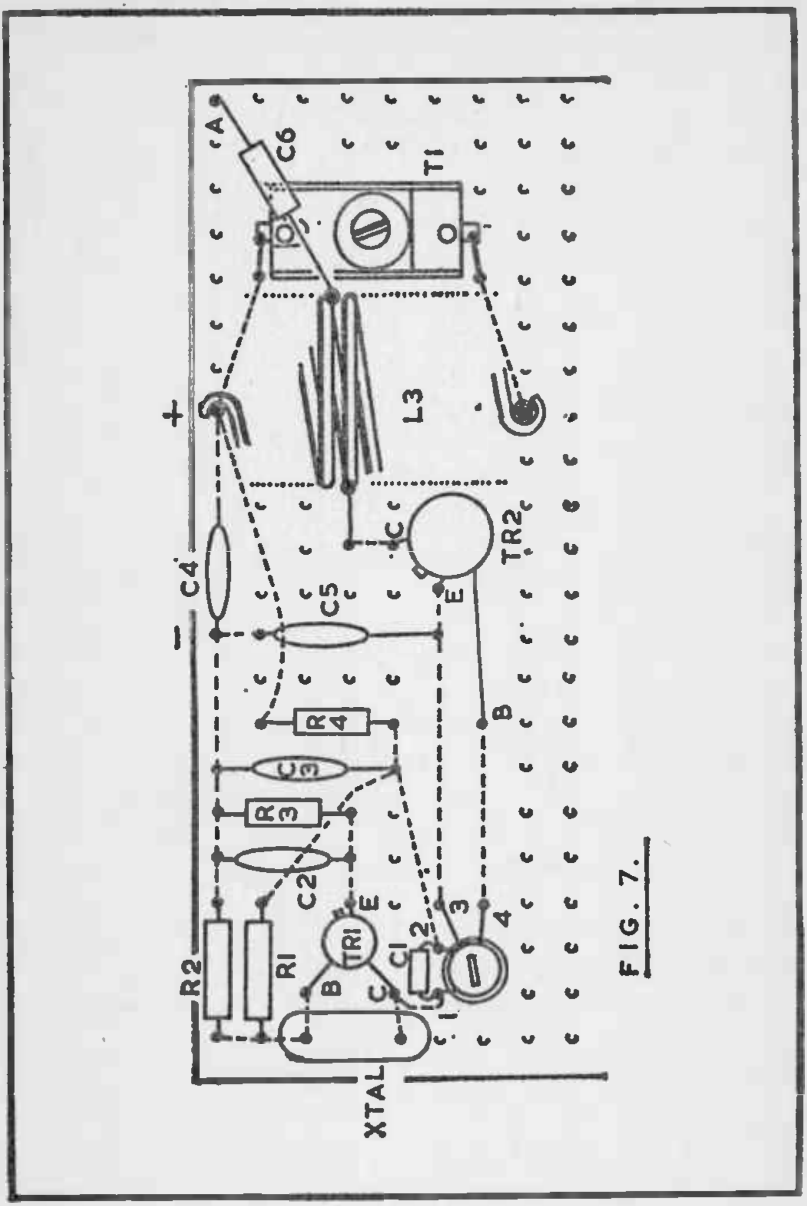


FIG. 7.

Components Transmitter: RF Section (Figure 5)

R1	56k
R2	15k

R3	100 ohm
R4	100 ohm
	(Resistors 5% ¼ W.)
C1	39 pF
C2	10 nF ceramic disc
C3	10 nF ceramic disc
C4	4.7 nF (5 nF suitable) ceramic disc
C5	2 nF ceramic disc
C6	1 nF
T1	60 pF trimmer
Tr1	2N2221A
Tr2	2N2219A with small clip-on heat sink
Crystal:	27.005 MHz, and holder
Board	22 x 15 holes, 0.15 in matrix.

To tune up and test this section with no modulator, temporarily connect a wire from Tr2 emitter to negative (e.g., across C5).

RF Testing

A non-metal tool for the core of L1/L2 and T1, will be of advantage, and can be made from plastic or other insulated material, filed or cut to shape.

An output load for an initial test can consist of a 6 volt 0.1 ampere bulb, screwed in a holder connected from positive to A. This will draw current otherwise passing to the aerial, and when well lit will show that RF energy of about 400 to 600 milliwatts (0.4 – 0.6 watt) is obtainable.

Best tuning up is greatly aided by using the indicating wavemeter described. Set L1/L2 core near the top of the former, and with a 9v supply, check with the wavemeter for RF. With the wavemeter a few inches from L1/L2, screw in the core for maximum meter reading on the wavemeter.

Adjust T1 for maximum brightness of the bulb mentioned. Later, when the aerial is connected, T1 will have to be slightly re-adjusted. Tuning is not exceptionally critical. However, if the wavemeter is placed a little distance from L3, it will be seen that there are best positions for the coil core and T1, resulting in best RF output. For this reason, the use of the indicating wavemeter is recommended. If it is not available, make the adjustments described for best lamp brightness.

Should T1 be hard screwed down, compress L3 a little, so that its turns are closer together.

Subsequently, and prior to distance operation, place the wavemeter aerial on, and connect the transmitter aerial. Situate the wavemeter a few feet from the transmitter, tune it for best indication on its meter, then adjust T1 for maximum reading on the meter.

When setting up and testing a model indoors, it can be convenient to use the transmitter with no aerial, or with RF power fed into a bulb. The receiving equipment can then be near at hand, without too severely overloading it.

This part of the transmitter radiates an unmodulated carrier wave, so no sound will be heard with phones plugged into the wavemeter audio socket. Normal control is with a modulated wave, as the un-modulated signal is only suitable for extremely simplified and very short range purposes and a few special applications.

Crystal Frequencies

The transmitter frequency is controlled by the crystal fitted. For isolated use, the frequency chosen in the band is not important. But with two or more sets of equipment operating simultaneously, the transmitters need to be on separated channels, so the crystals will be of different frequency.

Some transmitter crystal frequencies, separated by 50 kHz, are:

26.995 MHz
27.045 MHz
27.095 MHz
27.145 MHz
27.195 MHz
27.245 MHz

Naturally other frequencies may be used.

With a crystal controlled superhet receiver, the crystal oscillator in the receiver has to differ in frequency from the received signal by an amount equal to the receiver intermediate frequency. The receiver oscillator frequency may be higher or lower than the transmitter frequency. So if the transmitter operated at a frequency of 27 MHz, and the receiver intermediate frequency were 450 kHz, the receiver oscillator could operate at 27.450 MHz, or 26.550 MHz. In each case the difference between the oscillator and signal frequencies will be 0.45 MHz, or 450 kHz.

Thus a pair of crystals purchased for a transmitter and receiver for use together will be of different frequency, and this difference will be the intermediate frequency of the receiver. This is usually in the region of 450 kHz to 475 kHz or so.

If a home-built transmitter is to be used with a commercially made receiver, or a receiver is built for an existing transmitter, the need for a crystal of correct frequency must be kept in mind. There may be some latitude. As example, if the receiver has 465 kHz intermediate frequency transformers, these may be tunable to any frequency from about 455 kHz to 470 kHz, but this depends on the type.

Where the receiver is of fully tunable type, having no crystal, it can normally be adjusted to respond to a transmitter working at any frequency in the band.

Plug-in crystals allow easy changes of transmitter and receiver frequency, for groups or competitions, etc.

So for a 470 kHz IF, transmitter and receiver crystals could be:

Transmitter	*Receiver*
26.995	26.525
27.045	26.575
27.095	26.625
27.145	26.675

Similarly, with an intermediate frequency of 475 kHz, and the receiver oscillator operating at a higher frequency than the transmitter, a pair of crystals could be 27.005 MHz for transmitter, and 27.480 MHz for the receiver.

Because high frequency crystals were formerly less readily made, equipment may be encountered with lower frequency crystals, followed by a multiplier. Tripling was usual here. Thus a 9.007 MHz crystal, followed by a stage giving 3x multiplication, would provide a transmitter frequency of 27.021 MHz, and so on, for other frequencies.

Colour Channels

By having colour coding of the transmitter frequency, any user can indicate which frequency he is using, by means of a coloured pennant, on the aerial or displayed as convenient. With two or more persons within operating range of each other, the use of different colour channel crystals in the transmitters avoid interaction or interference of control. Superhet receivers are of course necessary, and the receiver crystal is chosen to suit the transmitter frequency in the way described. Thus if it is necessary to change the transmitter crystal because someone is already using it, the appropriate change of crystal must also be made in the receiver (Rx).

Assuming that the receiver intermediate frequency is 455 kHz, and the oscillator operates at a lower frequency, then colour designated frequencies are as follows:

Colour	*Tx*	*Rx*
Black	26.970	26.515
Brown	26.995	26.540
Red	27.045	26.690
Orange	27.095	26.640
Yellow	27.145	26.690
Green	27.195	26.740
Blue	27.245	26.790
White	27.275	26.820

Where equipment is being constructed for isolated individual use, it is convenient to employ a channel or other frequency around the middle of the band.

Tone Generator

This circuit places an audible tone on the transmitted signal. Tr1 and Tr2 in Figure 8 form the audio oscillator, and the frequency is largely determined by the resistor and capacitor values here, but is also influenced by the battery voltage. The collector of Tr2 drives Tr3 in and out of conduction, and the power amplifier of the radio frequency section, described earlier, has its emitter circuit connected at E.

When Tr2 is conducting, Tr3 is cut off, so that current is not available for the PA. When Tr1 is conducting and Tr2 cut off, Tr2 collector moves positive, so positive bias at Tr3 base allows Tr3 to conduct, providing current for the PA.

With a superhet receiver providing a quiet background in the absence of any RF signal, it is practical to switch on and off the whole transmitter, for control methods operated by slow pulses. This means that a push-button switch (or other device giving more realistic control) can be used in one battery lead, and the transmitter only draws current during the brief intervals when this provides contact. Among the simplest methods are those where, as example, one brief pressure on the switch gives motion straight ahead, two presses turn right,

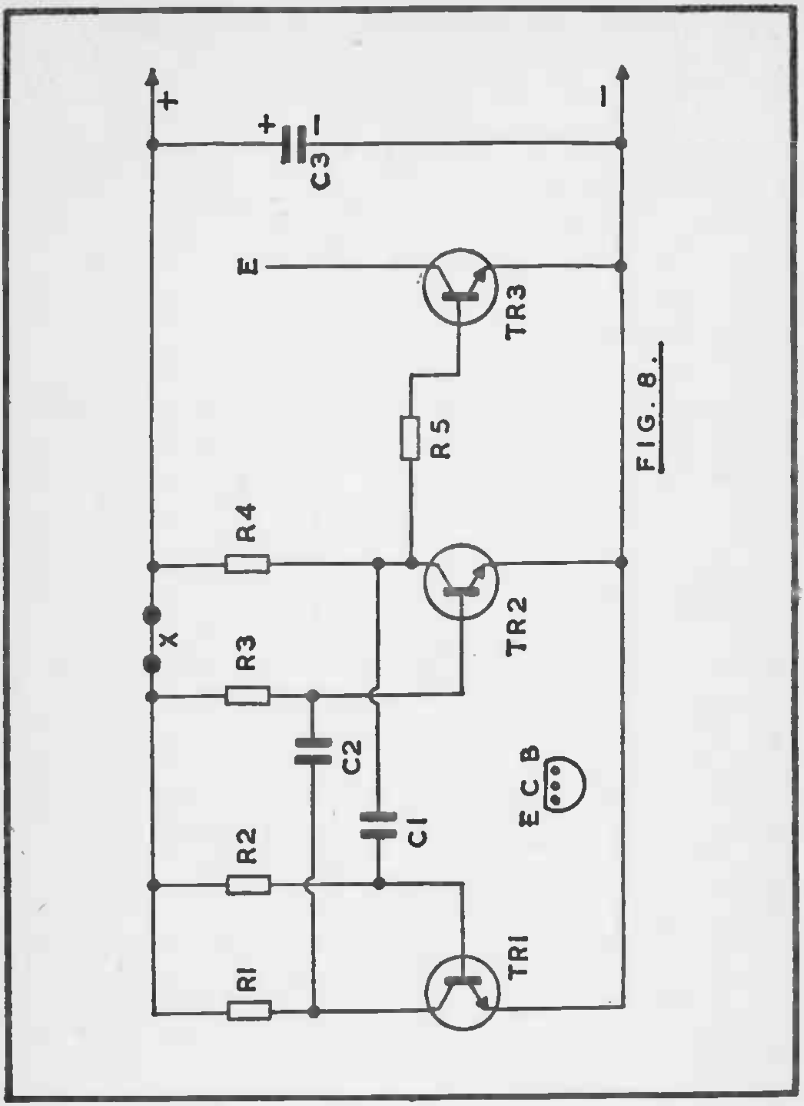


FIG. 8.

and so on.

In other cases it is necessary to have the transmitter carrier wave running for the whole of the time the model is in operation, and to place the audio tone on this carrier, for control purposes. An example of this arises with a super-regenerative receiver, where noise or oscillation above

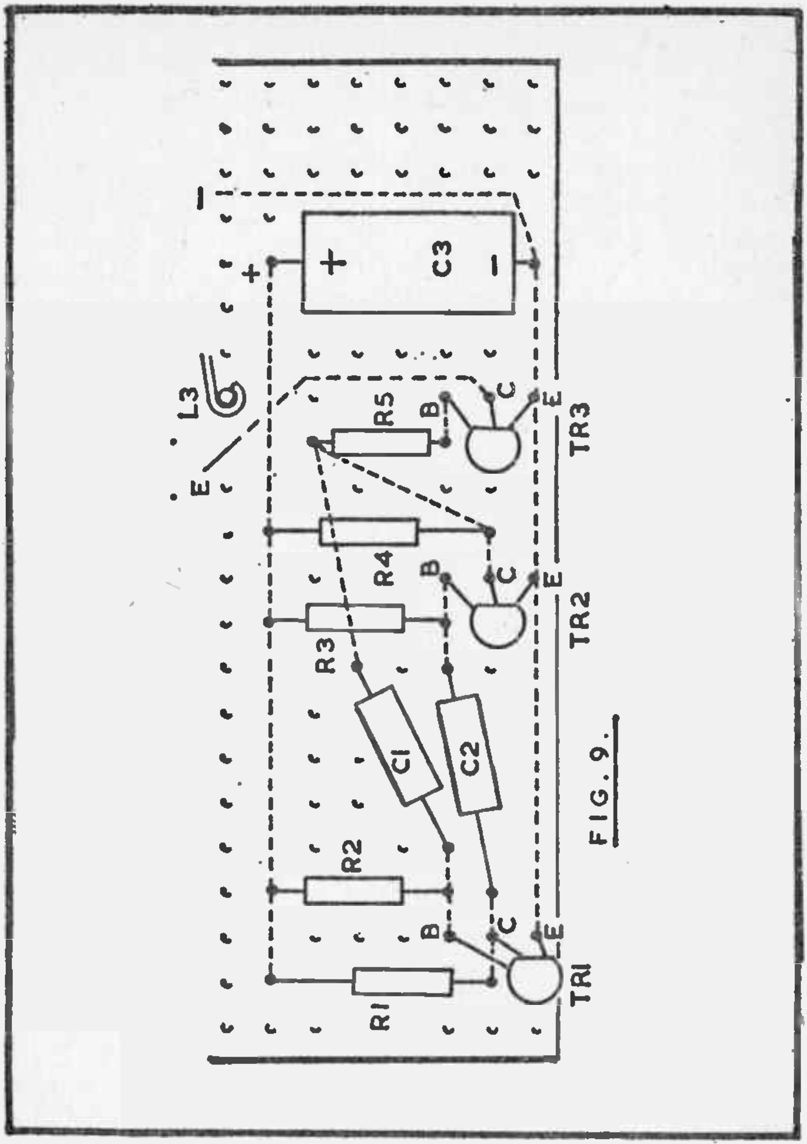


FIG. 9.

audibility may trigger circuits intended to be controlled by the audio tone.

By interrupting the circuit at X, Figure 8, the positive line to Tr1 and base of Tr2 is opened. In these circumstances Tr2 does not conduct, and Tr3 receives base current through R4 and

R5, so that the PA of the RF section operates. There will then be an ordinary on-off switch in one battery lead, and a push-button (or other control device) connected to X.

Components are assembled on the remaining space on the 22 x 15 hole board, as in Figure 9. Leads for the transistors are shown in Figure 8.

Run an insulated wire under the board from Tr3 collector C to the emitter circuit E of the RF power amplifier. Connect negative and positive circuits from C3 to the RF section.

With the RF section tuned up as described earlier, and operating into a lamp or aerial, and a 9v supply, listen for the tone. This can be done by plugging medium or high impedance headphones into the socket of the wavemeter/monitor described. Failing this, connect the phones to a loop consisting of a turn or two of insulated wire, with a detector type diode in series, and bring this towards the PA coil L3. A strong audio tone, of fairly high pitch, should be heard. Should RF be present, as shown by the lamp or wavemeter, but no audio tone be heard, check Tr1, Tr2, R1 to R4 and C1, C2. If RF is absent, suspect R4, R5 or Tr3.

If pins or leads are provided at X, for a push-switch, this will allow the tone to be included or not. The RF output (shown by lamp brightness or wavemeter reading) will change slightly between the unmodulated carrier and modulated carrier states.

Components: Tone Generator (Figure 8)

R1	1.5k
R2	22k
R3	22k
R4	1.5k
R5	1k
	(Resistors 5% ¼W)
C1	22 nF
C2	22 nF

C3	100 μF 12 v electrolytic
Tr1	2N3704
Tr2	2N3704
Tr3	2N3706

Transmitter Case

Current may be drawn from a PP9 or similar 9 volt battery, which is about 2½ x 2 x 3 in (64 x 51 x 76 mm) and this and the transmitter board can be accommodated in a metal case approximately 5½ x 3¾ x 2 in (140 x 95 x 51 mm) inside dimensions, as in Figure 10. This allows the equipment to be easily carried, and to be operated in the hand, with the telescopic aerial extended.

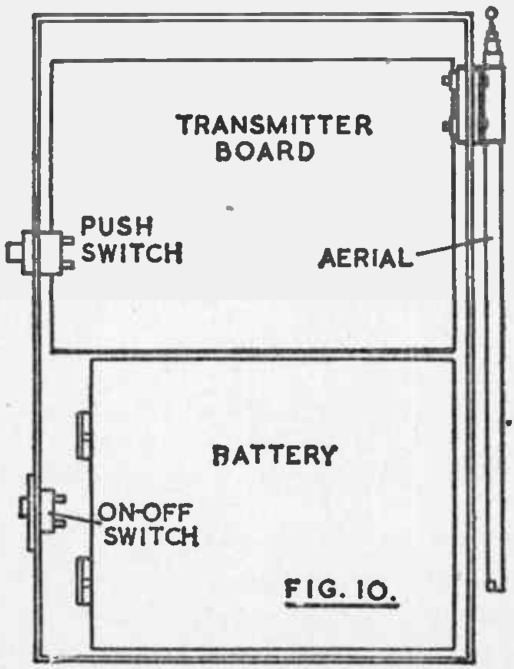


FIG. 10.

A slide switch provides for complete on-off, with a push button for momentarily blipping on and off the audio tone, as described. Where operation is going to be with carrier and tone always on or off together, the push switch is used, as battery current is automatically saved when this is released. Where the carrier is to run during the period of operation of the model, remember to open the battery circuit on-off switch after use.

The board is mounted by two 6 ba or 8 ba bolts long enough to take extra nuts, and leave clearance between the underside of the board and the box. The latter is common to the negative or earth line.

The aerial is completely isolated from the case, with bushes or strips of insulating material, fixing bolts passing through clearance holes. Telescopic aerials can be obtained in various types. Some have a bush and are designed to retract inside the case. If necessary, these can be fitted to a bracket outside.

For reasons of convenience, or because of the range wanted, an aerial of maximum efficiency may not be adopted. Details of aerials are given later.

Other sizes and types of casing may be used, depending on the batteries and other details, and will usually be strightforward.

Mini Transmitter

This is built on a perforated board 14 x 9 holes, or about 2¼ x 1 3/8 in (55 x 35 mm) and with a small 6v or 9v battery pack will give a useful range with the superhet receiver.

Figure 11 is the circuit, using five transistors. Tr1 is the oscillator, whose frequency is controlled by the crystal as previously described. R1 and R2 set the base operating point, with emitter bias by R3. L1 is core-tuned. This stage is decoupled by C1 and R4.

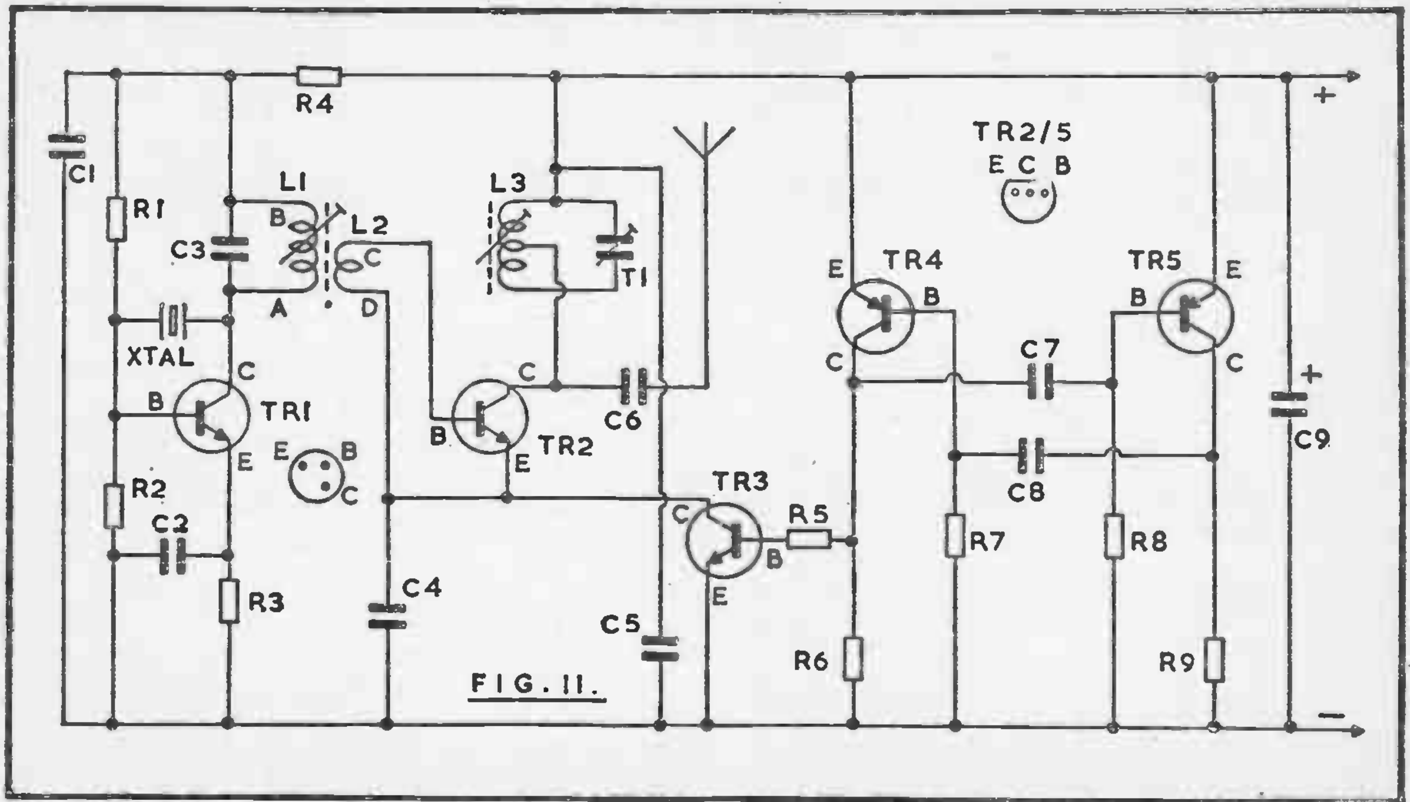

R4
C1
R1
L1
L2
B
C
C3
A
D
XTAL
L3
T1
TR2/5
E C B
TR4
TR5
E
B
C
C7
C8
C
B
TR1
E
E B
C
R2
C2
R3
B
TR2
E
C6
C4
TR3
C
R5
B
E
C5
R6
R7
R8
R9
C9
+
−

FIG. 11.

L2 couples RF energy to the amplifier Tr2, and L3 is the collector coil, tuned by trimmer T1. A common centre-tap is used for the collector and C6, which couples to the aerial.

Tr3 is the series modulator for Tr2, and its base is driven via R5 by Tr4, of the tone-generator Tr4/Tr5. Note that Tr1, Tr2 and Tr3 are NPN, but Tr4 and Tr5 are PNP transistors. The values R6 to R9, with C7 and C8, produce a fairly high tone.

For purposes such as the push-button control of a clockwork actuator, the whole transmitter can be on-off switched by means of a contactor in one battery lead. For high speed circuits, the supply can be interrupted as described elsewhere, to leave the RF section working.

The positions of components can be seen from Figure 12. The coils are wound on 4.5 mm diameter formers about 17 mm long, using 32 swg enamelled wire. L1 is twenty turns, and L2 four turns. Commence at A, near the top of the

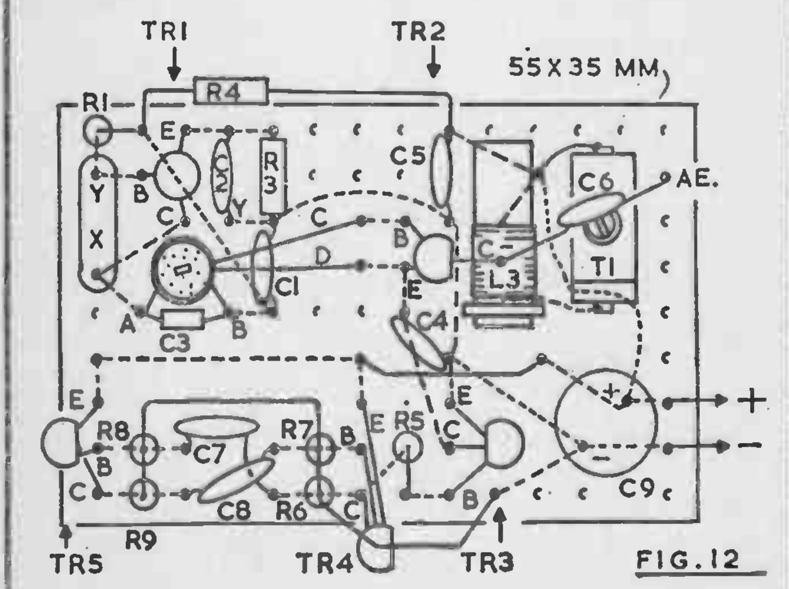


FIG.12

former. After finishing this winding at B, continue for L2 in the same direction, beginning at C, and ending at D. There is no space between L1 and L2.

L3 has seventten turns in all. The centre tap is made by scraping the wire and twisting a small loop, during winding. The ends can be held with touches of adhesive,

Cement L1/L2 in a hole near the crystal holder X. Nearly all resistors stand vertically, in the way explained earlier. C3 is soldered to the ends A and B of L1. Ends C and D of L2 extend over C1 to the base B and emitter E of Tr2, as shown.

When R1, R3, R4, C1, C2 and C3 have been connected as shown, take R2 and cut one lead short, soldering this to the tag Y under the holder X. Position R2 under the board, cutting its second lead to solder to Y at C2.

L3 rests on the board, with the tap on top. Bend the centre lead C of Tr2 upwards to reach this, and solder on here, together with C6. The free end of C6 goes to AE, for the aerial connection.

Note how the leads of the transistors Tr4 and Tr5 cross, to bring emitter, base and collector into the positions shown.

Resistors R6, R7, R8 and R9 stand vertically, and are wired together at the top, and to the negative line. The lead running to the emitter of Tr5 may be disconnected and extended to a switch or other device, if the RF section needs to be left running while the tone modulation is interrupted.

A full on-off switch may be in either battery line. The transmitter can be operated from four 1.5v cells in a holder, or taped together and wired in series, for a 6v pack. Current drain with this voltage is about 30-50 mA., and RF output is sufficient to show with a 6v 0.1 A. bulb. For greater output, a 9v battery can be fitted. Current can be kept down to about 70 mA. by placing a 100 ohm resistor between Tr2 emitter and Tr3 collector.

Adjustments

Temporarily connect a 6v 0.1 A or 0.06 A (60 mA.) bulb from AE to negative at the board, the lower consumption lamp giving the more sensitive indication.

Adjust the core of L1/L2, and trimmer T1, for best brightness of the filament. Adjustments are simplified if the indicating wavemeter coil is near the transmitter board, as this will give a more exact indication than does brightness of the bulb. L3 core can be about one-half in. If necessary, re-set this later so that T1 is not fully open, or fully screwed down. Insulated blades are required for the adjustments.

Phones plugged into the wavemeter socket, or a receiver, should result in the tone being heard strongly. If RF is produced but no tone, check Tr4/5 and associated items. Should no RF be obtained, first check that Tr1 is oscillating, using the wavemeter near L1/2 for this. If there is no indication of RF, check Tr1 and items in this part of the circuit. Should RF be found here, but output from Tr2 to be too small to give a visible indication on the bulb, check Tr2, Tr3 and items here, and tuning of L3.

Final tuning should be with the battery and aerial intended, and the transmitter cased. Aerial mounting, etc., can resemble that shown for the transmitter described earlier.

Components: Mini Transmitter (Figure 11)

R1	47k
R2	10k
R3	100 ohm
R4	100 ohm
R5	2.2k
R6	2.2k
R7	33k
R8	33k
R9	2.2k
	(Resistors 5% ¼W)

Tr1	ME6002
Tr2	2N3706
Tr3	2N3704
Tr4	2N3702
Tr5	2N3702
T1	60 pF trimmer
C1	10 nF
C2	4.7 nF
C3	20 pF
C4	3.3 nF
C5	3.3 nF
C6	1 nF
C7	20 nF
C8	20 nF
C9	100 μF 10v
L1	20 turns
L2	4 turns
L3	17 turns, 4.5 mm dia.

14 x 9 holes, 0.15 in matrix board

27 MHz band crystal and holder.

Batteries

In some cases transmitter battery voltage can be chosen to suit the range wanted. Thus if the Tx is intended for 12v, a 9v supply might be used for reduced power.

For low initial cost, ordinary dry batteries can be used. Typical 9v batteries are the PP6 and PP7, and larger batteries are available. Holders taking four 1.5v cells are useful for 6v, and two such packs in series provide 12v. SP11 and HP11 cells have useful capacity, but both smaller or larger cells can be used. Large batteries are not normally required, as current drain is fairly small, and a lighter and more compact Tx is possible with small batteries.

For much use or experiment at home or workshop, a mains power supply is convenient. A higher voltage than given should not be used with a transmitter unless a check has been made that transistors or other items will not be over-run.

Somewhat similar points apply to the receiver, except that with most models small 6v or 9v packs will be used, to avoid weight and excess size. PP3 and similar 9v batteries may be used. The actual receiver is likely to draw only a small current. But a power stage operating an actuator (or relay) may impose a much leavier load. Allowing the receiver itself to run from its own separate battery can avoid some troubles caused by relays, motors etc. on the same circuit.

Devices such as secondary relays and actuators can best run from their own batteries, or the propulsion battery. These items may need a fairly heavy current, though only for short intervals. Such devices may operate satisfactorily with a somewhat reduced voltage, but this should be checked if necessary.

Electric propulsion motors vary enormously in voltage and current needs. The same motor could be run from an accumulator or other high capacity supply for a power-boat or speedboat; or at much reduced speed from dry cells, for a cruiser or tug. With some models high speed would be out of keeping. Electrical propulsion has many advantages for boats, but is most economical with light craft and modest speeds. A range of voltages may be indicated for a motor, such as 4v to 12v. Thus a 3-cell (4.5v) or 4-cell (6v) pack would be economical, with modest speed, while a pack with more cells, or a battery able to maintain 12v on load, would give maximum power. With some circuits it is convenient to change voltage, such as from 6v for normal speed, to 4.5v or 3v for half-speed.

Where economy is in view, a permanent magnet propulsion motor can be used. This is also reversible by reversing the polarity of the supply to it.

Control of a model can be lost by the failure of a battery. Whether this is likely to result in loss of the model, or damage to it, depends on other circumstances. Where the model can be retrieved unharmed, battery failure may not be very important. Otherwise battery checks and replacements are necessary regularly.

Power Input, Output

No power amplifier has 100 per-cent efficiency, so if input is under 1.5 watts, output cannot exceed that allowed. Input is VI, or Volts *times* Amperes. Thus if the equipment has a 9v battery and the power amplifier draws 50 mA., its input is 9 x 0.05, or 0.45W or 450 milliwatts. If the PA drew 100 mA. from 12v, its input would be 1.2W.

Typical actual efficiencies of about 60 per-cent to 70 per-cent are very good. A transmitter power of under 0.5W is often easily more than adequate for many purposes.

Should output power ever be required, it may be found by squaring the output current, and multiplying by the load impedance. Thus if 100 mA. were found to flow in a 45 ohm load, power output is 0.1 x 0.1 x 45 = 0.45 watt. An RF meter is used to show current.

RF power may be estimated by using it to light a bulb, and finding the DC power input (VI) needed for equal brilliance.

With a grounded quarter-wave aerial, an approximation can be found by squaring current in Amperes and multiplying by 40. (This assumes the load presented by the aerial is about 40 ohms, and is matched).

Output measurements are only likely to be wanted (a) to find how efficient a circuit is, or (b) when wishing for some reason to use full permitted radiated power. Where an aerial provides gain, this has to be allowed for, so as not to exceed the permitted radiated power.

Transmitter Aerials

Telescopic aerials are commonly used for convenience. Typical lengths include 160 mm extending to 790 mm (31 in) and 190 mm extending to 1200 mm (48 in). They may have a threaded base; a threaded projecting stud to take a nut, or a bracket, or sliding fitting for retraction into the case.

An aerial which is a half-wave long at the working frequency is an efficient radiator (it would generally be fed at the centre). This is inconveniently long at 27 MHz. An alternative, generally used, is to have the aerial a quarter-wave long, and feed it at the bottom. The other quarter-wave is effectively supplied by some form of ground return, or capacitance effects to earth. For a plain aerial (one not loaded in any way) the height H at A in Figure 13 is then around 8½ feet or a little over 2½ metres. (Some "length" is made up by the connection to it in the transmitter, and by end effect).

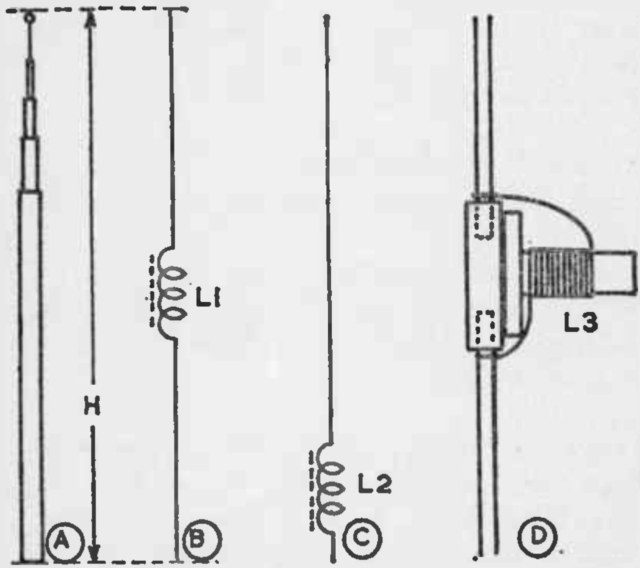


FIG. 13.

Such a length is by no means impracticable. It can be obtained from a long telescopic aerial, or by having one or more screw-on sections at the bottom.

Very often considerably shorter aerials are used, the falling off in radiation efficiency being ignored, since range may well be easily adequate in any case. In such circumstances, it need only be remembered that radiated field strength is reduced, as the length of the aerial is cut down.

Another approach is shown at B, Figure 13. Here, a loading coil L1 is inserted in the aerial. Its purpose is to increase the electrical length of the aerial, to improve its radiation without lengthening it. There are conflicting requirements for the position of L1, and it can generally be near the middle of the aerial. With a short aerial – say about 1 metre for H – B may double the field strength reading, compared with A.

D shows one way of making such a loaded aerial. L3 has 25 turns of 28 swg enamelled wire, side by side on a 7 mm (9/32 in) diameter former. A piece of insulated tube, or rod 1 in long drilled each end, forms a support, and L3 is cemented to this. The bottom rod can be 19 in (485 mm) and the top 22 in (560 mm) making the aerial about 42 in overall.

To adjust this aerial, set up the indicating wavemeter, with its pick-up aerial extended, at a little distance, to obtain a small reading on its meter when it is correctly tuned. Rotate the core of L3, preferably using a quite long and fully insulated blade, for the best reading on the wavemeter. This corresponds to best signal strength.

Sometimes a loading coil may be positioned at the bottom of the aerial, L2 at C. It may be inside the case, between the transmitter output stage and aerial. Here, it does not contribute to improved aerial efficiency by artificially lengthening the aerial, as at B, but it does allow the impedance of the load at the feed point of the output stage to be adjusted. For this reason, it can bring about some increase in signal strength.

With a small hand-held transmitter, a short (possibly loaded) aerial is more appropriate and convenient. Where the transmitter stands in a case on the ground or some convenient support, it can be convenient to have a longer, vertical aerial.

With a transmitter which is self-contained, held in the hand, the radiated field strength may be increased by having about 6 ft (or 2m) of flexible or other wire, attached to the case and negative line, hanging downwards to the ground. This tends to change the system into a centrally driven dipole. The increase in strength is best observed with the field-strength meter/monitor, as already described.

For normal operation, the transmitting aerial is roughly vertical, and this provides about equal radiation in all directions. Field strength is greatest at any point about at right angles to the aerial, and at a minimum about in line with the aerial, but there is normally no sharp maximum or minimum.

An increase in field strength can be achieved by an aerial or loading circuit which causes the power amplifier to draw more current and deliver more RF energy effectively. Increases in range from this cause may be considered distinct from those where power remains the same, but the aerial is able to radiate it more effectively.

Except with an insensitive receiver, extremely small receiver aerial, or need for great range, maximum power and maximum effective radiation of the power produced will not be necessary. But with a given set of equipment, improving the transmitting aerial, or power amplifier output, are obvious steps to take if range is to be increased.

Receiver Aerials

For reasons of convenience and appearance these will often not be of anything like optimum efficiency in providing maximum signal strength for the receiver. Despite this the range obtained with a superhet receiver of normal sensitivity is generally easily sufficient.

With some boats, a vertical rod aerial is not out of keeping. A yacht may conceal a similar style of aerial, of insulated wire, taped to the mast. Elsewhere, it may be possible to use wire instead of cord in some position, not necessarily vertical. In terms of signal pick-up, a vertical aerial rising to some 8 ft or so overall above the water, would be excellent, but often impracticable. An actual aerial is more likely to be some 12 in to 24 in or so, though longer may be possible.

A vertical rod aerial is appropriate for some vehicles, such as military models (tank, armoured car, etc.) where one or more aerials would often be present for communication. Again, length increases signal strength at the receiver, but cannot become too inappropriate for the model.

Telescopic aerials may close down into the model, or may be of the hinged type which fold flat when closed. A rod may be plug-in or arranged to screw into a threaded terminal hole. It can be stout steel wire, 1/8 in (3½ mm) steel or brass rod, or anything convenient. Fit a small bead, ball or ring to the top (to protect the face when bending over the model).

It is possible to conceal a receiver aerial by arranging it as a boat deck rail. Vehicles which may be followed or only run quite a small distance from the transmitter may have aerials inside a body of insulated material.

On aircraft, wire aerials may be extended from wingtip to tail, or from a support above the engine and radio position back to the top of the tail. Alternatively, the aerial may be inside some part of the model.

A superhet receiver is not normally touchy regarding its aerial, though the first circuit, or aerial coil, should be tuned with all equipment in position, and the actual aerial which will be employed. This adjustment can best be done at some distance, where the peak in tuning is easily found in the way described. Such receivers can continue to function correctly despite movements of the hands or other parts of the model near the aerial.

The super regenerative type of receiver is generally critically responsive to changes to the aerial, both as regards its length, and position relative to the person adjusting it, or parts of the model. This arises because the aerial influences regeneration, upon which working of this kind of receiver depends.

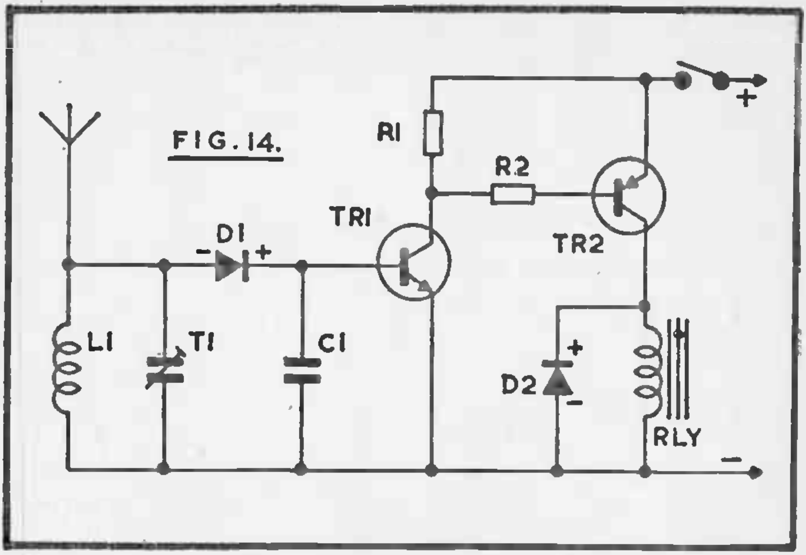
It should be appreciated that the strength of the radiated signal falls off as the distance to the transmitter increases. If damage to a model can arise from loss of control, a test must always be made in advance, at full range. Maximum range is influenced by all the factors of the equipment. At the transmitter, these will be power generated, amount of power radiated, radiation in the direction of the model, influence of surroundings, and similar points. At the receiver, the limit at which the available signal can be used will depend on aerial efficiency, signal pick-up influenced by surroundings, receiver sensitivity, and the adjustment of any operational devices such as relays.

Diode Carrier Receiver

This receiver is not intended for use at the ranges normally associated with radio control, but is of very simple type, and operates from the unmodulated carrier. The transmitter may also thus be of the simplest type. It is intended only for indoors, or in a garden or similar situation where a relatively slow-moving model will be followed on foot, or for demonstration purposes.

Figure 14 is the circuit. Normally Tr1 is not conducting, so there is no voltage across R1. Emitter-base potential of Tr2 is similar, so the relay is not energised.

With a received signal, D1 provides positive bias for the NPN



transistor Tr1, which passes collector current through R1, moving the base of the PNP transistor Tr2 negative. R2 serves to limit base current. Tr2 thus passes collector current, energising the relay. Its contacts can control any usual actuator circuit. D2 is to suppress back emf developed in the relay windings.

The receiver can be assembled on a tagboard, or small perforated board. L1 can have fifteen turns of 24 swg enamelled wire, side by side on a 10 mm or 11 mm diameter former. T1 can be 30 pF. Any point contact detector type diode may be fitted for D1. Tr1 must be NPN, and needs high current gain (an example is the BC109, hfe 240/900). Tr2 is PNP (such as AC142). D2 is 1N4001.

C1 may be 2 nF, R1 3.3k, and R2 1k. At a distance providing 5 μA reading on a meter clipped across C1, Tr1 collector current should be 0.25 mA. or so through R1, and Tr2 collector current with a 200 ohm relay, around 25 mA., when employing a 9v battery. Other relays will be suitable, as explained elsewhere.

Tuning consists merely of adjusting T1 for maximum current, at a distance of a few feet, and a meter set to its 10v range can be clipped across the relay to check this. Tuning must be done with the aerial attached and extended. If the aerial is longer than about 20 in, T1 will need to be very near minimum capacitance. If so, remove a turn from L1.

The range of this simple receiver is very small, as mentioned. For normal purposes, a very much more sensitive receiver circuit is needed.

Super-regenerative Receiver

A super-regen receiver is easier to build than a superhet, as a single regenerative detector replaces the mixer, oscillator, intermediate frequency amplifier and detector of the superhet. As it needs fewer components, its building cost is less. The advantage of relative simplicity is obtained at the cost of the usual limitations of regenerative detectors. It lacks the stability of the crystal controlled superhet, and is influenced by the aerial length, and may have some hand capacity effects. It is also relatively unselective, so can respond to a transmitter other than that proper to the model concerned.

Figure 15 is the circuit of a 4-transistor super-regenerative receiver. Here, Tr1 is the detector. Tr2, Tr3 and Tr4 are audio and current amplifiers, and may be found in this or similar circuits in this part of a superhet receiver.

L1 couples the aerial to L2, tuned by the trimmer T1. T2 is a trimmer from drain to source of Tr1, adjusted for best regeneration of the individual transistor. As excess regeneration can produce output from this stage which may operate the relay (instead of this being operated only by the transmitter tone) a pre-set potentiometer VR1 is provided, to allow setting regeneration in Tr1. R2, R3, C4 and C5 are the quench and audio network, providing an audio signal at C6.

Tr2 is an audio amplifier, the audio signal being developed

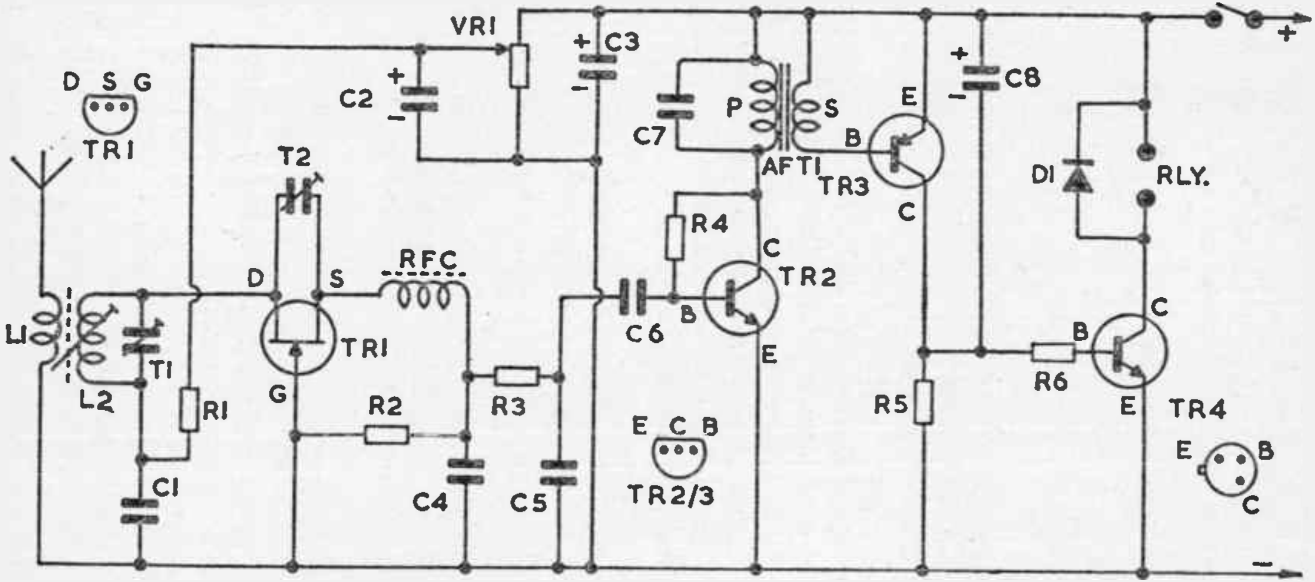

D S G
TR1
VR1
C2
C3
T2
P
S
C7
AFT1
E
B
TR3
C
C8
D1
RLY.
L1
L2
T1
R1
D
S
RFC
TR1
G
R2
R3
C4
C5
C1
R4
C
TR2
C6
B
E
E C B
TR2/3
R5
R6
B
C
E
TR4
E B
C

FIG. 15.

across the primary P of the audio transformer AFT1. In the absence of a tone, Tr3 is not conducting. When the tone is present in the secondary S, negative peaks drive Tr3 into conduction, so that a voltage arises across R5, and the base B of Tr4 moves positive. Tr4 collector current rises, to operate the relay.

Tagboard Assembly

Figure 16 shows assembly on a tagboard approximately 38 x 64 mm. Some reduction in size would be possible if wished, but tends to make wiring a little difficult.

L1 is eight turns of 32 swg enamelled wire near the bottom of a 4.5 mm or 5 mm diameter former 18 mm long, and L2 eighteen turns, also side by side and just above L1. Cement the coil on a small block of insulated material at tag 2. Take L1 to tags 1 and 2. Tag 1 is the aerial connecting point. Connect L2 to tags 3 and 4.

T1 solders from 3 to 4, and T2 between tags 4 and 5. Trimmers of the type requiring several complete turns are preferable. Join tags 2, 20, 15 and 12. Also 7, 9 and 18.

Locate Tr1 leads from Figure 15 and solder to C1, RF Choke, and a lead passing to 4. Take R1 from 3 to 19, C2 from 19 to 20, and C3 from 18 to 20, observing polarity.

Connect outer tags of VR1 to 18 and 20, and wiper to 19. Take RF Choke, R2, C4 and R3 to 16. Complete wiring of these to negative line as shown, and connect C6 from 14 to tag 17.

Check this part of the wiring carefully. If wished, this stage can be tested with high impedance headphones. To do this, clip the phones to tags 14 and 12. Connect a 9v battery. With the transmitter tone on, rotate the wiper of VR1 from tag 20 end, until a hiss commences in the phones. T2 will probably best be nearly at minimum. Set T1 at about half capacitance,

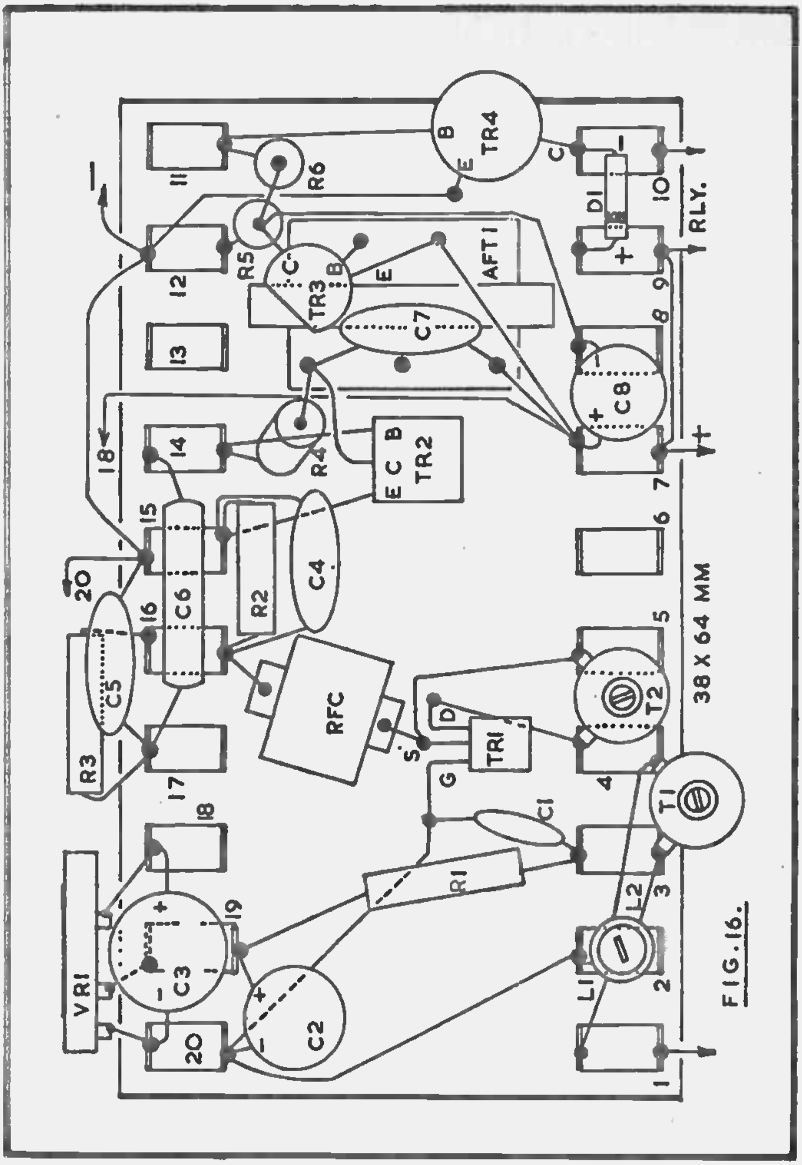


FIG. 16.

and rotate the core of L1/L2 until the transmitter tone is heard. The transmitter RF output only (no tone) should silence the hiss, but the hiss will recommence when the transmitter is completely off. The wavemeter described will show the presence of RF in L1/L2.

The audio amplifier is Tr2, AFT1, and associated items. Cement AFT1 to the board. Connect Tr2 emitter to 15 and base to 14. R4 is from 14 to collector, at the primary tag of AFT1. C7 is across the primary. The other primary tag is connected to 7 (positive line). When this stage is completed, clip phones to the secondary of AFT1, and re-check as described earlier.

To fit the direct current amplifier, take C8 to 7 and 8 (note polarity) and D1 to 9 and 10 (again note polarity). Tr4 collector goes to 10, and base to 11. Extend the emitter lead E to 12. Join R5, R6, Tr3 collector and 8. R5 goes to 12, and R6 to 11. Complete wiring as shown.

A test-meter, set to a 100 mA. or similar range, will be required to check working. Clip this to 9 and 10 with a 150 ohm or similar resistor (to limit current) in series.

The aim is to secure a rise in current when the transmitter tone is on. Initial tests for rough adjustment can most conveniently be made without aerials, and with transmitter and receiver near each other. It will then be necessary to fit the actual aerials which will be employed, and to move the receiver progressively to a greater distance. Several points must be noted, as all super-regenerative receivers tend to be touchy in adjustment.

(1) Settings are non-critical and easy near the transmitter, where the signal is strong, and grow more and more critical as range is reached. Eventually a point arises where no further adjustment can provide control, and this is the maximum range with the aerials and transmitter power.

(2) A completely insulated tool should be made for L1/L2 core, and T1 and T2. This can be plastic rod or anything similar, filed or cut to engage these items.

(3) Regenerative hiss may produce a voltage across R5, and hence current at 9–10. This may be above audibility, but is suggested as a defect if it ceases when VR1 is turned to reduce

Tr1 drain voltage. With some transformers it may be worth changing the value of C7, or increasing this if the tone is not very high in pitch. This reduces sensitivity to the regenerative hiss, while not much affecting response to the transmitted tone.

(4) Final adjustment of the receiver has to be with the actual aerial, etc., as installed in the model. A self-supporting, vertical aerial is excellent for most ground and water models.

(5) If satisfactory regeneration is not obtained with any settings of VR1 and T2, try changing the aerial length; or adjusting the core of L2 and re-tuning with T1 (to alter the L/C ratio).

Current for the relay circuit can be drawn from a separate battery, such as that operating an actuator. Various relays which have a coil of some 100 to 250 ohm resistance may be used.

Components: Super-regenerative Receiver (Figure 15)

R1	1k
R2	10k
R3	15k
R4	270k
R5	1k
R6	680 ohm (Resistors 5% ¼W)
VR1	20k pre-set potentiometer
C1	1 nF disc ceramic
C2	22 µF 10v electrolytic
C3	100 µF 10v electrolytic
C4	5 nF disc ceramic
C5	10 nF
C6	0.1 µF
C7	10 nF
C8	10 µF 10v electrolytic
T1	30 pF trimmer
T2	30 pF trimmer

RFC	1.5 mH miniature cored choke
L1/L2	see text
Tr1	MPF102
Tr2	2N3704
Tr3	2N3702
Tr3	2N3053
D1	1N4001
Board approx. 38 x 64 mm with 20 tags	
AFT1	6:1 ratio (or similar) miniature audio transformer.

Superhet Receiver

Because of its stability and sensitivity, a crystal controlled superhet receiver is almost invariably used. Such a receiver has good range and will operate reliably without tricky adjustment. It is not "touchy" as regards the length or position of the aerial, and has enough selectivity to respond to intended signals only, so that more than one model can be operated simultaneously. These features normally justify its choice.

Figure 17 will clarify operation of the receiver. Signals picked up by the aerial pass to one gate of the dual-gate 40673 mixer,

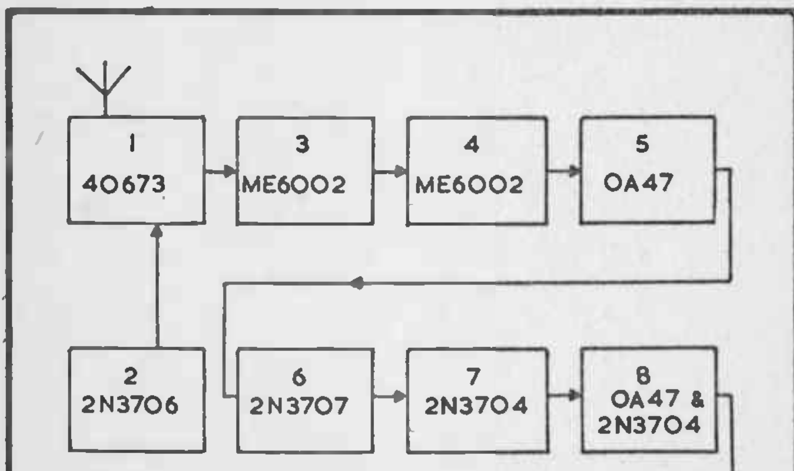


FIG. 17.

section 1. Section 2 uses a 2N3706 as a crystal-controlled oscillator and its frequency is approximately 450 kHz to 470 kHz different to that used by the transmitter. This oscillator is controlled by its crystal, just as the frequency of the transmitter is governed by the crystal fitted to the latter. Correct working, without tricky tuning, or drifting off frequency, is thereby assured.

Aerial and oscillator signals are mixed in section 1, and pass to the first intermediate frequency amplifier, section 3. This uses the ME6002, an alternative being the BF195 (with base connections to suit). The IF transformer is of the kind used in miniature transistor receivers, with an adjustable core. This core is set to peak up reception of the transmitter signal. E.g., the IFT is tuned to the difference in frequency between transmitter and oscillator 2.

Amplified signals pass to the second IF amplifier, section 4. This has a similar IF transformer, also core tuned.

From here, the amplified signal reaches section 5, where a diode acts as demodulator to recover the audio tone provided at the transmitter. This diode also supplies an automatic volume control voltage to section 3, to reduce gain when signal strength is high.

The audio signal passes to the first audio amplifier, section 6, and from here to the second AF amplifier, section 7.

Output from section 7 is used to obtain positive base bias for the 2N3704 in section 8, by means of diode OA47. The 2N3704 passes collector current when the audio tone is present, so operating the relay. This, in turn, controls the steering or other actuator.

With a superhet, the frequency of the oscillator is the critical factor, and this is set in the manner explained. Thus the only adjustments are to the cores in section 1, 3, 4 and 5, and these are of a straightforward nature, readily carried out in practice, as they are to secure the largest current, as shown by a meter in series with the relay.

There is no need to leave the transmitter carrier running, with this circuit. So its push-button, for simple escapement type work, can control the battery supply. This minimises battery drain, and makes it impossible to leave the battery on, as explained.

If wished, it is fortunately very easy to test oscillator, mixer, IF, detector, and other stages one by one, as they are assembled on the board. This avoids wiring up the whole receiver, and perhaps having to trace a fault due to an omitted connection or some other defect.

To keep size down, low voltage disc ceramic and other small capacitors are necessary, and small 1/3rd or ¼ watt resistors. It is as well to prepare the board for the three IFTs first, by drilling holes for their pins, and slightly englarging or shaping these with a small file, if necessary, so that no force is needed to insert them.

The receiver itself occupies approximately 85 mm on the board, the extra length being for the relay. The board can be cut shorter with an external relay, or left longer is needed, or only cut off after construction is finished. In this case, grip the unwanted section firmly in a vice, support the wired board with one hand, and saw carefully down a row of holes. It would be possible to reduce the size of the receiver, but it is quite small and can probably be accommodated in most models without difficulty.

All resistors, transistors, capacitors, and the coil, RFC and IF transformers occupy the top of the board, and wiring is underneath, shown in broken lines. Where resistors stand vertically, one lead passes to an adjacent hole, and the other will be directly under the resistor, issuing under the board.

Test instructions are given after wiring directions for each section. To avoid undue cramping, while keeping the whole receiver reasonably compact, the board is approximately

110 x 42 mm, this including the relay. If preferred, the latter could be external to the receiver.

Oscillator

This is Tr2 in Figure 18. C5 provides feedback from collector C to emitter E, and the crystal is from collector to base B. No adjustable tuned circuit is provided, the RF Choke RFC completing the collector circuit. Base current is via R4.

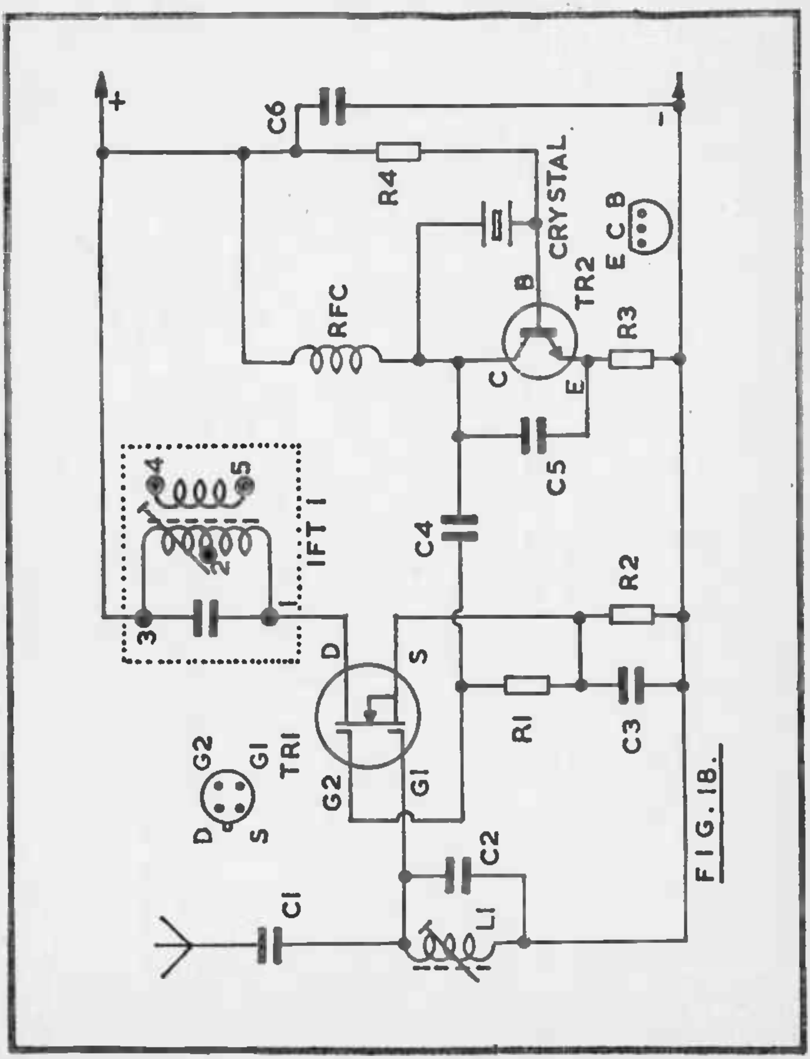


FIG. 18.

The RF choke is 50 turns of 34 swg enamelled wire, side by side on an insulated rod ¼ in (6 mm) in diameter and 7/8 in (23 mm) long. This can be plastic (insulated volume control spindle, or ball-pen case, etc.) and the ends pass through small holes near the ends. Secure with a few traces of adhesive, but do not paint the whole winding.

Figure 19 shows the mixer-oscillator end of the board. The RF choke is glued in place. "X" is the crystal holder.

To wire this stage, insert one or two items at a time, as in Figure 19 then turn the board over, shape and cut the leads,

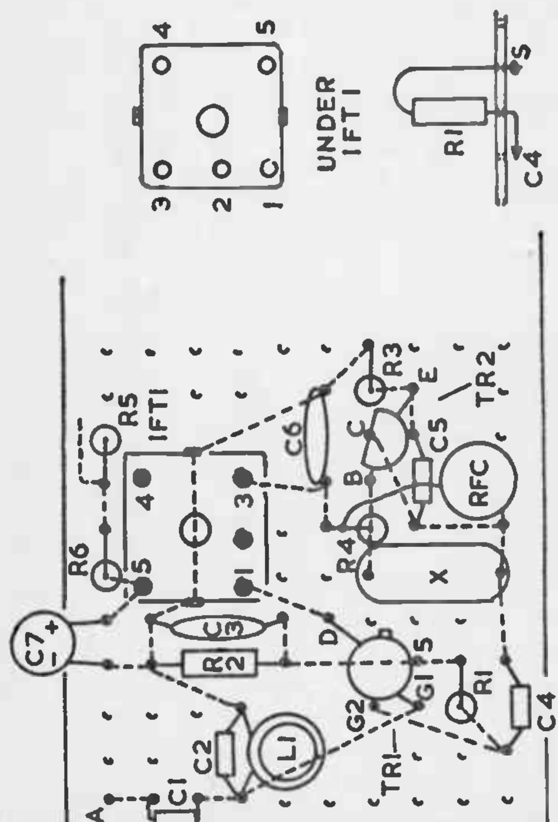


FIG. 19.

and solder the joints. Note collector goes to crystal, RF choke, and C5. C4 may also be added. Base goes to crystal and R4. Take the top lead of the choke to R4 and C6, which will also go to 3 on IFT1, and the positive line. Connecting R3 from emitter to C6 and the negative line completes the oscillator stages.

Assuming this section is to be tested, insert the crystal, and clip on a 6v or 9v battery, observing polarity. If the indicating wavemeter coil described is brought near the RF choke, and tuning on the wavemeter adjusted for best reading, the instrument should show about 50 μA. This indicates Tr2 is oscillating. If no such reading is obtained, check connections and Tr2, as the completed receiver cannot operate until this is corrected.

Mixer

This is Tr1 in Figure 18. L1 is a 9/32 in (7 mm) diameter former about ¾ in (19 mm) long carrying 13 turns of 24 swg enamelled wire. Wind L1 with turns side by side, near the board end of the former, and scrape the ends, taking them down through the holes shown in Figure 19. Solder on C2 in parallel and C1. Point A is a pin or projecting wire, for the aerial connection.

The 40673 is a protected-gate device, so needs no special care when handling, other than to avoid lengthy cooking of the joints. If the iron has reached its full temperature, the solder should flow and form the joint in two or three seconds, and the iron should then be removed at once, as when soldering other transistors.

Similar dual-gate FETs which are not of protected-gate type may be used. These will have a binding of fine wire round the leads, or a small spring shorting these together. This must not be removed until gate-source circuits are completed. That is, L1, R1 and R2 are soldered in. If joints have to be unsoldered, a binding of wire must be replaced first. Without this care, the device can be damaged by touching leads with fingers, or metal or plastic tools.

Note positions of leads from Figure 18, and particularly Gate 2 and Gate 1. G1 goes to L1, and G2 to R1 and C4.

Connect Source S to R1, R2 and C3. Drain D goes to 1 of IFT1. When fitting this and the later IFTs, note how pins are numbered, from the underside diagram in Figure 19. Pins 1 and 3 are the primary, with a tapping 2, and the capacitor shown is included in the can. Pins 4 and 5 are secondary. The can has two tags, and is earthed to the negative line by these.

With the mixer completed as in Figure 19 connect medium or high impedance headphones to 5 of IFT1, and to one of the diodes. Temporarily solder the remaining diode lead to 4 of IFT1. With transmitter and this section of the receiver near each other and switched on, adjust the core of IFT1 to tune in the transmitter tone. Tuning is flat, and volume will not be great. No aerials will be needed.

On no account use a metal blade or wedge-shaped tool for the core, as this may fracture it and cause it to jam permanently in the former. A strip of paxolin, or a plastic knitting needle, may be cut or filed to engage the slot correctly, or the Denco TT5 trimming tool can be used. Also peak up the core of L1 for best volume.

Should the transmitter tone not be heard, check the extra components added, including Tr1 and associated wiring.

IF Amp. & Detector

Figure 20 shows the 2-stage intermediate frequency amplifier and detector. IFT1 is already present. Secondary pin 4 supplies the base of Tr3. Collector output is to the primary of IFT2. This IFT drives Tr3 via C8, with base bias by R8.

Tr4 collector circuit is to IFT3 primary, the supply point being

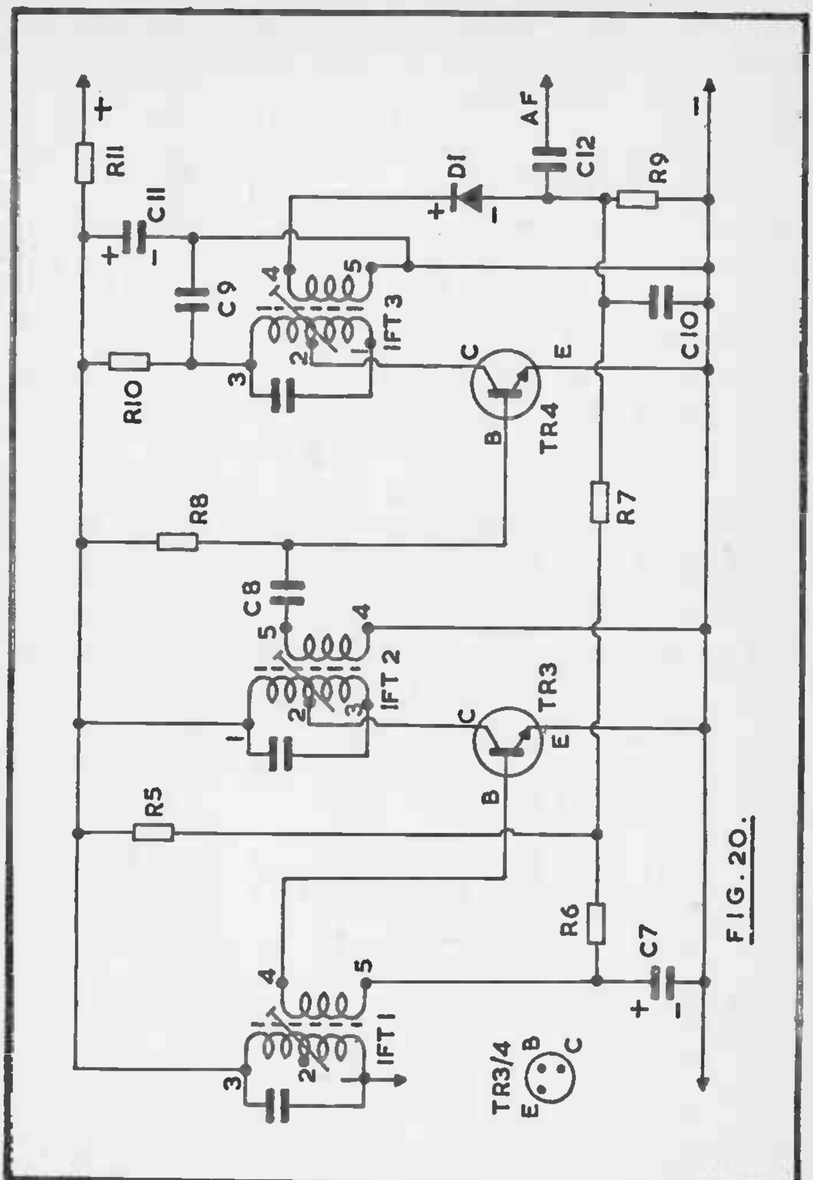


FIG. 20.

decoupled by C9 and R10. The whole positive line is by-passed by C1.

Diode D1 provides detection to make available the transmitted tone, coupled to later stages by C12. A negative bias is also developed across R9, this increasing with signal strength. This shifts the operating point of Tr3 (via R7 and R6) to reduce amplification in this stage.

It is easy to assemble this part of the receiver, before making further tests. That is, IFT2, IFT3, Tr4 and D1, with associated items. The audio tone can then be heard at C12.

Construction Points

The related components can be located in Figure 22. Note IFT2 is reversed, compared with IFT1 and IFT3.

Run the negative line along to the can tags, transistor emitters 4 on IFT2 and 5 on IFT3, C7 negative (see Figure 19), C10 and R9.

Positive runs to 3 of IFT1, 1 of IFT2, R5, R8, R10, R11 and C11, as well as C6 etc. as originally. Underneath wiring is more easily identified by placing red sleeving on these leads. Sleeving is in any case necessary where wires may touch each other, or pins.

D1 must have the polarity shown. Numerous detector type or point contact diodes are suitable, but some have a *black* ring to show positive. With correct diode polarity, a small voltage will arise across R9, with a strong signal input. Use a high resistance voltmeter, clipping positive to earth line, and negative to the junction of R7 with R9.

The optimum value for R11 depends on whether a 6v or 9v supply will be adopted, and the individual gain of Tr3 and Tr4. However, 1k should be satisfactory.

To test this part of the receiver, connect the phones from C12 to negative line. Adjust the cores of IFT2 and IFT3, in the way described for IFT1, for best volume. The transmitter tone should be heard at considerable volume, even at some distance.

Remaining Section

Figure 21 shows the two audio amplifiers, and relay stage. Tr5 is driven by the coupling capacitor C12. Note that this transistor has its supply, via R13, from the positive line from C11 (already present).

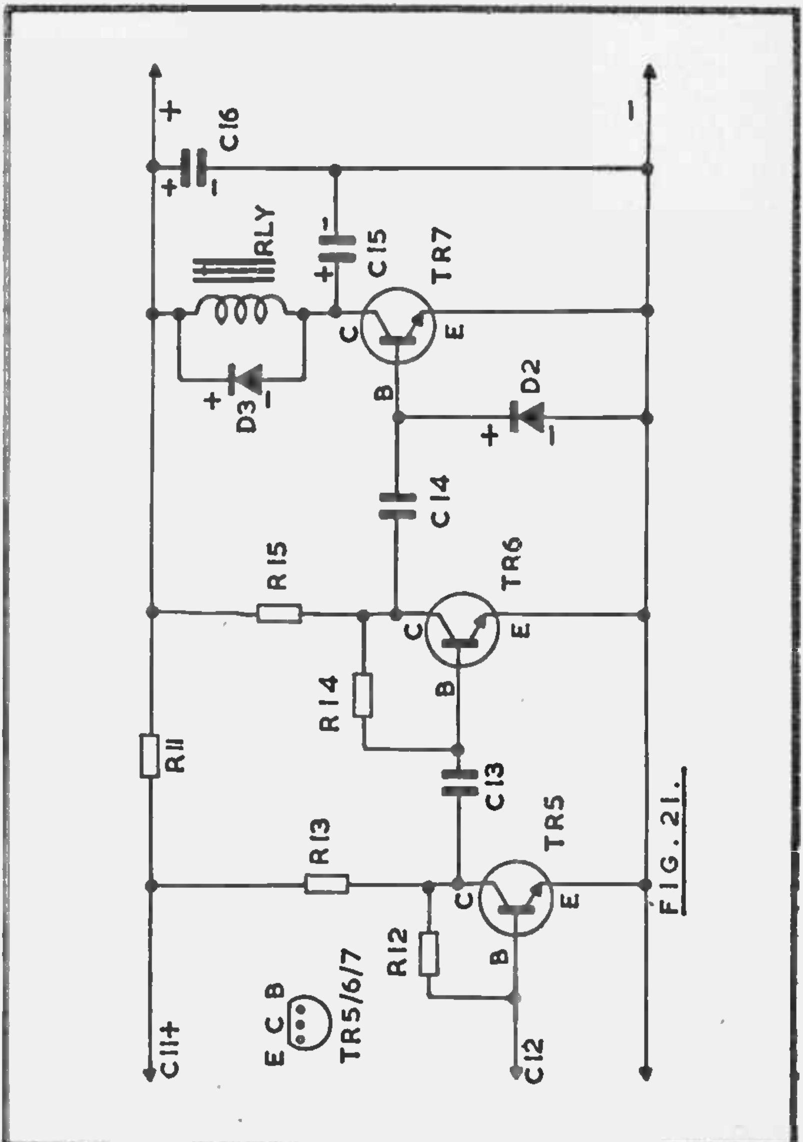


FIG. 21.

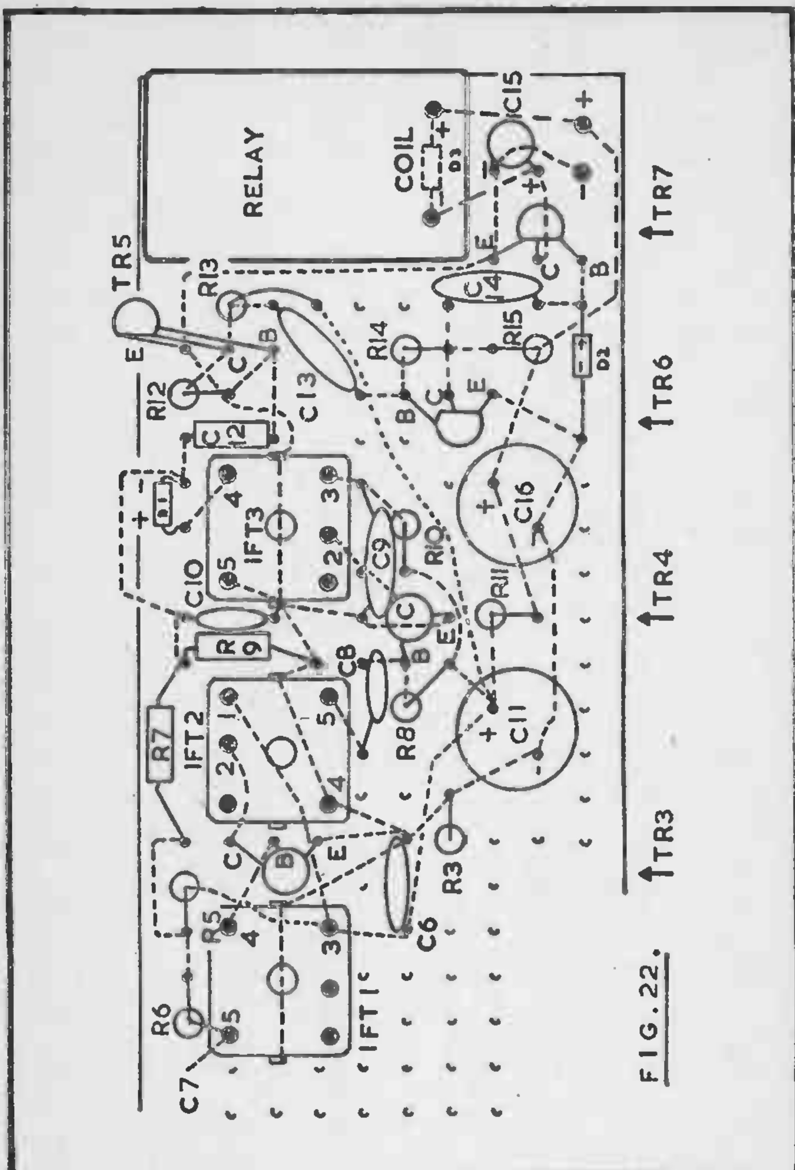


FIG. 22.

The next audio amplifier, Tr6, operates from the 6v battery line. Its output is through C14 to the diode D2. Rectification by D2 produces positive bias for Tr7, so that collector current rises, to energise the relay. Current here is limited by the relay resistance. A relay of about 250 ohms, which will close strongly with some 20 mA. or so, will be suitable. However, other relays can be fitted, as described elsewhere.

The further components for these stages are located on the board as in Figure 22. Proceed first to wire Tr5, with emitter to negative line, base to R12 and C12, and collector to R12 and R13. Add C13 to couple to the base of Tr6.

Tr6 is wired in a similar way. Should it be necessary to test these stages, signals should be found much amplified at Tr5 collector and again much more at Tr6 collector.

There is space for a small relay on the board, but a larger type can be fitted externally. Temporarily include a test-meter, set to a 100 mA. or similar range, in series with the relay coil, for tuning up.

Operating Adjustments

With the transmitter off, relay current (as shown by the meter) should be zero, or nearly so. If appreciable current flows, a signal is reaching D2. This may be generated in the IF amplifier, or arise from instability in the audio stages Tr5 and Tr6. If the current falls to zero when one or more of the IFT cores is slightly de-tuned, IF instability is indicated. This can arise from having unnecessarily long leads to Tr3 or Tr4. It can be cured by placing a small resistor in series with the base or collector circuit of Tr3 or Tr4. Use the smallest value found to stop the trouble. This may be from about 47 ohm upwards, depending on the transistor gain. R11 may also be increased in value.

Instability in the audio section does not seem likely. When current is zero with no signal, tuning is arranged for the maximum current rise, with the transmitter on.

For convenience, initial tuning can be with no aerial on the transmitter (fit a 6v bulb as explained) and a few inches of wire for the receiver aerials, moving the units several feet apart.

Afterwards, L1 core in particular has to be adjusted with the aerial which will be employed. With a 9v battery for the Tx, and a plain transmitting aerial (e.g., not loaded or tuned) roughly 4 ft or 1½m long, and a plain aerial about half this size on the receiver, final tuning up can be at a range of some 50–100 paces or so, in clear space. Both aerials can be roughly vertical. Screening such as by grounded wire netting fences or other items may reduce range.

In circumstances where a model cannot be recovered if control is lost, or damage may arise, full care must always be taken not to exceed the range at which the equipment can be relied upon to operate. A range test or similar check should be made in advance.

Components: Superhet Receiver

Figure 18 (Mixer, Oscillator)

(All Resistors 5% ¼W)

R1	100k
R2	2.7k
R3	1.2k
R4	47k
C1	18 pF
C2	18 pF
C3	4.7 nF
C4	10 pF
C5	22 pF
C6	0.1 µF
L1	13 turns, 7 mm diameter
IFT1	Denco (Clacton) Ltd. IFT13
Tr1	40673
Tr2	2N3706
RFC	50 turns, 6 mm diameter

Miniature plug-in receiver crystal
Holder for same.

Components: Superhet Receiver

Figure 20 (IF Amplifier, Detector)

R5	120k
R6	47k
R7	27k
R8	330k
R9	10k
R10	390 ohm
R11	see text
C7	10 μF 6v
C8	10 nF
C9	0.1 μF
C10	20 nF
C11	220 μF 10v
C12	0.1 μF
IFT2	Denco (Clacton) Ltd., IFT13
IFT3	Denco IFT14
Tr3	ME6002
Tr4	ME6002
D1	OA47, OA81, etc.

(Alternative Tr3/4, 2 x BF195)

Components: Superhet Receiver

Figure 21 (AF and Relay Stages)

R12	1 megohm
R13	15k
R14	470k
R15	8.2k
C13	0.1 μF
C14	0.1 μF
C15	10 μF 10v
C16	220 μF 10v
Tr5	2N3707

Tr6	2N3704
Tr7	2N3704
D2	OA47
D3	OA47
RLY	See Text

0.15 in matrix board 10 x 26 holes.

Front End Protection

Variations in signal strength at the receiver at medium range are compensated for by the automatic gain (or volume) control circuit of the receiver. At increased range, where the AVC is not operating to reduce gain, output falls off until control is lost. At very short ranges, and particularly when adjusting a receiver near the transmitter, the signal strength can be so high that overloading arises. It is for this reason that adjustments of this kind are best made with no aerial on the transmitter, as explained.

The first stage of the receiver can be protected against severe overloading by using two diodes, Figure 23. These have no significant effect at low signal levels, but conduct at high levels.

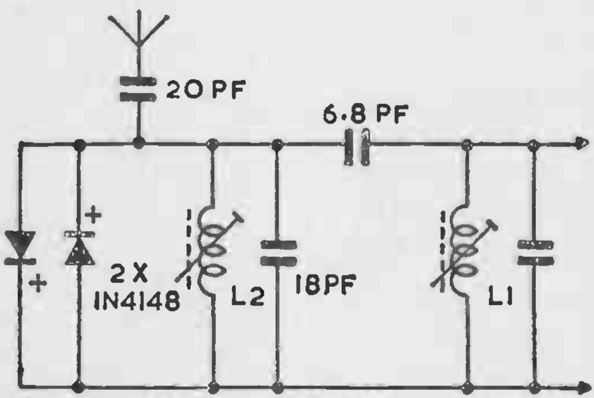


FIG. 23.

L1 is the existing aerial coil, with its parallel capacitor. L2 is 14 turns of 28 swg enamelled wire, side by side on a 7 mm diameter former, with adjustable core. The 6.8 pF capacitor provides top capacitance coupling between the two tuned circuits.

With this circuit, adjust both cores for maximum sensitivity, with the aerial which will be employed. This should be done with transmitter output reduced, or at a distance, where the clipping action of the diodes is not evident.

Receiver Housing

Protection for the receiver can often take the form of a light plastic box. These are available in many sizes, or can be fabricated if necessary. The box can be virtually sealed against the entry of moisture, spray, lubricating oil, etc., with battery, relay and aerial leads issuing through tightly fitting holes. Any trimmer, core, or other adjustment provided on the receiver should be accessible through small holes drilled in the case. These can be covered later with adhesive tape.

Somewhat stronger plastic boxes with lids secured by screws are also available, and can be used when a little extra size or weight is unimportant. Rectangular wiring accessory plastic boxes may sometimes prove suitable.

Greater freedom from electrical interference can be expected with a metal box providing complete screening for the receiver. These are also available in many sizes. Again, holes allowing essential adjustments to be made can be covered with adhesive tape afterwards.

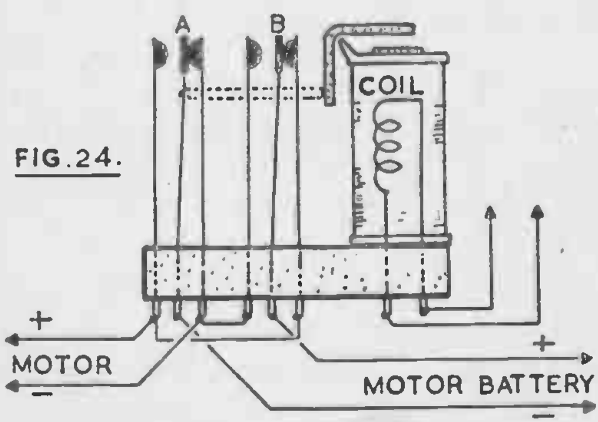
Sometimes a relay is included internally with the receiver. Or this item may be external, in association with the actuators it controls, or may be replaced by transistors serving similar purposes. The receiver battery and switch will be external, conveniently placed. The receiver position should be convenient for the aerial connection, and leave this and the aerial away from other electrical items, if possible. A suitable board or mounting, with strong elastic bands, can generally secure the receiver in its case.

Relays

A relay is an electrically operated switch, and may be used to control an actuator, motor, or other items. The relay may be energised by a low current from the receiver, and switch on a propulsion motor or item needing a much larger current. It can also isolate one circuit from another, or allow a single circuit to control two or more other circuits.

Relays differ considerably in size, design and other features, such as coil resistance and the number of contacts, but Figure 24 will enable operation to be understood. Here, the relay is used to reverse a permanent magnet motor. When no current flows in the relay coil, contacts A and B are as shown. As a result, the polarity of the supply to the motor is as indicated. When current flows in the coil, the core is magnetised, and movement of the armature and insulated push-rod presses contacts A and B to the left. The circuit is then changed, so that polarity at the motor is reversed. When current ceases

FIG. 24.



to flow in the relay coil, the contacts return to the position shown.

This relay is a 2-way 2-pole or double-pole double-throw type. A relay may have fewer contacts, such as single-pole change-over or may have four or more sets of contacts. Unwanted sets of contacts can be ignored, provided a relay is otherwise suitable.

The operating coil of the relay will be of some particular resistance, and this determines its most suitable operating voltage and current. Low resistance coils pass a heavier current than do coils of higher resistance. Many relays will be some 100 ohms to 500 ohms or so, for operation from around 6v to 12v. Some circuits call for sensitive, high resistance relays. Model control receivers often employed relays which could be set to operate with an extremely small current change (under 1 mA.) but transistor amplifiers have generally made these unnecessary.

The current rating of the relay contacts may be only up to 0.25 A. or so, at low voltage, for a small relay. A propulation motor would be expected to require more current than this, so that a relay with contacts to suit would be needed.

In some circuits, capacitors or diodes may be found across the relay coils, to suppress back electro-motive force developed by the coil inductance. This may be necessary where the back emf would damage a control transistor. Contact circuits may also be suppressed, to avoid interference to the adjacent receiver, and avoid sparking and the need to clean the contacts as a result.

A relay can often be adjusted to work over a considerable range of voltage, by careful setting of the spring or contact tension. Further information on relays will be found in "50 Projects Using Relays, SCR's & Triacs" Book No. BP37, Babani Press.

Actuators

The receiver will operate a relay or other power control device (such as a transistor) which can in turn bring into action some mechanism, the purpose of which is to work the controls of the model. The mechanism or actuator may use electrical power to obtain motion, or may employ a wound spring, or twisted elastic.

An electrically powered actuator may consist of a small electric motor, moving a rudder or other means of guidance through reduction gearing. Gearing may consist of worm and pinion drives, a nut system traversing a long threaded rod, and similar means of obtaining a relatively slow action from the rapidly turning motor shaft. The motor may be reversible, or use other means of returning the model to course after turning.

Various solenoid and electro-magnetic devices are also used. A motorised actuator, servo mechanism, or any such system might be concerned with some other item of control, such as speed adjustment or reversing, instead of with steering.

Some actuators can place rudder or guide wheels, as example, in only any of a number of pre-arranged positions. Others allow the complete adjustment of these to any angle, for large radius and sharp turns, and so on.

Actuators deriving power from twisted elastic are most appropriate for simple and light aircraft. Such an actuator may be of the 4-position type with escapement. The plane may gain altitude when flying straight, lose height when turning, and glide to land when fuel is exhausted. For more advanced manoeuvres, a more complex form of control is necessary.

Clockwork escapement actuators have similar uses in steering a boat of simple design. These (as with elastic) can perform a considerable number of actions with one winding, but have to be rewound from time to time.

Some devices have been commercially produced which operate mechanically to make available increased control of the model, even with a simple single-channel set of equipment. As example, a quick or brief signal may immediately release a steering escapement, to change position of the rudder, while a second and weighted escapement may not have time to respond. A longer signal will operate that also, stopping or reversing the motor.

Some of the simpler actuators are not too difficult to make, using toy clockwork motors, small electric motors, constructional toy parts, or other items of similar kind. But the more complex (and smaller) actuators are not easily made, and are more usually purchased ready for use. These may have moving or rotating arms, to be connected to rudders or cranks by links, and so on.

The need for an actuator providing sufficient power output should not be overlooked. Thus a very small, light clockwork escapement, easily able to control the rudder of a small boat, might be unable to move the rudder of a large boat, and could not be used with the latter. Usually alternative pivot or link holes, and similar methods, give some initial adjustment over the degree of movement provided by the actuator.

Rotating Pulser

This is among the simplest devices to give a measure of realism in control of a boat having a 4-position clockwork escapement actuator. It is readily constructed, and replaces the push-button switch fitted at the transmitter.

A panel is marked for Ahead, Right, Stop and Left position, Figure 25. The arm or pointer has a knob, and is fixed to a shaft which also carries the small square cam shown. Two leaf contacts, normally open, are situated near the cam.

When the arm is rotated in the direction of the arrow, the cam rotates in the same way. There is thus one closure and opening of contacts as the pointer moves from Ahead to Right, another as it is moved from Right to Stop, and so on. Rotation of the actuator in the model follows the rotation of the arm on the control box. The rudder and propulsion motor are operated in the way explained. If the actuator has quarter-positions, obtained by magnetically holding the armature, these will be obtained with the rotating arm pointer mid-way between the four named positions.

A pawl may engage with a ratchet wheel on the shaft (or an ordinary toothed gear may be utilised instead) so that the control arm can only rotate in the correct direction. If control arm and actuator are set together when starting, they will remain together until the actuator needs re-winding. The model should be steered in before this arises.

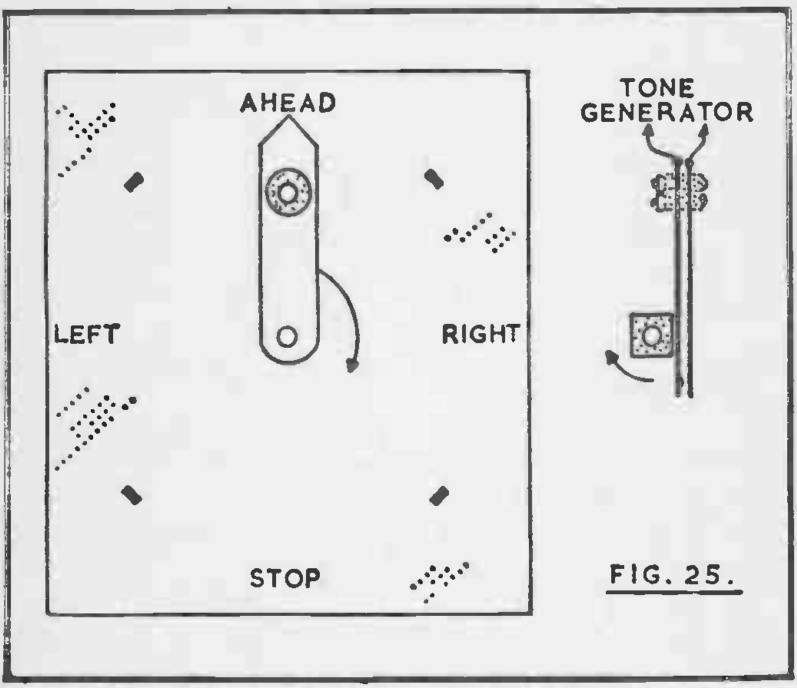


FIG. 25.

Clockwork Actuators

A clockwork actuator offers a simple and economical means of controlling a model such as a small boat. It can be light and small, and as its operating power is derived from a spring, makes no extra demand on the batteries for rudder movement.

Figure 26 is a typical clockwork actuator. The toothed part has four projections A, B, C and D, and the spring wound drive below tries to turn this in the direction of the arrow. Rotation is prevented because tooth A rests against the catch E. E is normally held in this position by a light spring.

When the relay controlled by the receiver operates its contacts close, completing the battery circuit to the electro-magnet of the actuator. E is drawn towards the magnet, releasing tooth A. At the same time, F moves in slightly, catching tooth D. When the relay contacts open, E is released, so tooth B rotates until it comes to rest against E. The rotating part carries a pin, which engages in the slot G of the component H.

Each time E is drawn to the magnet core and released, the pin travels one-quarter of a turn. Thus the arms H can be swung from side to side, or brought to rest as shown (A against E), straight (B or D against E), or in the opposite position (C against E).

Two thin lines from the holes in H, or a single wire, operate

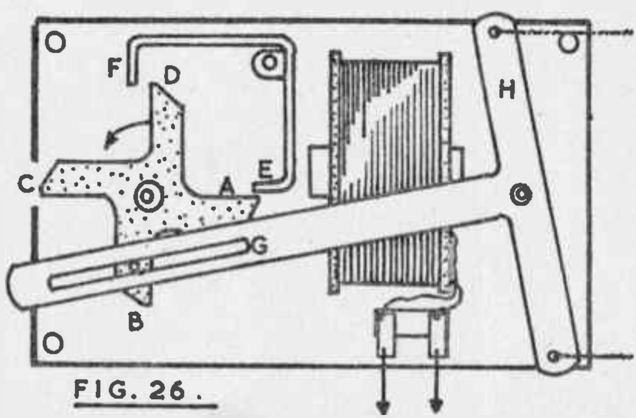


FIG. 26.

the rudder. It may thus be set straight, or to right or left, by movement of the actuator.

The sequence of events arises in the same way: straight ahead, right, straight ahead, left. In use, unwanted settings are flicked through almost instantly, before the model has time to respond.

If the escapement wheel has eight teeth, instead of the four shown, the rotating part can be brought to rest in any one of eight positions. Two of these would furnish half-port, and two half-starboard, thus allowing sharp and half turns.

Actuators of the type in Figure 26 are not very difficult to construct, using a small clockwork motor as a basis. Ends A, B, C and D must be free from roughness, and also ends E and F, and the escapement action should be adjusted so that only a very small movement of E–F is required. Current for the magnet can be drawn from the main propulsion battery, and is required only when E is being held clear of the rotating teeth.

Other Positions

Figure 26 has two straight-ahead positions. One serves no useful purpose, so can be adapted for stop, half-speed, or astern. Figure 27 show methods of doing this.

"A" is a thin leaf spring, and a small insulated cam is fitted to the spindle of the rotating escapement wheel at "B". Contact "C" is so positioned, that when the cam is as shown, the circuit from "A" to "C" is interrupted. This arises at one unwanted straight-ahead position.

At E, the switching thus made available allows the propulstion motor to be stopped. It is then possible to stop the boat, or start it, sailing ahead, or turning either way as wanted.

At F, the switch provided by "A" and "C" leaves a resistor in series with the motor, for half-speed in one straight-ahead

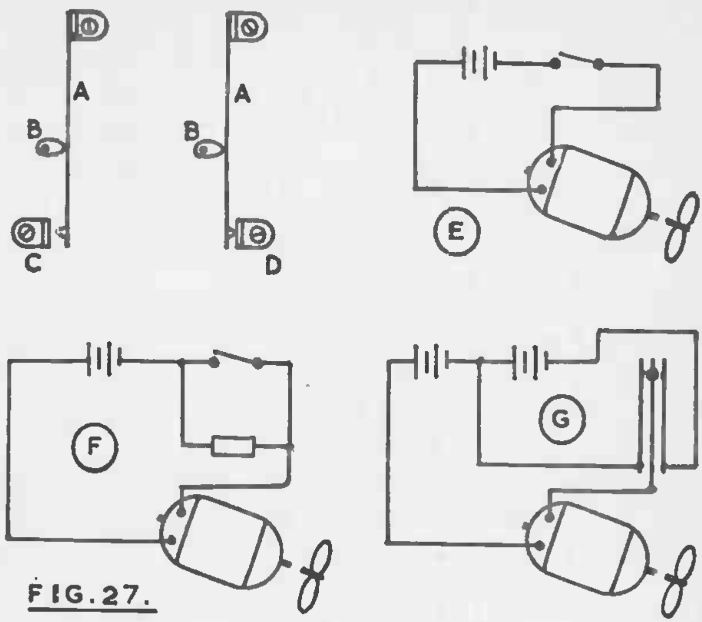


FIG. 27.

position. If a variable or pre-set resistor is used, this lower speed can be adjusted as wished in advance.

In the case of contacts "A" and "C" closure arises with the straight-ahead position. This would allow full-speed running (F) with reduced speed at the other settings. Alternatively, a relay may rest in the position connecting one battery, G, until contacts "A" and "D" close to energise it. The circuit is then changed to place two batteries in series, as shown, giving high speed for straight-ahead only.

If the polarity of one battery is reversed at G, this position will give sailing astern, with a permanent magnet motor. A lower voltage may be used, for reduced speed. Reversing by means of a relay, and using a single battery, is shown in Figure 24.

Steerage Motor

Figure 28 shows the essential items of a unit for steering, with power from a small electric motor. Two sets of pinions and gears provide a reduction drive, to rotate the arm or wheel to which the crank pin is fitted. A quite high ratio is required – at least 50:1. Motor speed may to some extent be reduced with a resistance speed controller, or appropriate voltage, but there are limits to this while maintaining reliable starting.

A stiff wire link carries motion to an arm, fixed at right angles to the rudder, which moves with it. Two or three holes for the pirvot pins at each end of the link allow the sharpness of turning to be altered to suit the model.

This type of actuator can be made from a small, low voltage motor, and clock parts, constructional toy components, or gears which can be purchased. Motors are also available with a reduction drive incorporated.

An alternative is to use a worm drive, with the worm on the

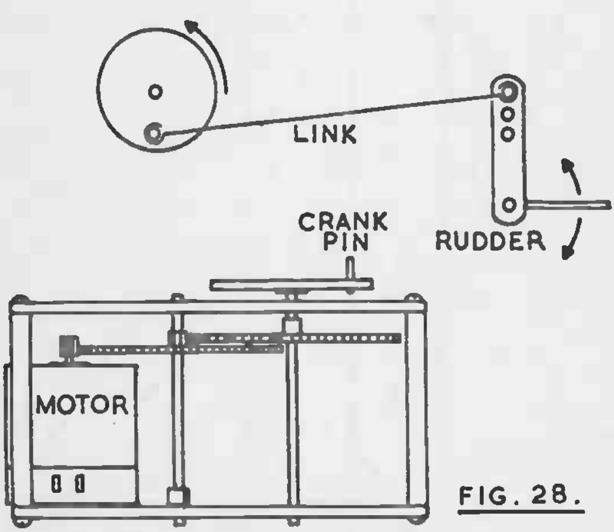


FIG. 28.

motor spindle. A high ratio is readily obtained by this means. Motion from one extreme rudder positon to the other can take some two to four seconds or so. With a high ratio drive, considerable force is available. There might be an initial gear drive of perhaps 5:1, followed by a worm engaging a 60-teeth gear, so that the overall ratio is 5 x 60 or 300:1. If the motor runs at full speed, say 300 rpm, one half-revolution of the crank pin will take 3 seconds.

The usual permanent magnet motor can be readily reversed, and this allows any degree of adjustment of rudder position in either direction. Rotation of the crank in one direction only can be considered satisfactory for some models, but obviously gives less control. Unwanted positions have to be run through rapidly, as with a clockwork escapement.

Figure 29 shows the application of a similar actuator to steer a wheeled model. Adequate reduction gearing is necessary, and can be by gear or worm. The sharpness of turn in either direction can be initially adjusted by changing the throw of the crank. The means of control should allow reversing of the steerage motor. A heavy model can be guided by this means.

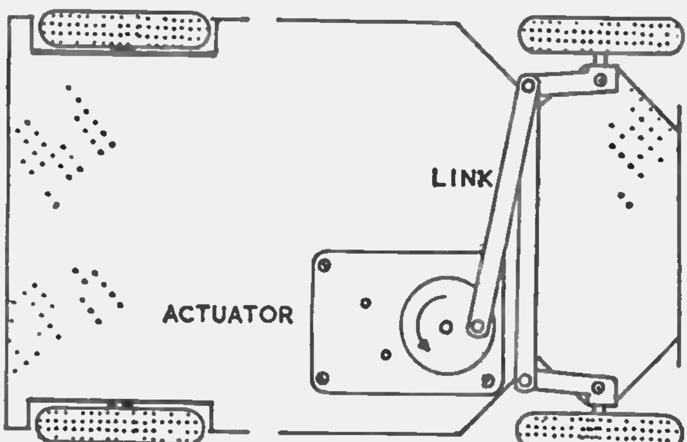


FIG. 29.

With a worm drive, or gearing of other than quite low ratio, the crank is locked when the motor is not running, holding the rudder or wheels in the position chosen. Linkages should not have excess free play.

As an alternative, the crank pin sometimes runs in a slot in a long arm, swinging this from side to side. This can operate a rudder without linkage. Other models may convey rocking motion to the rudder by means of cords (see Figure 26).

Transistor Control

In some circuits a power transistor able to pass sufficient current may replace a relay. Figure 30 shows the relay operating stage of the superhet receiver as Tr1, where the increase in collector current closes the contacts of relay RLY1.

In the second circuit, connections are altered to place R1 in

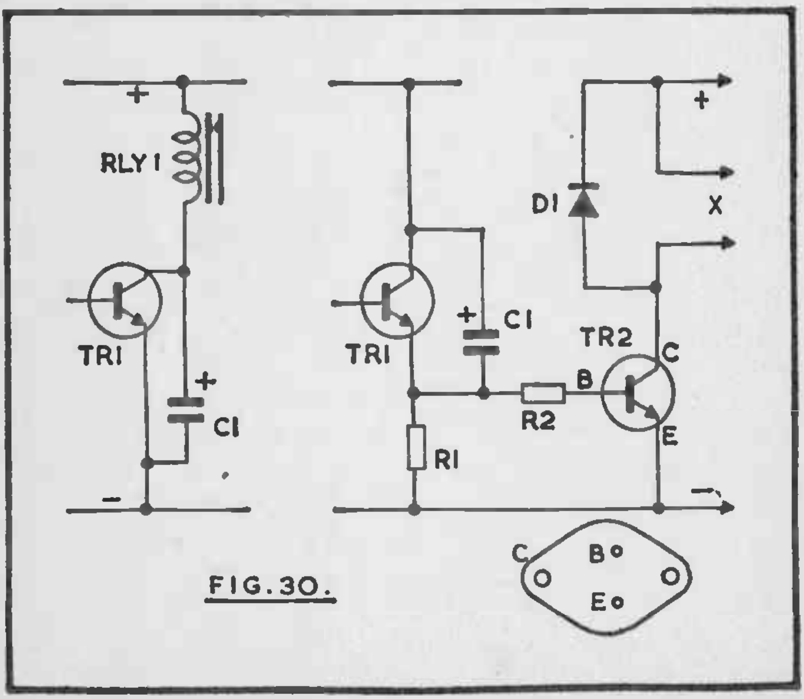


FIG. 30.

the emitter connection. When Tr1 conducts, the junction of R1 and R2 moves positive. Tr2 also conducts, and current is available at X to operate a motor or escapement. D1 is to protect Tr2 against back emf generated by inductive loads here. Connections are shown for the 2N3055. This transistor can pass up to 15 A., but in this circuit is intended for a load of about 1 A. Note that its negative line is common to the negative line of Tr1, but that a separate positive can be used -- such as obtained from the actuator or propulsion battery.

Tr2 in NPN. A PNP transistor conducts when its base moves negative, so for this R1 would replace RLY 1, and the emitter would be taken to positive.

Collector current at X is limited by Tr2 gain and base current. Thus if the current gain of Tr2 is 40, and 1 ampere is required, this is 1,000 mA., so about 25 mA minimum will be required for the base. Base current may be increased by operating Tr1 from a higher voltage source and by reducing the value of R2. Transistors with only low current gain are best avoided.

PNP and NPN

Figure 31 will clarify the use of switching transistors and the directly coupled amplifiers which may be used to raise output.

A is a PNP transistor in which the emitter is taken to positive. Negative base bias moves the transistor into conduction, so that collector current flows through the relay coil, operating the relay. When bias ceases, collector current drops, and the relay returns to its first position. A sudden drop in current may create a back electro-motive force or emf due to the coil inductance, and this could damage the transistor, so is suppressed by the diode.

At B the NPN transistor has emitter to negative line, and needs positive base bias to cause conduction, and operate the relay. Thus A or B may be used as directly coupled

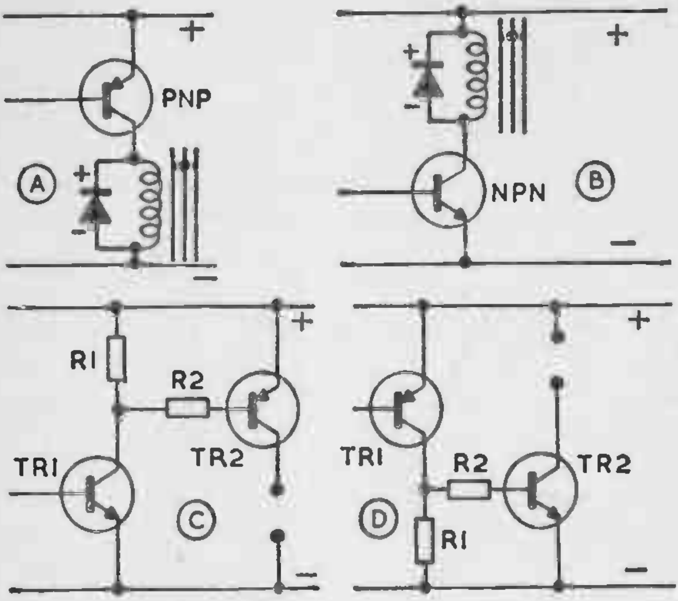


FIG.31.

amplifying stages, according to the presence of negative or positive bias.

At C, Tr1 is NPN, so positive base bias causes the collector current to rise. With no collector current through R1, the junction of R1 and R2 is positive, so that Tr2 (PNP) does not conduct. When Tr1 conducts, a voltage drop arises across R1, moving R2 and the base of Tr2 negative, so that Tr2 conducts. This can operate a relay or other device in the collector circuit of Tr2.

At D, Tr1 is a PNP transistor, so that negative base bias causes conduction, raising the voltage drop across R1, and moving the base of Tr2 (NPN) positive. Tr2 thus conducts. Resistors R1 serve a similar function in both circuits, and may usually be around 1k to 2.2k. Resistors R2 limit base current when Tr1 is conducting, to avoid damage to Tr2. R2 can usually be around 1k to 2.2k for small transistors, but will be of lower value where Tr2 is a higher power transistor, and the stage is intended to provide enough current to control an actuator or other device directly.

Any of these circuits can provide a substantial gain in current, on switching, to provide strong and reliable working. The method of operation of any of them can be changed by placing the load (relay or R1) in the emitter circuit.

Delay Circuits

A delay circuit will allow the control of two separate actuators from a single channel. Figure 32 shows two circuits of this type.

The receiver relay is closed by operation of the transmitter as explained. When its contacts close, current from the battery

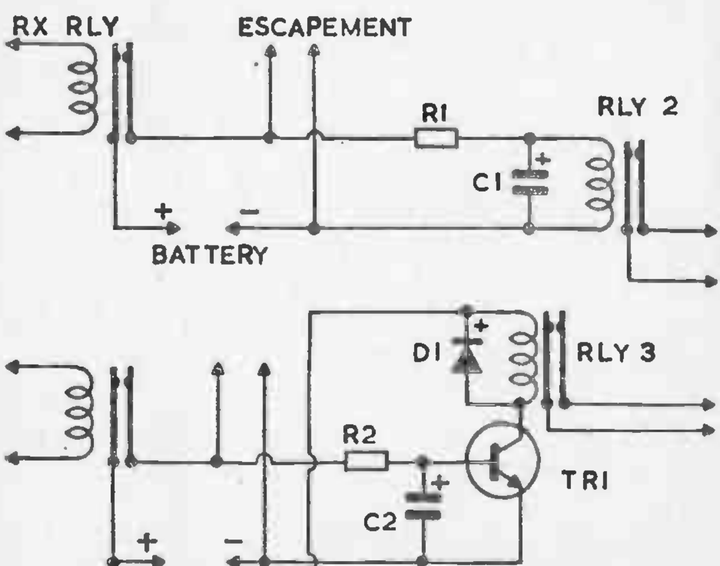


FIG.32.

flows through the escapement coil, allowing the escapement wheel to turn to re-position the rudder. For this purpose, only a very brief closure of the receiver relay contacts is required.

The second relay, RLY 2, receives current through R1, and the time taken for the voltage across the coil to rise to a point which will close RLY 2 contacts depends on the resistor R1 and capacitor C1, and on the relay itself. If RLY 2 is 2,000 ohm, and C1 1000 μF, the delay is roughly two seconds using a 12v supply. Thus RLY 2 does not respond to quick impulses which release the escapement. To operate RLY 2, the receiver relay has to be held for about two seconds, and RLY 2 may in turn operate another escapement, or a propulsion motor or other device. If RLY 2 contacts were placed in series with the propulsion motor, brief pulses could steer the model (with one position giving reversal of propulsion), while holding the receiver relay would stop the propulsion motor.

The second circuit operates in a similar way, but allows a low resistance relay RLY 3 to be used. Tr1 can be a 2N3706 or other audio, general purpose or switching transistor suitable for the relay current. With a 200 ohm relay and 6v supply, the delay is similar to that of the earlier circuit, R2 being 3.3k, and C2 1000 μF. D1 is to suppress back emf generated by the relay coil.

The time delay of these circuits can be modified by altering the values, but R1 in that using RLY 2 cannot be too large, or enough voltage may not remain to close the relay. Increasing C1 will increase the delay. A long delay is unnecessary and best avoided from the operating point of view.

Motor Control Circuits

Figure 33 shows some of the propulsion motor control circuits which may be used. At A is shown the on-off switching of the motor by the receiver operated relay RLY. This is normally open. When closed, the circuit is completed and the motor operates. Switch S1 is required if circuit arrangements are such

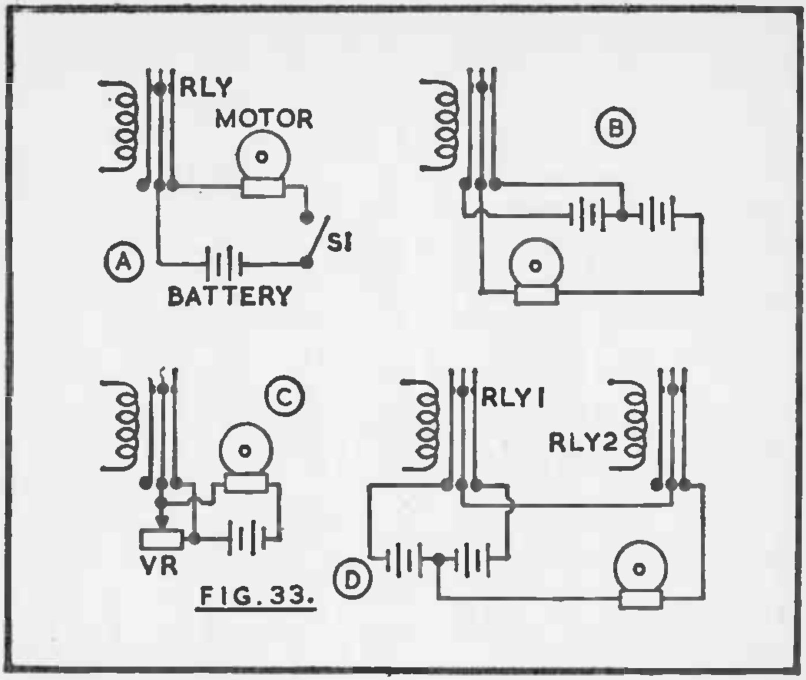


FIG. 33.

that stopping of the motor would be obtained with the relay energised, and so allows switching off when the model is not in use. Separate switches, or a single switch with two or more poles, will be required for switching off the receiver and other circuits, so that nothing is left on when the model is put away. To suppress radio interference, a capacitor of about 20 nF is often placed across a propulsion or other motor.

At B change-over contacts on the relay are used for normal and slow running. A tapped battery (or two batteries in series) provides full power for one relay position, and half voltage for the other positon. Or this can provide normal speed running, with intervals of high speed on increased voltage.

C obtains reduced speed by means of the variable resistor VR, which is shorted out of circuit for normal speed in one relay position. This is more appropriate for small motors. VR could be a wire-wound fixed resistor, found by trial. This is less economical than B, and has disadvantages for motors requiring a high current.

D is a circuit with two relays, controlled by 2-channels or the other possible methods. RLY 1 changes the polarity of the supply to the motor, reversing it. One battery may be of lower voltage, for reduced speed astern. This relay could be used as at B, for two speed running instead, or could incorporate B as a third relay. RLY 2 interrupts the motor circuit. The two relays thus provide complete control of the motor, for running either way, or stop. This could operate a tiller or road wheels for steering, through a reduction drive and linkage.

Figure 34 shows how a relay may be electrically latched on, and will stay in this position until released. RLY 1 is controlled by the transistor switching stage, and has two sets of change-over or 2-way contacts. Contacts at A are normally open. The contacts at B of RLY 2 are normally closed.

When RLY 1 is momentarily energised, contacts A close, and current flows through resistor R, contacts B and contacts A, and through RLY 1 coil. RLY 1 thus stays closed, once it has moved to this position. Current for it is no longer required

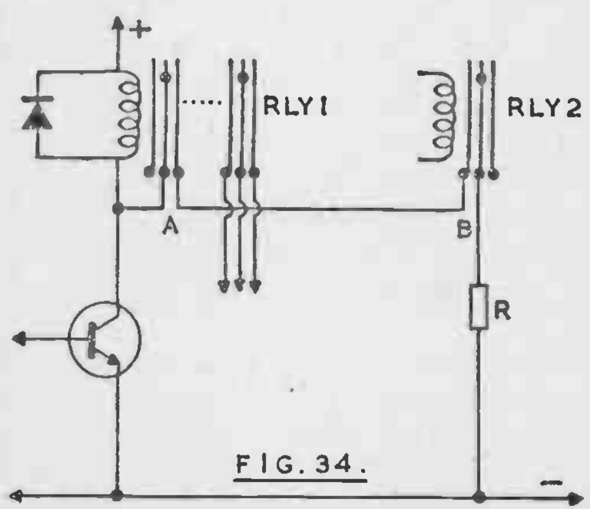


FIG. 34.

through the switching transistor. The second set of contacts on RLY 1 can carry out any of the functions described, or other operations. and will also remain latched in this position. To release the circuit, RLY 2 has to be energised, in the absence of current through the switching transistor. Current is no longer available for RLY 1 coil through R, and the system returns to its original state.

Resistor R can generally be a few hundred ohms. A somewhat smaller current will hold RLY 1 closed, than will be necessary to close it from its open position, and R can easily be found by trial. Unnecessarily low values at R merely impose additional drain on the battery supply.

Other Mechanisms

Figure 35 shows the working of some mechanisms which may be used for various forms of control. At A a threaded rod is rotated through a reduction drive from an electric motor, which may be run either way. Rotation moves the nut along the rod, and a link transfers this motion to guide wheels or rudder. This holds the steerage system firmly in any set position.

B shows a rudder operated by a stiff wire link, various degrees of turn being arranged in advance by selecting the pivot hole for the link. Drive here is from a device offering little resistance to rotation from pressure on the link – as a light mark-space actuator. The tension spring has just sufficient power to return the rudder to the central position, in the absence of motion from the link. This gives automatic centring after a turn. C is another self-centering device. The rotating disc or crank can be turned either way by a motor with light reduction drive, and the pin takes linkage to operate the rudder. A leaf spring each side of the pin is under pressure when the pin is moved either way, so that when power is removed, the pin is returned to the central position.

At D is shown a contact device which halts a motor-driven

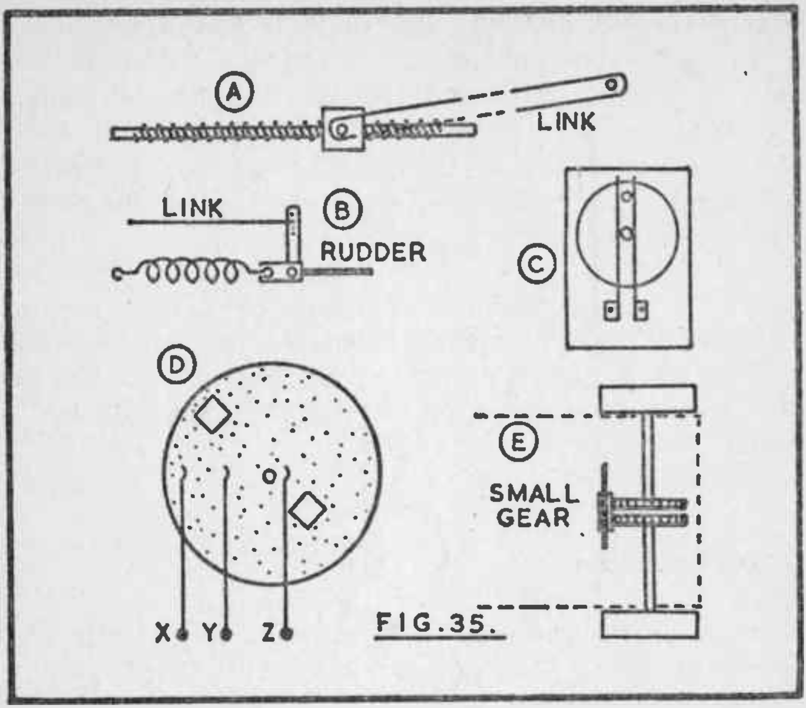


FIG.35.

actuator in a wanted position. A conducting disc is fitted to the shaft of the actuator, and contact Z bears upon it. One circuit (e.g., that giving 'right') is completed through X, and the second circuit (giving 'left') through Y. Cut-out sections corresponding to these positions can come under contacts X or Y, breaking the circuit..

The actuator, driven by its motor, rotates until the chosen position is reached, and the circuit is then interrupted to either X or Y, so that it comes to rest. It then stays in this position. It can be reversed to the other position since only one contact, X or Y, will be out of circuit. A disc of this type, and more complicated types, can be made by etching a foil covered circuit board, as used for radio and electronic construction.

E shows one method which may be used with tracked and some other vehicles. The small gear engages with both large gears, turning both track wheels equally, for straight running.

The shaft carrying the small gear can be moved a little either way, and thus the gear falls out of engagement with either one of the large gears, so that power is applied to one track only, for turning. Steering is thus by a mechanism moving the small gear shaft from side to side. Similar results are obtained if two seaparate motors, each with its own drive, are used, and each motor can be run at reduced speed, to slow the track that side, for turning.

For aircraft of simple design, rudder control may be obtained as at A in Figure 36. To avoid weight, the escapement is driven by twisted elastic, and this can be re-wound by a loop at the tail, giving a considerable number of movements with each winding. The actuator pin travels in a slot, producing a

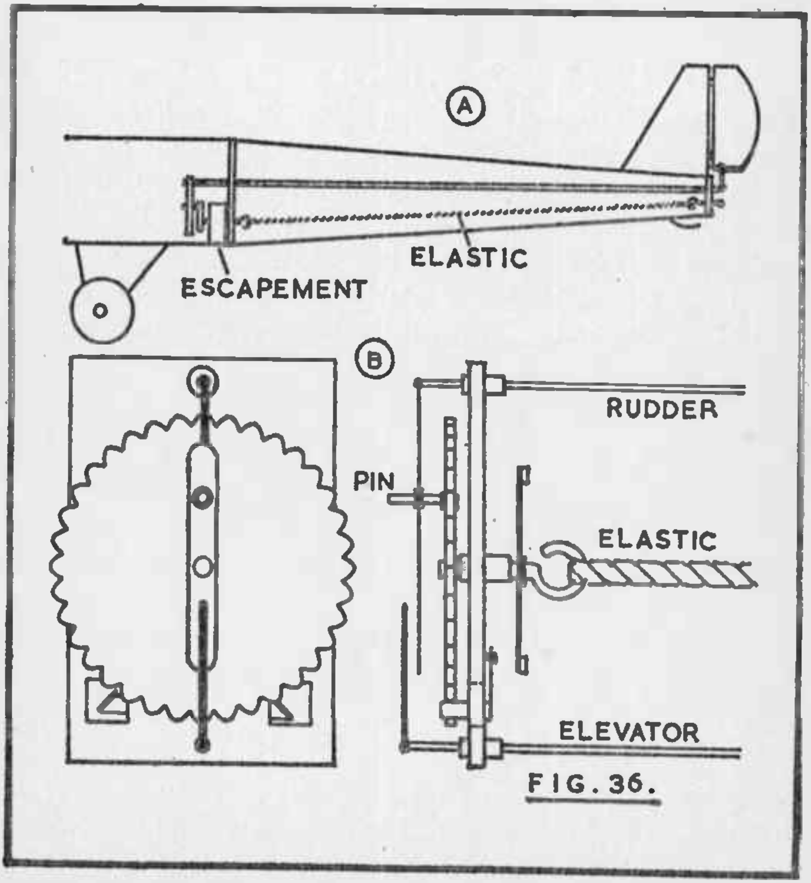


FIG. 36.

partial rotation of the long control rod, which in turn operates the rudder by crank linkage. With control of rudder only, aircraft trim provides for stable flight as with a plane with no control, with altitude gained flying straight. Altitude may be lost by spiral turns, or quick left-right signals. The plane should glide to land with engine stopped, as with a non-controlled model.

At B is shown an escapement including elevator control. Rotation of the toothed wheel carrying the crank pin is obtained from the twisted elastic, and controlled by the actuator mechanism. The pin runs in a slot in a long wire loop, so rocking this from side to side, for rudder adjustment in the way described for A. In one straight ahead position, the pin engages the upright rod of the elevator control. This setting raises the elevator, for climbing, or looping if power permits, following a spiral dive.

The rotating member is commonly toothed, so that a simple vibrating escapement can engage with it. This prevents a very abrupt snap round from one positon to the next.

Linkages for rudder and elevator may have adjustable throw, so that the degree of turn or rise can be modified to secure satisfactory results. Aileron control may be linked to that of the rudder, or may be used alone to produce turns. They need to be operated from a self-centring arrangement.

For more advanced control, fully adjustable rudder, elevator, and other items can be provided. Engine control is often present. Various relatively fast planes cannot be flown successfully without a good range of control, as they will not tend to restore themselves to normal flight as do inherently stable models. Complex methods of control and decoding have to be used at transmitter and model.

Tone Modification

More than one channel of control may be provided from the transmitter to the model by changing the frequency of the tone radiated. At the receiver, some frequency-selective device is used, and responds only when its own particular tone is present. Thus, with two tones, one could be employed to steer the model, and the second to control the propulsion motor. Or one tone might be used for 'left' and the other for 'right' or as arranged.

The frequency of the tone generator in the transmitter can be altered by disconnecting one base supply resistor from its supply line and placing a pre-set in series with it. Adjustment of the pre-set then allows alteration of the tone. Each pre-set is selected by a push-button activating the tone generator. So for two tones, two push switches will be fitted, one producing a high tone, and the other a lower tone. For tones of rather low pitch, a 470k or 500k potentiometer will be satisfactory in the pre-set position. For higher tones, 100k will be sufficient. Some fixed resistance is left in circuit so avoid taking the base directly to the supply line, with careless adjustment. Where a higher tone is required, the fixed resistance present will have to be reduced in value, or that supplying the other base, or the feedback capacitor values. A very wide range of adjustment (from under 100 Hz to over 100 kHz) is generally readily obtained.

For two channels, it is of advantage to have them fairly widely separated in frequency, as the filters at the receiver then need be less effective.

Where several channels will be provided by different tones, it is usual to avoid direct harmonic relationships, so far as possible, as there might be some harmonic response. So, for three channels, 500 Hz, 1.5 kHz and 3 kHz would be unwise, as example. Such systems can operate successfully with six or more channels.

Receiver

Audio output from the receiver, preferably a superhet, will be taken to some tone-sensitive device. Here, a tuned reed relay was commonly used, having three or more reeds. Each reed is a light armature, near a common electro-magnet core, and it tends only to vibrate at a particular frequency. When a reed is vibrating, its free end comes into contact with a spring or adjustable screw which completes the circuit.

To use such a device, the transmitter tones are slowly adjusted until the appropriate reed is seen and heard to respond. It is then possible to set in motion any of the reeds, by using the appropriate tone button, and thus complete any chosen circuit in the model.

The intermittent contact of the reed, when vibrating, might be used to drive a motor or other device. However, this can be avoided by using it merely to provide base current for a switching transistor, with reservoir capacitor. The reed contacts are thus relieved of the need to supply other than very small current, or to switch on inductive loads. This secures very much more reliable working, and helps avoid dirty reed contacts.

This type of unit is not easily made. It has a number of advantages for the beginner, in avoiding complicated electronic circuitry. It was once very much employed.

Electronic Filter

Figure 37 is the circuit of a 2-transistor high-pass filter. The audio input from the receiver is to C1, and Tr1 is an amplifier, with base supplied by R1, and R2 as collector load. Amplified signals reach the filter L1/C4 by C2. C3 couples to the base of Tr2, which has its base resistor R3, and collector load R4. Audio output is from C5. C6 is a by-pass capacitor across the supply lines.

L1 and C4 in parallel form a resonant circuit with high

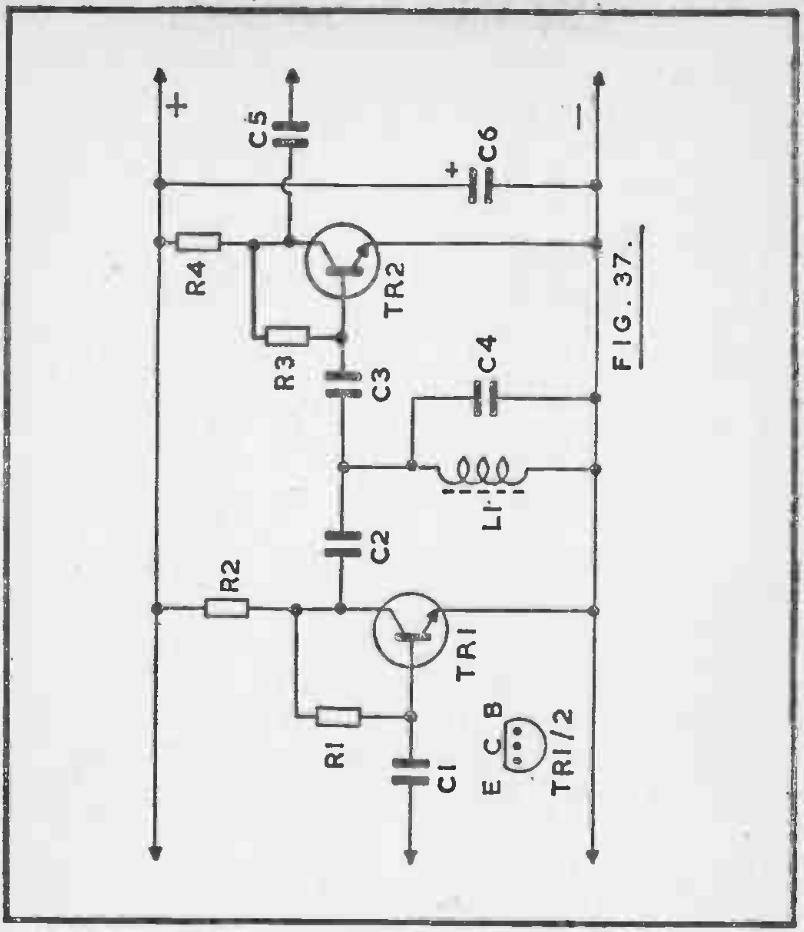


FIG. 37.

impedance at resonant frequency. Audio signals at this frequency develop a voltage at Tr2, and are amplified. Signals at other frequencies are tuned out or lost in L1/C4, so do not appear at Tr2.

For approximately 4 kHz, L1 can be 30 mH, and C4 47 nF. The resonant frequency, in Hertz, can be found by:-

$$1/6.28\sqrt{LC}$$

Here, values are expressed in henrys and farads.

Typical component values for Figure 37 are:-

R1	1 megohm
R2	10k
R3	330k
R4	3.3k
Tr1	2N3706
Tr2	2N3706
C1	1 nF
C2	1 nF
C3	1 nF
C4, L1	see text
C5	1 nF
C6	100 μF

For low frequencies, L1 tends to become heavy. Figure 38 shows a selective feedback operational amplifier providing a low-pass filter. This peaks at about 200 Hz, and will need about 700k in all in the tone generator position described (to be adjusted by trial). This and the previous circuit are for 9v, but may be arranged for other supplies if necessary.

Component values for Figure 38 are:-

R1	8.2k
R2	39k
R3	470k
R4	470k
R5	10k
R6	22k
C1	0.5 μF
C2	50 nF
C3	50 nF
C4	1 μF
C5	1000 μF
IC	μA741CE

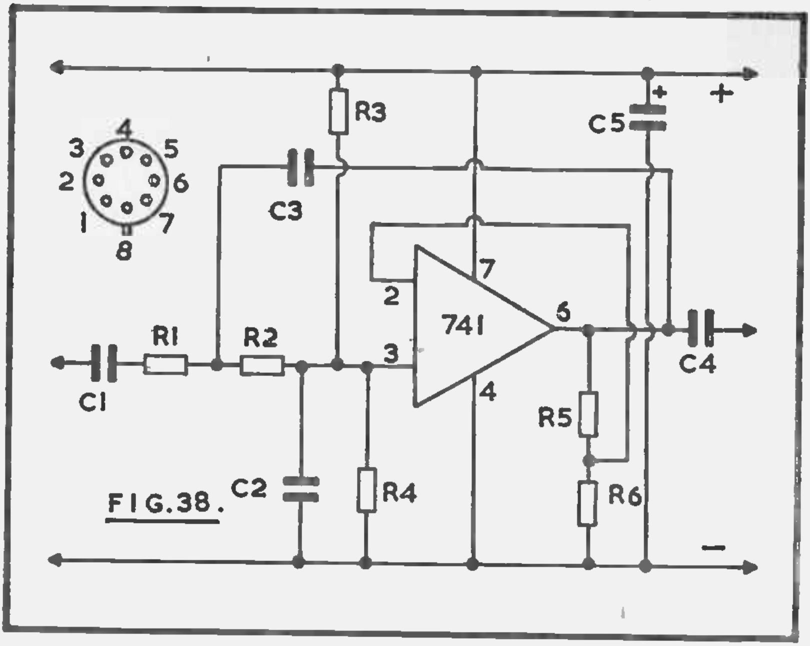


FIG.38.

Very high and very low frequencies will lie outside the best frequency range of the receiver – over 10 kHz or under 100 Hz should be avoided.

Each frequency-selective circuit should be driven by an audio amplifier, and has to be followed by stages giving additional gain, and with a switching transistor to control a relay, or power transistor. A pre-set audio gain control can be provided in the input to each selective stage, to allow some equalisation of the sensitivity of operation.

Tones at the transmitter are then adjusted, observing the output of the control transistor circuit, to obtain best deflection, with minimum response from the other circuit.

Pulse Length Generator

If pulse length is being used to provide control, some means of switching the transmitter tone on and off in the required manner is wanted. This was once carried out mechanically by means of a tapering contact, and this method is easily understood and makes working clear.

An insulated roller (such as a piece of broom-handle 2–3 in long) is fitted to an axle and revolves in bearings. A tapered contact surface is fixed to the roller, either made from thin metal sheet cut and folded round the roller, or sawn from copper pipe. This contact surface completely encircles the roller one end, but grows more and more narrow so that it is only a point near the other end. The roller is rotated by a motor drive. A sliding or swinging contact strip bears on the roller. The circuit to the transmitter tone oscillator is completed when this strip rests on the tapering contact surface. If the strip is in its central position, for half the revolution of the roller it bears on the metal contact surface and for the remaining half revolution rests on the wood. So the tone is on half the time. This is a 50–50 mark-space ratio. Moving the strip towards the narrow end of the contact surface results in shortening the on periods, so the ratio becomes 40–60, 30–70, and so on. If the strip is moved towards the wider end, contact is provided for alarger part of each revolution of the roller, so the mark-space ratio becomes 60–40, 70–30, and so on. No change in frequency arises – only a change in the relative lengths of 'on' and 'off' intervals. These can be anything from 50–50 to minimum or zero 'on' with the strip at pointed end, or maximum or fully 'on' with strip at that end of the roller fully encircled by the contact surface. In fact, for those with a mechanical interest, this type of mechanism is not difficult to make.

A circuit generating pulses of varying mark-space ratio is shown in Figure 39. Tr1 and Tr2 form a multivibrator, with the frequency determined by values. When the wiper of VR1 is placed centrally, the additional resistance in series with R2 and R3 is equal. Tr1 and Tr2 then have equal periods of conduction and non-conduction. When Tr2 is conducting, the voltage dropped in R4 moves the base of Tr3 negative. Tr3 then passes current to the tone generator of the transmitter.

When the wiper of VR1 is moved, the conduction times of

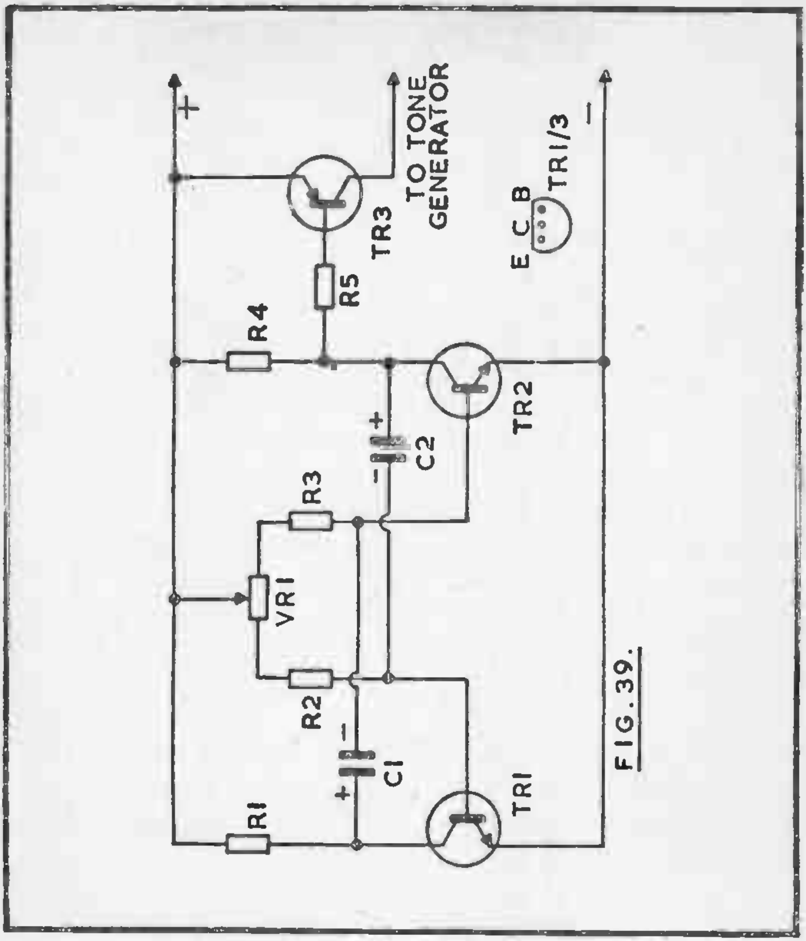


FIG. 39.

Tr1 and Tr2 become unequal. The on-off ratio of the switching transistor Tr3 is thereby changed. There is some change in overall frequency, but this is not important.

Two 2N3706 transistors and similar types may be used for Tr1/2. R1 and R4 can be 2.2k. R2 and R3 may be 4.7k, and VR1 100k linear. C1 and C2 may each be 1 μF to 4.7 μF, depending on the ability of the steering mechanism to follow. R5 can be 470 ohm.

A high resistance relay may be substituted for R4, R5 and Tr3, and one set of contacts used to switch the transmitter.

Tr3 may be 2N3702, or a larger transistor, according to needs.

VR1 may have an extended arm or tiller, fitted so that moving this from side to side rotates the spindle.

Utilising Mark/Space

The signal obtained at the receiver may be used to control a rudder or propulsion motor, or for other purposes. At A in Figure 40 relay contacts operated by the receiver are used to switch a motor. With a continuous tone (or long mark) holding the contacts closed, the motor runs at normal speed. As a space is introduced, and is lengthened, the intervals during which the motor receives current grow shorter, and the intervals with no current grow longer. Due to the momentum of the mechanical system, this has a similar effect to reducing the motor voltage, so that speed falls. Speed is at its lowest with a long 'off' and short 'on' interval, and rotation stops when the tone is completely off.

It is thus possible to adjust the speed of the motor by altering the mark-space ratio of the transmitted tone. Assuming that the motor would be propelling the model, it should have some momentum, and there is then a reasonably

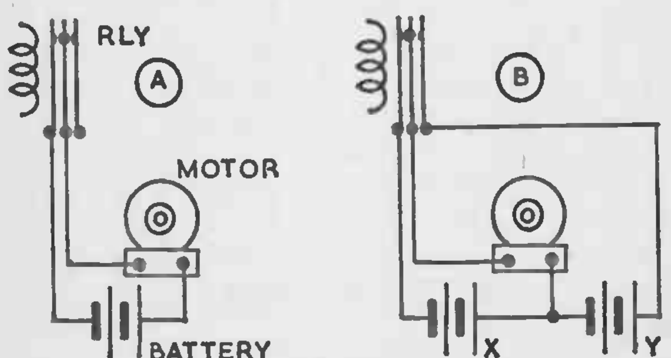


FIG.40.

smooth rise and fall in speed, with adjustment of control, although power is only applied in the way described.

At B, reversing of a motor is shown. This could turn the boat rudder through reduction gearing and linkage, or open or close a throttle or speed control, or operate other mechanisms. When the relay rests one way, current for the motor is from battery X. With the armature in the other position, current is from battery Y. These batteries are placed in opposite polarity.

With equal mark-space ratio, the motor will start to revolve one way, stop, revolve equally the other way, stop, and continue in this manner so that its overall movement is cancelled out. Any steering mechanism is thus not moved to a significant degree. When either mark or space length increases, due to adjustment of the potentiometer at the transmitter, the relay contacts remain closed longer in one direction, and for a shorter interval in the other. The motor thus tends to rotate more one way than the other, this depending on the mark-space ratio radiated. To return the motor, the potentiometer has to be moved the other way, so that battery current is applied for longer intervals in that direction which will turn the motor back to its first position, or further if required.

This type of system should have very little inertia, so that the motor responds immediately. A small permanent magnet motor can be used, and will generally need about 3 volts.

The rate at which mark-space signals is generated can best depend on the purpose for which they are used, and ability of the device in the model to respond. If they are at a slow rate, the motor will run in obvious spurts at A, or hunt from side to side in B. High rates will increase relay contact pitting, and above a certain limit will produce virtually no improvement. As a starting point, and using home-built devices, 2 μF coupling capacitors can be fitted in the tone generator. These may later be reduced to 1 μF or smaller. Various commercially manufactured mechanisms which respond to mark-space signals are rather outside the range of construction carried out at home.

Relay contacts can be relieved of current by switching transistor amplifiers, which in turn provide the motor current. Details appear elsewhere.

Transistor Control

The single-pole on-off action of a controlled transistor or relay contacts can be arranged to reverse a steerage or other motor by using the circuit in Figure 41.

A 6v tapped supply is shown, and can be from two 3v batteries in series, or from a 6v pack of separate cells used elsewhere. Tr1 is a switching transistor which is normally not conducting, but which conducts when the received tone is present.

When Tr1 is not conducting, no negative voltage is available at the diode D1, and base current for Tr2 is obtained through R1, so that Tr2 conducts. Its emitter current is obtained through the motor. The latter is operating from the 3v section A, polarity at the motor terminal being as shown for A.

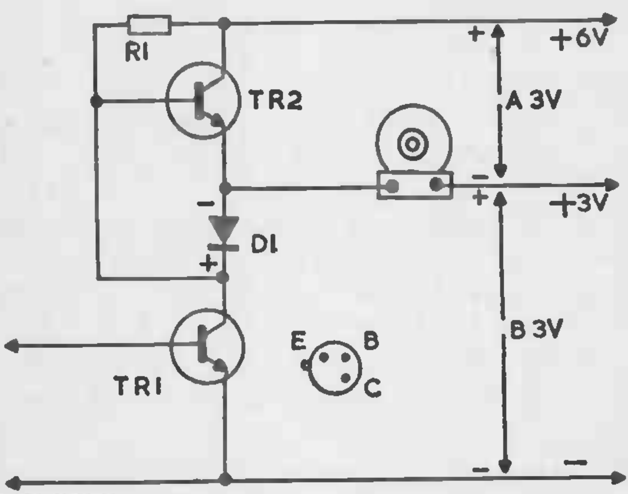


FIG. 41.

When Tr1 conducts, its collector is negative, switching off Tr2. Current ceases to flow from supply A, through Tr2 to the motor, and motor current is now through Tr1 and D1, from the 3v section B. This has reversed polarity at the motor.

This circuit allows the motor to be run in either direction, by means of control of Tr1. By using a mark/space signal, either Tr2 or Tr1 can be conducting for the longer interval, so that the motor can be caused to rotate slowly either way, or can be brought to a halt by having equal mark and space intervals.

For the usual small motor which runs well on 3v, and requires only a low current, Tr1 and Tr2 can be 2N3053, or BFY51, with R1 680 ohm and 1N4001 at D1. Some motors will operate with 1.5v, but some voltage is lost in the control circuit, so a check needs to be made that operation is not too sluggish. For larger motors, Tr1 and Tr2 can be increased in power-handling capacity, and R1 adjusted to suit.

In Figure 41 Tr1 is brought into conduction by moving its base positive. For low power, Tr1 may be present as the output stage of the receiver. For larger power, a PNP switching transistor can supply Tr1 base through a current limiting resistor, from the positive line. Relay contacts could also provide positive bias for Tr1 base, again with a limiting resistor. The latter will generally be from about 2.2k to 470 ohm or so, depending on Tr1. Its purpose is to limit the base current to a safe level for the transistor, which would not be so if the base were switched directly to the positive line, either by relay contacts, or by means of a switching transistor. The relationship between base and collector current has been covered elsewhere. If the base resistor is too large in value, the transistor collector current may prove to be too low, this depending on the load.

The Model

Some users main interest is in the detailed construction of the model, such as a tug, cruiser or speedboat, finished and fitted out to a high standard, and the addition of radio control may be almost an afterthought. Numerous kits are available, and are excellent for this purpose. A length of at least 2 ft. (600 mm) is wise, though radio control can be accommodated in smaller craft. It may be helpful to deviate slightly from constructional plans, so that a portion of the deck, or deckhouse or other features, can lift off, for easy access to radio and other equipment.

Where interest lies more in the working of the radio control, ready-made hulls can be purchased. Larger 'toy' boats should not be overlooked, motorised or otherwise.

The hull should be able to carry the heavy items such as batteries low down, for stability, and have enough buoyancy when fully loaded for proper sailing. Electric propulsion is convenient for moderate speeds. It is also possible to use high drain high speed motors, but a water-cooled marine diesel and similar engines become more suitable as speed rises, with planing hulls. These become matters of specialised model-buidling knowledge and expert handling.

Model cars and other vehicles raise similar points. An enthusiastic model maker can produce a useful vehicle, possibly employing constructional toy or kit gears, axles, wheels and other items. But complete kits are obtainable, and models for radio control. These ease the mechanical side of the work.

Aircraft are more generally made from kits, or obtained ready-mad Chances of damage or loss are much greater than with a boat or vehicle, where these risks may be negligible. A stable, quite slow flying model would probably be wiser than the fast, small span planes.