RADIO CONTROL FOR MODELS

R H Warring

Technical developments in the field of radio-controlled models were spectacular during the fifties and sixties. With the near-perfection of proportional control systems, the development is virtually complete. This definitive work is right up to date and has been deliberately presented at a practical rather than a highly technical level.

The author first gives a brief history of how radio control systems evolved and developed. He then discusses basic radio facts and principles and single-channel systems before going on to describe multi-channel systems and then the modern true proportional systems. Separate chapters are devoted to aircraft controls, aircraft installations and model aircraft design; the installation and operational requirements for the control of model power boats, model yachts and model cars. Finally, there are chapters on radio control engines (as a guide to choosing the best type and size for any model—as well as to handling techniques), installation, wiring and workshop notes and batteries. Lavishly illustrated, the book is the most comprehensive yet produced.

£

ISBN 0 273 25231 3

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PITMAN PUBLISHING

First published 1974

SIR ISAAC PITMAN AND SONS LTD
Pitman House, Parker Street, Kingsway, London WC2B 5PB
PO Box 46038, Banda Street, Nairobi, Kenya

SIR ISAAC PITMAN (AUST.) PTY LTD
Pitman House, 158 Bouverie Street, Carlton, Victoria 3053, Australia

PITMAN PUBLISHING CORPORATION
6 East 43rd Street, New York, NY 10017, USA

SIR ISAAC PITMAN (CANADA) LTD
495 Wellington Street West, Toronto 135, Canada

THE COPP CLARK PUBLISHING COMPANY
517 Wellington Street West, Toronto 135, Canada

ISBN: 0 273 25231 3

Computer Typesetting by Print Origination, Bootle, Lancs, L20 6NS
Printed in Great Britain By Unwin Brothers Limited
The Gresham Press, Old Woking, Surrey
A member of the Staples Printing Group.
(G 316 : 14)

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FOREWORD

The radio control of models has reached near perfection. Modern radio equipment offers literally anyone the chance to fly an aeroplane, drive a racing car or power boat, or helm a racing yacht with no personal hazard, and at a fraction of the cost of the 'real thing'. Even the models themselves can be bought in easy-to-assemble prefabricated kit form. But that is only part of the story. Radio control offers the serious model builder the ultimate satisfaction of controlling his masterpiece in operation—whether purely for pleasure, or in competition with other modellers.

Modern radio control equipment is bought, and used, as 'black boxes'. Plugged together, it works. If it does not, then only a specialist electronic engineer can trace the fault and put it right. Fortunately, the standard of reliability is very high, and troubles experienced with radio controlled models are usually 'pilot error' or 'driver error'. The human element in the link is far more fallible than the electronic element!

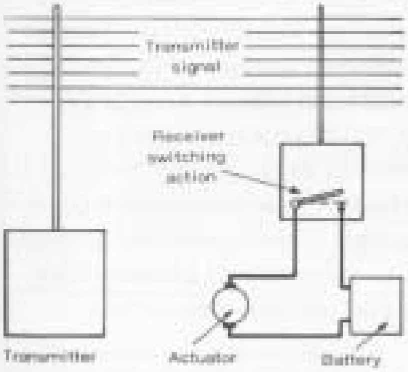
This near-perfection of electronic equipment has taken much of the romance out of radio control—and to some extent lessens the technical achievement of individual modellers. They have countered this to a large extent by building even more elaborate models—realistic scale models which could hardly be distinguished from the 'real thing', except in size. And aerobatic aircraft with better manoeuvrability than their full size counterparts.

This book digs more deeply into the *story* of radio control, as well as aiming to be a comprehensive guide on all aspects of the subject. Thus it deals at some length with simpler systems—single-channel radio which is now on the way to becoming obsolete; and multi-channel 'reeds', which equipment is no longer manufactured—as well as up-to-date *proportional* systems.

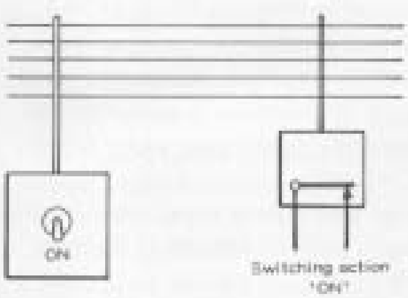
There is a very good reason for this. With these simpler systems it is easy to learn *how* radio control works, and how radio control can be attempted on a low-cost basis. There is nothing much to learn about modern proportional radio equipment, except how to install and use it. But basically it is merely an extension of earlier systems, with control systems developed directly from 'old-fashioned' multi-channel. Knowing how these work can help.

Virtually all modern commercial control equipment is 'proportional', giving control movements corresponding to the movements of the control sticks on the transmitter. The electronics are a mystery to most people—the various units are simply accepted as 'black boxes' that work. This is a far cry from the old days of radio control where only a single on-off switching link was provided by the Transmitter-receiver combination. Most early radio control equipment was also home-built by modellers.

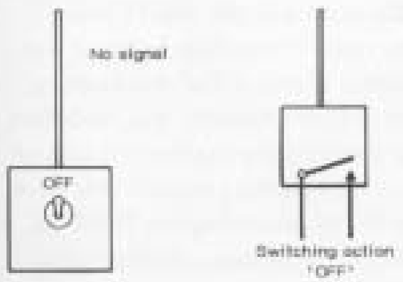
1 RADIO CONTROL SYSTEMS



1.1 In a simple radio control link the Receiver works as a 'switch' worked by the transmitter signal and controlling the actuator circuit.



1.2 With the Transmitter signal 'ON' the receiver switching action is also 'ON'.



1.3 With the transmitter signal 'OFF' the receiver switch action is also 'OFF' breaking the actuator circuit.

Radio is a part of everyday life. Everyone knows how to switch on and tune a radio receiver, or a television set. There is nothing mysterious about it. The only 'mystery'—to most people—is how radio works.

Radio control is very much the same. It includes the same basic elements as 'ordinary' radio working: a *transmitter* which sends out a broadcast signal, and a *receiver* which picks up that signal. The main difference lies in the fact that the signal sent by a radio control transmitter is just an electronic signal. The purpose of the receiver is to pick up that signal and respond to it by working like a *switch*.

One further element is involved in radio control—an *actuator*. This is a device which turns electronic signals into mechanical output (or 'muscle power', in simple language), which can make whatever it is connected to move or work. The relationship between the *receiver* and the *actuator* is basically a very simple one. Since the receiver acts as a switch, it switches the actuator 'on' or 'off' in response to 'command' signals sent out by the transmitter.

To take a very simple case, suppose the actuator is an electric motor used to drive something (*figure 1.1*). The receiver operates as a switch for this electric motor circuit. A command, signalled by the transmitter, produces a 'switch-on' response in the receiver, completing the actuator circuit. The electric motor starts and runs as long as the original signal continues to be given, i.e. the receiver is held in a 'switch on' response condition as long as the transmitter continues to send out its signal. As soon as the transmitter signal is turned off, the receiver reverts to a 'switch off' condition and the electric motor stops. Start and stop switching of the electric motor is thus provided by remote control—the main limitation being the range over which the transmitter-receiver link will function with relatively simple and low powered radio circuits.

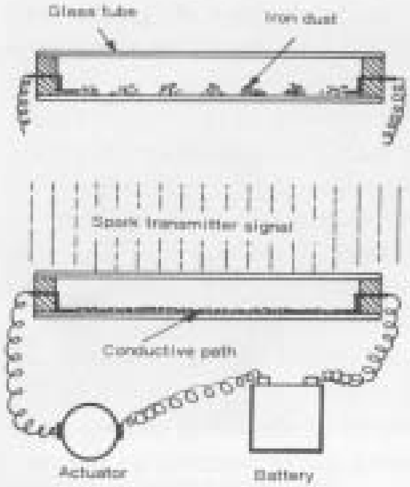
The basic radio link requirements are quite straightforward. For simple working the transmitter has only to be capable of sending a simple radio frequency (RF) signal, which can be switched on and off at will by the person giving the commands. The receiver can be another simple circuit, capable of being tuned to the transmitter signal frequency and of responding to the difference between 'signal on' and 'signal off' in such a manner as to provide a switching action for the actuator circuit.

All of the earlier radio control systems worked on this basis. Provided the circuits functioned properly, the radio link was established. The main problem was then to design actuators which did more than run-and-stop, like the electric motor, but performed definite movements which could be coupled by mechanical linkage to work controls on models. Later on when more experience and knowledge had been gained of the design and operation of transmitter and receiver circuits, the *type* of signal sent became more sophisticated, making it possible to send 'compound' signals, and even separate signals simultaneously. This proved far more satisfactory—and workable—than 'compounding' the response to simple on-off switching at the actuator end. At the same time this greatly increased the complexity, and cost, of the electronics involved, leading to the general classification of radio control systems under two distinct types of working: (1) single-channel (or 'single signal'); (2) multi-channel (or 'multiple signal').

Both types of equipment persist—single-channel because of its relative simplicity and much lower cost; multi-channel because of its better, and more extensive, control coverage. But simple classification on this basis is no longer valid. Single-channel working lends itself to a degree of 'compounding' or signal modulation without necessarily involving complex electronics. In fact, the original multi-channel systems were a straightforward extension of single channel 'tone' signalling. These were eventually replaced by fully *proportional* control systems which instead of 'on-off' switching at the receiver end provided actuator movement in exact response to movement of a control stick (or wheel) at the transmitter end. We shall see how these various systems developed.

The first known examples of radio control date from the beginning of this century. In 1905 a Professor Branly demonstrated the remote operation of machinery by radio link (the first known example of industrial radio control); and in the early 1920s a demonstration of remote control of a model airship is reputed to have been given in a London music hall (the first quoted example of model radio control).

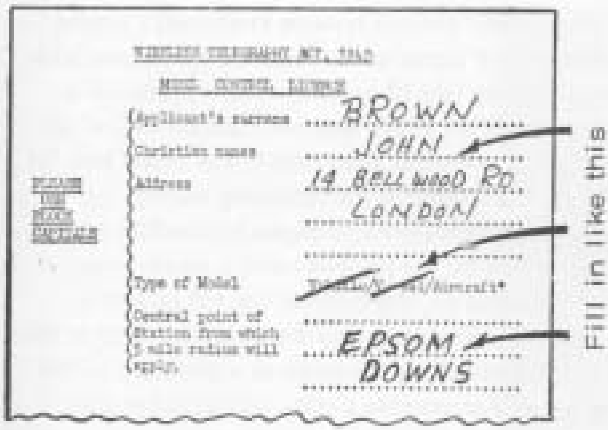
The equipment used was very crude—a spark transmitter (nothing more or less than a Morse key); and a coherer receiver, the latter consisting of a glass tube partially filled with fine iron filings or iron dust. (*figure 1.4*). Anything electrical that produces a spark can cause interference on radio, as is well known. (It is for this reason that spark transmitters were long ago made illegal). Interference is caused by the fact that a spark generates a radio frequency signal, over a very broad range of frequencies.

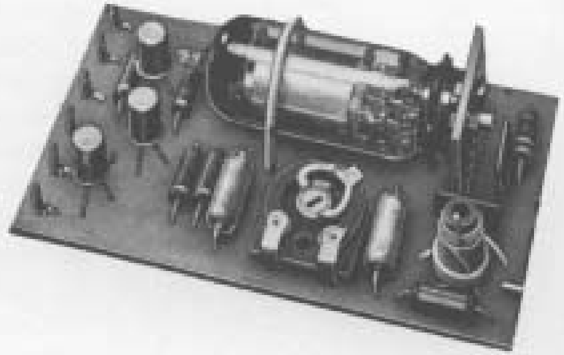


1.4 The Coherer receiver. With no signal present the iron dust is in random groups. In the presence of a signal the iron particles are magnetised and join up to form a continuous conductive path completing the actuator circuit.

A coherer receiver works in this way. Iron dust is a magnetic material. Assuming that it is first lying in random fashion in the tube the presence of a strong RF signal will cause each particle to become a magnet. These tiny magnets will then immediately link up in the form of a chain running the length of the tube. Since iron is also a conductor of electricity this chain, once formed, can complete an electrical circuit between contacts inserted in each end of the tube. In other words, the coherer has been transformed to an 'on' switch for any external circuit connected to the tube contacts. To break the chain, and thus switch 'off' when the RF signal is removed, it is necessary to tap the tube.

Interest in model radio control really started in the mid-1930s, principally in America. To operate any radio transmitter legally it was necessary to hold an amateur radio licence and so initial development work was largely restricted to amateur radio enthusiasts, and modellers who had also qualified for an amateur transmitting licence, working on frequencies allocated for 'ham' radio. Aeromodellers in particular were attracted to radio control—the United States also being the 'home' of the mass-produced small spark-ignition engine in sizes suitable for powering model aircraft, which evolved at this same period. But the fact that to fly a radio controlled model aeroplane the modeller also had to be qualified as a radio amateur seriously limited the number of





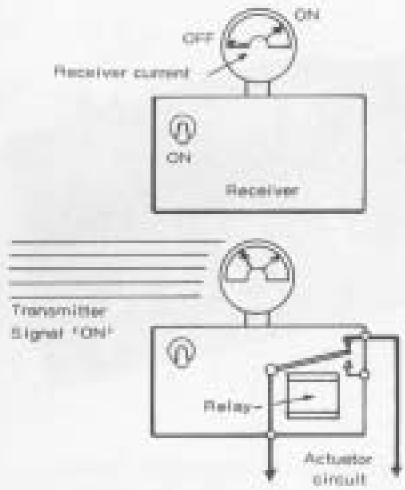
1.5 A Licence, issued by the Post Office, is necessary before operating any model radio control equipment. No practical test or written examination is involved; just fill in and return the Application Form obtainable from:
The Ministry of Posts and telecommunications,
Waterloo Bridge House,
London SE1.
The cost of a Licence is £1.50, this covering a five-year period.

(Above right) Example of valve transistor single-channel transmitter of the type which remained popular in Britain up to the early 1970's.

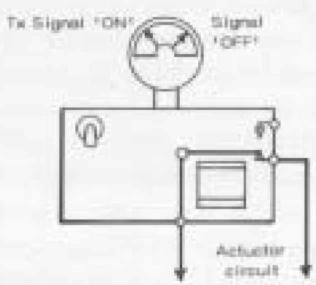
individuals contributing to these early stages of development. Nevertheless, contests for radio controlled models were included in pre-war American National Championships held at centralised venues.

This licence requirement, incidentally, persisted in America until 1952 when the Federal Communications Commission (FCC) eliminated the code and written examinations required for licenced operation on 27.255 MHz and 465 MHz; previously most of the work had been done on the 50-59 MHz amateur band, which required an operating licence. The position was rather different in Britain. There was virtually no interest in model radio control until after the war when the (then) GPO allocated two specific frequency bands for model radio control use, the necessary licence being obtainable on application. These bands were 26.99 MHz to 27.28 MHz and 464 MHz to 465 MHz. The second (higher) frequency band presents considerable technical difficulties in equipment design and construction and has been little used, either in America or Britain. The 27 MHz band became the virtual standard for model radio control work all over the world, American modellers changing over from 54 MHz to 27 MHz with the easing of their licence requirements.

Aircraft were always the most popular subject for radio control. A high wing layout was adopted for years, because of the good automatic stability it provided in flight.



1.6 Changes in the Receiver current when switched on (top); and when the Receiver responds to a Transmitter signal (bottom). The fall in current in response to signal causes the Relay to drop out.



1.7 Working the other way round, the Transmitter signal is normally 'ON' all the time, holding the receiver in a 'low current' state. Keying the Transmitter switches the signal 'OFF', causing a current rise in the Receiver, pulling in the Relay. Note difference in Actuator circuit connections to the Relay.

All of the earlier model radio control systems employed a simple oscillator for generating the RF signal at the required frequency, with or without power amplification (see Chapter 3). These produced a straightforward carrier wave (CW) which was switched on and off to transmit commands. The super-regenerative circuit was found best for receivers (see Chapter 4), responding in the following manner (see *figure 1.6*). With no signal being received from the transmitter a fairly high standing current is drawn by the receiver, with a steady value. If the transmitter is then switched on, the receiver current falls to a substantially lower value and remains at this lower value as long as the transmitter signal is present, assuming the receiver is correctly tuned.

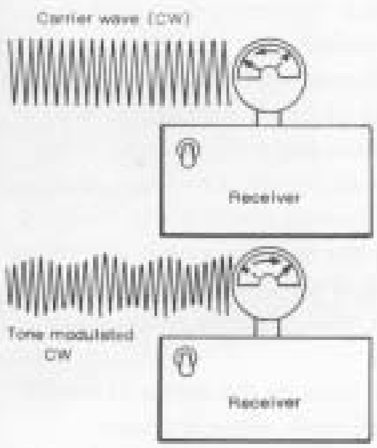
This *current change* is used to operate a *relay* connected in the receiver circuit. Thus with high standing current the relay is adjusted to pull in and remain in this position until receipt of transmitter signal produces a fall in current causing the relay to drop out. The armature of the relay thus acts as a switch, controlling the external actuator circuit connected to it and the relay contacts, as shown.

In practice the switching system was often worked the other way round (*figure 1.7*). Normally the receiver will spend more time idling than responding to the transmitter signal. To reduce receiver battery drain, therefore, it is better to have the transmitter signal present all the time (holding the receiver in its low current condition). A command is then initiated by keying the transmitter signal *off*, which causes the receiver current to rise, pulling in the relay and changing over the switching contacts.

One of the main limitations of this system was the relatively small change in current available from simple single valve receiver circuits. This called for use of a sensitive relay, and very careful relay adjustment.

Performance was much improved by the introduction of two-stage receivers, although this increased the number of components and bulk and weight of the complete unit. By using the first stage as a signal detector and the second as an amplifier it was possible to produce much larger current changes, making relay operation far more positive and less critical. At the same time the receiver could now be made to work with a low idling current falling virtually to zero on receipt of signal, using this to trigger off the second stage which could now pass a current of 3 to 5 milliamps, or even higher when transistors became available for the amplifier stage(s).

The next big step was the adoption of a modulated tone signal rather than a simple carrier wave for transmission. Basically this simply means superimposing a lower frequency (usually an *audio* frequency, and hence the description *tone*) on the original carrier. The carrier wave signal is on all the time and the tone is only keyed to modulate the carrier when a command signal is required (*figure 1.8*). The receiver circuit is designed to have a moderate idling current with no signal, which falls to a steady low current in the presence of the CW signal. When the CW signal is modulated with tone this is detected and expressed in the form of a current rise to a steady maximum.



1.8 With a Carrier Wave signal the Receiver response is a 'current fall'. With a Tone Modulated signal the Receiver response is a 'current rise'.

Line up of models at an early radio control contest in Britain. Flying sessions could be ruined by high winds because of the limited control available (rudder only).

Today even a model helicopter can be flown perfectly under radio control—using proportional equipment. This type of flying model was thought 'impossible' only a few years ago.

Typical example of an early sensitive relay, as used in receivers as the switching element.

At first sight this may appear a more complicated way of producing the same results as a CW system. However, there are a number of advantages. For one thing, it is a simple way of producing a 'current rise' receiver, and of achieving a good current change without resort to a high degree of amplification. There is also the fact that since the receiver is *always* influenced by the CW being present it tends to lock onto this particular signal, which considerably reduces its susceptibility to any interference from spurious signals of adjacent frequency. A secondary effect of this 'locking on' characteristic is that less radiated transmitter power is needed—which can be particularly advantageous in the design of small transistorised transmitters.

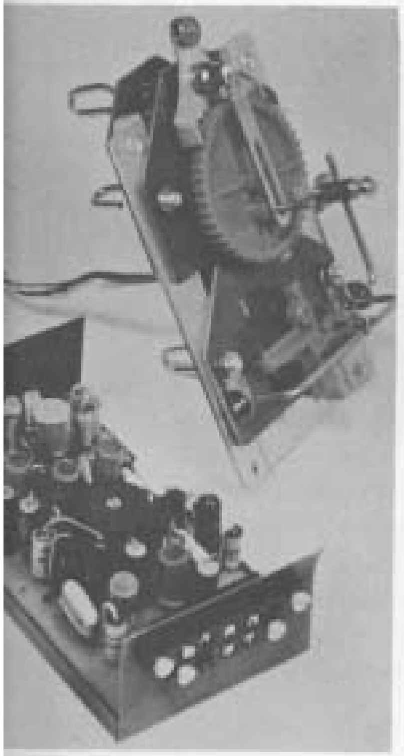
Tone receivers were introduced in the 1950s and have virtually replaced CW working for single channel radio controls.

The availability of suitable transistors for complete (all-transistor) receiver circuits led directly to two further important developments: the *relayless receiver* and the *superhet* receiver.

Receivers so far had utilised an electro-mechanical device, the relay, as the switching element for the actuator circuit. The 'mechanical' elements of the relay—the moving armature and fixed contacts—are external to the relay circuit and are, in fact, merely a mechanical switch for the actuator circuit. The amount of current which can be switched in this manner is then governed only by the limiting current loading for the relay contacts used. Within this limit, if the actuator needs a higher voltage (or current) to operate properly, then it is only necessary to increase the size of the actuator *battery*.

Transistor circuits made it possible to increase the degree of amplification possible within the receiver circuit itself, without unduly

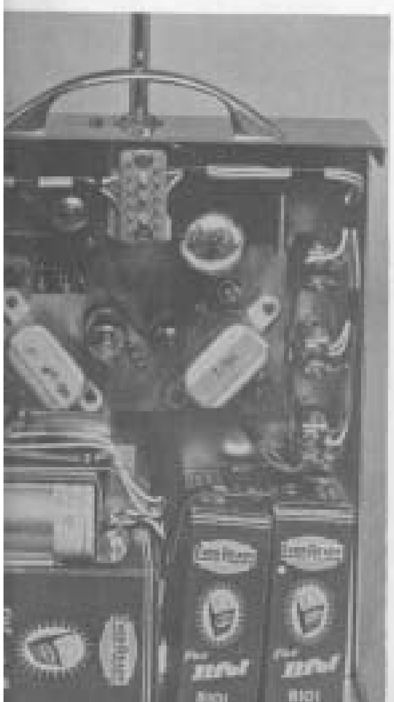
Another example of the type of model which can be flown safely with modern proportional radio control. Scale model subjects—even dating back to pre World War I—are extremely popular.



The relayless receiver reduced the size and weight of a single-channel receiver to a minimum—less than one ounce in some cases. It made possible radio control of models less than 18 inches span.

Relayless all-transistor tone receiver with matching escapement-type actuator.

The valve Transmitter continued to be used for some time after all-transistor receivers became standard. Eventually it was replaced by the all-transistor transmitter, permitting a substantial saving in battery size and weight—and operating cost.



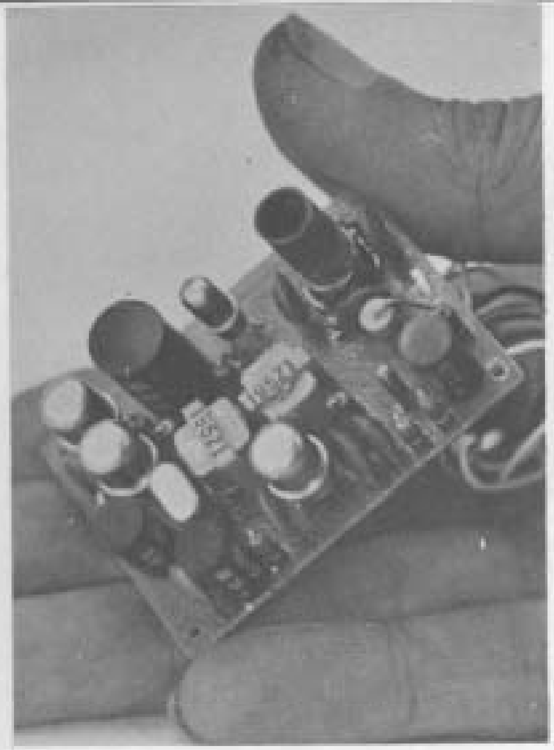
increasing the bulk and weight of the receiver, so that the final current change could be high enough to operate an actuator direct. Making the last stage of the receiver a high current *switcher* circuit, therefore, eliminates the need for a relay at all. The actuator can be connected directly to this circuit, and draw its current from the same battery as the receiver.

The advantages are obvious: a saving in bulk and weight for a complete receiver installation by eliminating both the relay and the actuator battery; plus the substitution of electronic switching instead of mechanical switching via relay contacts, eliminating relay adjustment and contact 'wear' as possible sources of trouble.

However, this is not a complete answer to simple receiver design. The switched current available as direct output from a relayless receiver is limited by the loading permissible on the final stage transistors. This means that the actual load—the electrical resistance of the actuator—has to be matched to the receiver. In practice this means that the choice of *type* of actuator is limited, usually to an *escapement* with a coil resistance of the order of 8 ohms.

A secondary disadvantage is that since one battery now supplies both the receiver and the actuator, the drain on the battery can be quite high when the actuator is being operated. At the same time since the actuator itself is now connected into the receiver circuit, operation of the actuator can cause interference in the radio circuit. The question of battery drain is not particularly critical as a nickel-cadmium battery can be used instead of small dry batteries and readily meets the full demand required. The weight of nickel-cadmium batteries is quite low, their performance under load is more stable than dry batteries, and they can be re-charged. They are thus a much better proposition for working miniature and sub-miniature relayless receivers than pen cells, although their initial cost is higher (see Chapter 21).

It is possible to treat this question of battery drain and interference in another way. The relayless receiver circuit can be designed to take two batteries, one for the radio side and another to supply the output power via the final 'switching' circuit. This has the further advantage of



Another example of the compact arrangement possible with an all-transistor single-channel tone receiver.

making the receiver circuit as independent of interference from the actuator as a normal relay receiver. A number of commercial relayless receivers have been produced on this basis, although the usual form adopted is a straight single-battery circuit.

Since a relayless receiver requires an actuator matched to its switching output, there is still a demand and need for relay receivers—particularly for use with motorised actuators (see Chapter 6). Modern circuit designs usually follow the same form as that of a relayless receiver, only in this case the relay connected in the output circuit forms the load, instead of the actuator. This means a low resistance relay can be used (usually with a coil resistance of 30 to 50 ohms), and because of the high current switched through the relay coil it can be a simple, non-sensitive type, providing positive and reliable operation.

Most modern single-channel all-transistor receivers, in fact, are produced in either 'relayless' or 'relay' form. The two circuits are identical. In the first case an actuator (escapement) is connected directly to the receiver output for relayless operation. In the second case the receiver panel includes a relay mounted on it, and connected to the switcher circuit. The actual output from the receiver is connected to the relay contacts, which function as a 'mechanical' switch.

Superhet receivers

The superheterodyne or *superhet* is a more highly developed type of receiver circuit with the advantage of providing a far greater degree of *selectivity*. The superregen circuit works well as a receiver, but its tuning is inevitably broad and even the best of designs does not have sufficient selectivity to reject spurious signals several hundred kHz from the true signal to which it is tuned. This means that it is not really possible to operate more than one superregen receiver at a time* in the 27 MHz band, even if tuned to opposite ends of the band. Also, of course, an individual receiver is susceptible to interference from any other sources of RF transmission overlapping the 27 MHz band.

The superhet receiver tackles this problem by providing far greater selectivity to signal frequency, so that spurious signals even as little as 5 kHz away from the tuned frequency are rejected. The transmitter/receiver combination, in fact, tunes and works on a 'spot' frequency,

The superhet receiver circuit is distinguished by its 'cans' or IF transformer stages.

*One 27 MHz transmitter operating will usually affect *any* superregen receiver, whether tuned in to that particular transmitter or not, over a range which may be several miles or much less (depending on the power of the transmitter and the spacing of the receiver tuning to the actual signal frequency transmitted). Increasing distance will reduce, and finally eliminate, interference, because the signals become so much weaker. Fortunately the range of model radio control transmitters *is* limited, otherwise operation of one transmitter could virtually blot out whole areas for use by other transmitter-receiver combinations!

Even the all-transistor receiver got quite complicated and bulky when developed for multi-channel working.

and only other transmissions at that particular 'spot' frequency are likely to interfere with it. Within the permitted transmitting frequencies of 26.96-27.28 MHz it is thus possible to select a considerable number of different 'spot' frequencies for working, making it possible to operate that number of receivers simultaneously with no interference from transmitters working on other 'spots'.

In practice six standard 'spot' frequencies are employed with 50 Hz spacing. It is possible to split these further, e.g. doubling the number by adopting 25 kHz spacings; and possibly at some later date 10 kHz spacings may prove practical.

The introduction of the superhet receiver solved a major problem by making simultaneous operation of radio controlled models possible at a particular site. Previously other operators had to wait whilst any one modeller was operating, and take turns for 'radio space'. It also minimised the effects of interference generally and made it possible to develop more complex radio control systems with an assurance of high reliability as regards signal selectivity. Otherwise the operating principle remains the same. Superhet receivers are produced in both relayless and relay form. They have not replaced the superregen receiver, however, because their cost is appreciably higher on account of the greater complexity of the circuit and the greater number of components required. Thus they offer an alternative for the modeller seeking more troublefree operation on single channel working; but the superhet receiver is an essential feature of all the more sophisticated proportional control systems.

Multi-channel working

The single-channel tone transmitter/receiver combination uses a single tone signal with a frequency of anything between 200 and 1000 Hz superimposed on the carrier. The actual frequency is not important, and receivers designed to match will usually respond to a broad range of tones within this range.

If the receiver is made more selective as far as tone response is concerned, then there is the possibility of utilising more than one tone signal superimposed on the carrier and thus arrive at a multiple signal radio link. This is the principle of *multi-channel* working, as it originally evolved.

Basically the transmitter is the same as for single-channel, except that there are a number of separate tone generator circuits (one for each tone required), any one of which can be switched on to modulate the carrier with that particular tone. The receiver is tuned to the carrier wave frequency (again as with single channel working), but must also have provision to respond to each individual tone separately, so that each individual tone is identified as a separate command signal.

This can be done electronically, using tone filters in the circuit. Each filter 'passes' its particular tone to produce an output (e.g. a current change to operate a relay), but blocks other tone signals. There can thus be as many switching outputs (e.g. via individual relays) as there are

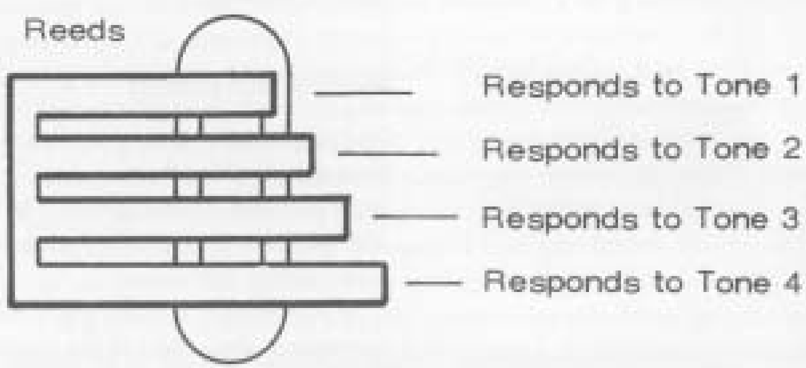
Tone receiver with tone-filter circuit.

filter circuits. In practice the number of such circuits was generally limited to two or three. Since each output circuit controls its own actuator, this provided two or three channel working, respectively.

Multi-channel working using receivers with tone filters was developed mainly in Germany and America, with up to six channels being made available on standard commercial equipment. It remained a rival to, but never achieved the same scope or popularity as, the *reed bank* system of tone identification which originated almost simultaneously in Britain and the United States but was mainly developed in the latter country.

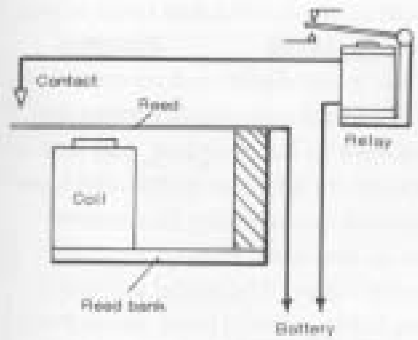
The main disadvantage of a tone-filter system is that AF filters are not nearly as selective as reeds and so the channels must be more widely spaced. Also it is more difficult to filter two tones simultaneously, due to the presence of harmonics or 'mixed' signals. Also AF filter units are heavier and more bulky than a reed bank designed to handle the same number of tones, mainly because the AF tones which can be used require the use of fairly large capacitors and inductances in the filter circuit.

A *reed bank* is rather like a relay but instead of having a single pivoted armature has a number of fixed reeds or flat metal strips mounted over the coil. Each reed is a 'resonator'. That is to say, it will have a natural frequency of vibration or *resonant frequency*, depending on its length, width and thickness (and the metal from which it is made). Reed proportions are thus carefully selected so that each reed is resonant at a particular tone frequency.

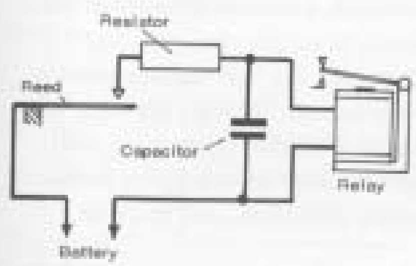


1.9 With a set of sensitive reeds (a Reed Bank), each Reed responds to a particular Tone signal equivalent to the resonant frequency of the reed.

Early valve-transistor reed-type receiver.



1.10 Basic geometry of a single reed in a Reed Bank. The vibrating reed completes the circuit to the Relay through the Contact.



1.11 This shows the electrical circuit of a single Reed. The Capacitor acts as a 'reservoir' to supply a continuous current to hold the relay in when the reed is vibrating. A Resistor is included in the circuit to limit the peak current.

Compact type of all-transistor multi-channel reed superhet receiver (note the IF 'cans'). This configuration remained a popular favourite for years, but primarily developed in the United States.

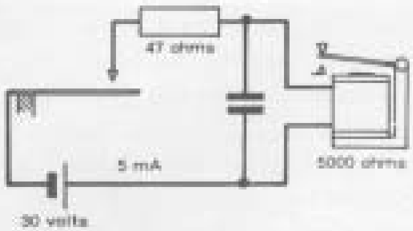
All the reeds are mounted over the top of a coil with a magnetic core (*figure 1.9*) which is connected in the receiver circuit in the same manner as a relay. The 'tone' signal is, however, fed through this coil, after detection and amplification as necessary. Thus the coil is excited with an alternating current having a frequency corresponding to that of the tone signal. When this corresponds to the resonant frequency of a particular reed, the reed will be set in vibration and continue vibrating as long as that tone signal is held.

The amplitude of vibration of each reed is limited by a stop, which also acts as a contact (*figure 1.10*). When the reed is vibrating it will, therefore, touch this contact during part of each cycle of operation. If both reed and contact are connected to a relay circuit, as shown, the relay coil will be energised (momentarily) once for each cycle of reed vibration.

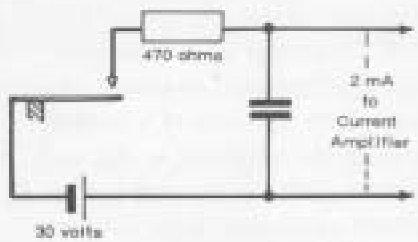
The actual period during which the reed is touching the contact will be quite small—probably of the order of 1 to 10 per cent of the complete cycle of vibration. However, if a capacitor is included connected across the relay coil, this will act as a 'reservoir' to charge up when contact is made and then discharge when the contact is broken again to maintain a flow of current through the relay coil. In this way the relay can be made to pull in and remain pulled in through the whole of the reed vibration cycle. In other words, excitation of the reed into resonant vibration by passage of a particular tone signal through the reed bank coil operates a relay to give a switching response (via the *relay* contacts) to control an actuator circuit. This is the same as basic single-channel working except that both a reed bank (to respond to the tone signal) *and* a relay (to switch the actuator circuit) are involved.

Many reeds can be mounted in a single magnetic circuit and if each is of different length, each will resonate (vibrate) at a different tone frequency. Any particular tone signalled will, therefore, energise its particular resonant reed, which will in turn cause the relay connected to it to pull in and hold in, completing the switching on of an actuator circuit connected to the relay contacts. The system will have as many channels (or command signals) as there are individual reeds, with each reed having its own relay (to which can be connected a separate actuator circuit).

The main limitation with this system is that the tone range must lie within one octave, as the individual reeds will respond to harmonics as well as fundamental tone frequencies. This octave will also lie within the usual tone frequency range of 250 to 650 Hz. Each reed, therefore, must provide sufficient sensitivity for independent response within one octave, i.e. have a narrow band width for response. The greater the number of reeds used, the more sharply peaked the resonant frequencies of the individual reeds need to be. This places a premium on reed design and precision manufacturer; and also adjustment. Thus the lower the contact position, (i.e. the more restricted the amplitude of the vibrating reed), the greater the band width over which contact will be made. Nevertheless it is practical to produce reed bands with up to 12 individual reeds which perform satisfactorily, i.e. giving up to



1.12 Practical values in a Reed circuit commanding a Relay with a 5000 ohms coil resistance and giving a 5 milliamp current through the relay coil.



1.13 In relayless operation the Reed contact can carry a lower current (e.g. of the order of 2 milliamps). This current is then boosted by an amplifier circuit to provide a high enough current to operate an actuator direct, instead of being switched by the contacts of a relay.

12-channel working. *Simultaneous* operation of individual reeds is also possible, although not usually on adjacent reeds.

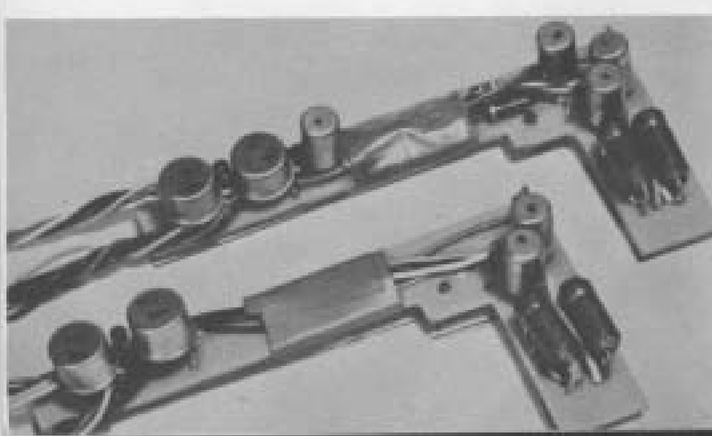
Apart from practical factors involved in the design and construction of the reed bank itself (which is a very critical component), there are two main disadvantages of the reed system so far described. The first is the fairly obvious one of bulk and weight. In addition to the reed bank, itself fairly bulky and heavy, each channel needs a relay to complete the switching function to control the various actuators.

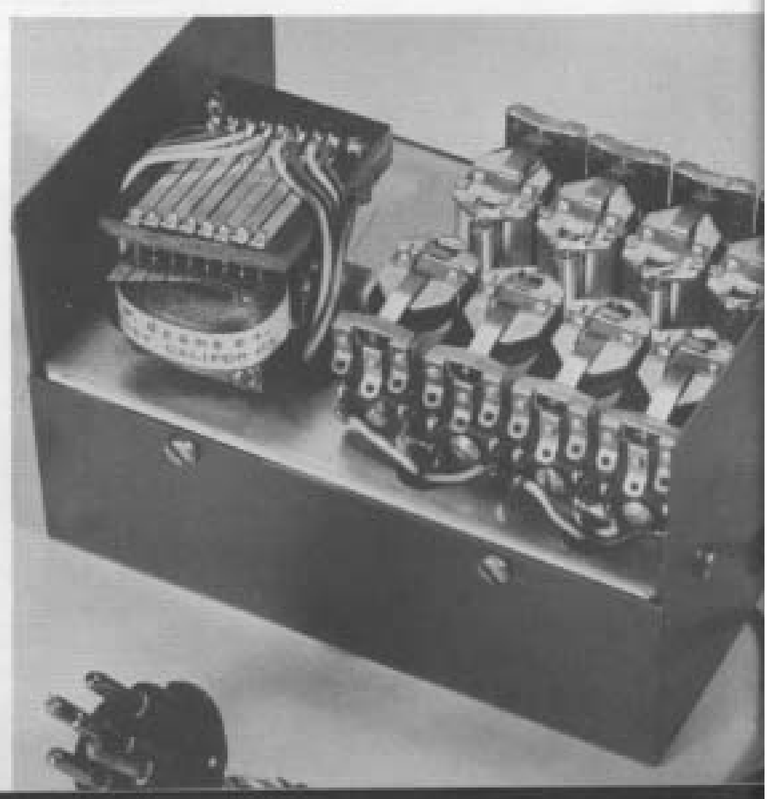
The second is concerned with current values. The actual current carried by the two contacts in each switching circuit (reed contact and relay contact) is considerably higher than the nominal operating current of the relay itself, due to the low-duty cycle involved. Thus with a 10 per cent duty cycle, and with the relay drawing 5 milliamps, say, to pull in, peak current values of up to 10 x 5 = 50 milliamps may be carried by the contacts, which can cause pitting and burning and troublesome operation. It is necessary, in fact, to include a resistor in series in the circuit to limit the initial or peak current when the circuit is first closed to an acceptable value. Unfortunately if a high resistor value is used to produce a low peak current, the current through the relay will also suffer. It is thus usually necessary to limit the resistor to a relatively low value (e.g. typically 47 ohms) in order to obtain the necessary current through the relay for satisfactory operation, and to avoid excessive waste of battery power.

Considerable improvement is possible with *relayless* operation. Here the power output handled by the reed contacts can be kept quite low (typically of the order of 0.2 milliamps), which can then be fed to a *current amplifier* in the actuator circuit. A series resistor is still needed to limit the initial peak current, but this time its value can be relatively high (e.g. typically 470 ohms). Apart from the considerable saving in bulk and weight, the elimination of the relays also reduces the number of contacts effective in each circuit to two (those on the reed bank).

(Right) With relay working, each reed channel required one relay. This added considerably to the bulk and weight of the receiver.

(Below) Transistor-amplifier circuits for relayless operation of multi-channel servos. The L-shaped board was designed to fit inside the actuator casing.





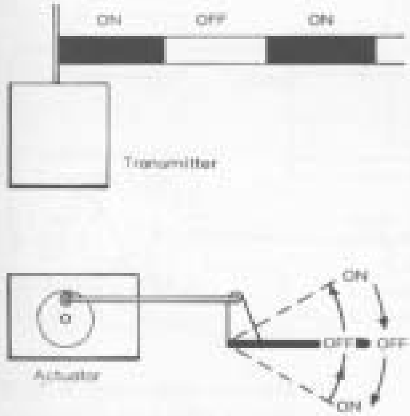
Multi-channel actuators

Each channel on multi-channel working can be used to control a single-channel actuator. This, however, is not the normal mode of working, except for minor or secondary controls on some applications. Instead *two* channels are used to control *one* actuator. The advantage of this is that this provides for *selective* operation, whereas single channel working can only be sequential.

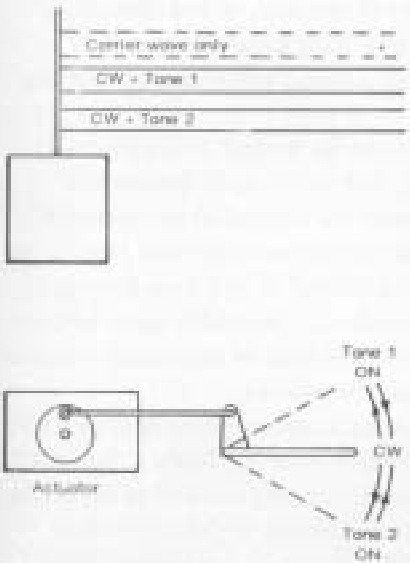
This can be demonstrated by a simple example (*figure 1.14*). Single-channel signalling applied via an actuator to, say, a rudder control, can only produce a sequence of movements (see also Chapter 6), viz: neutral–right rudder–neutral–left rudder–neutral. To signal 'right rudder' after the last command had also been 'right rudder' would mean switching through the complete sequence.

The use of two channels controlling the rudder actuator provides alternative command possibilities, viz: right rudder (one channel); left rudder (the other channel)–*figure 1.15*.

The actuator would be designed to return to neutral on release of signal. Thus the signal for either 'right rudder' or 'left rudder' can be selected at will; and on cessation of signal, the rudder will return to neutral. This is the basis of conventional multi-channel working.

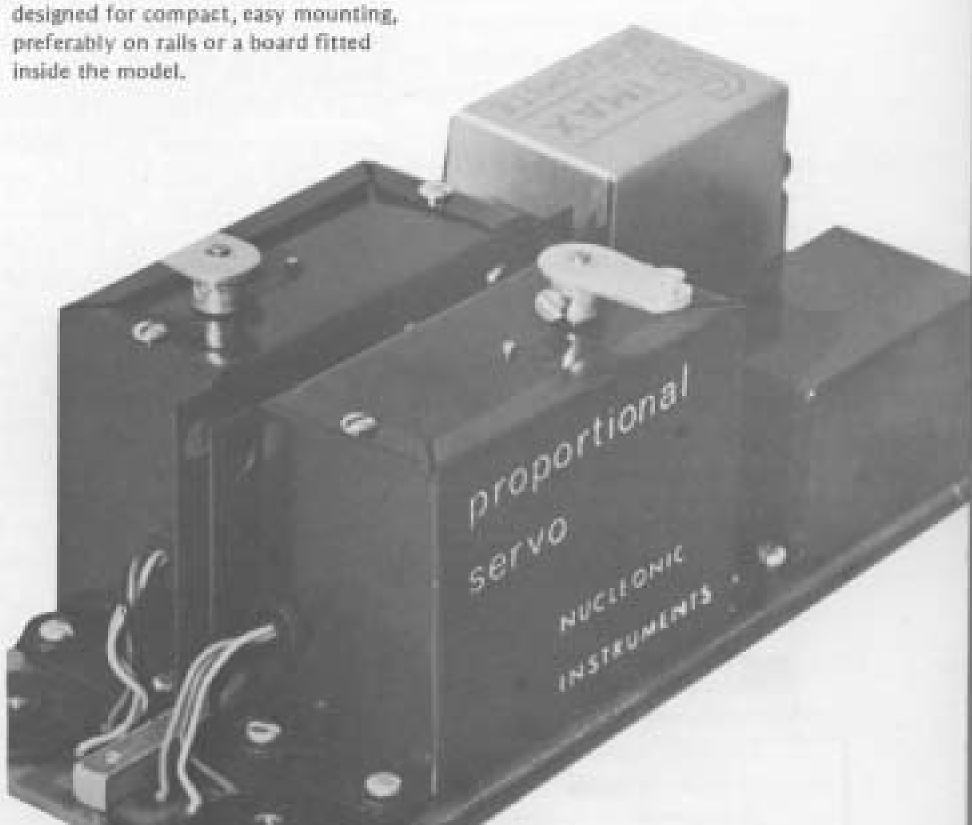


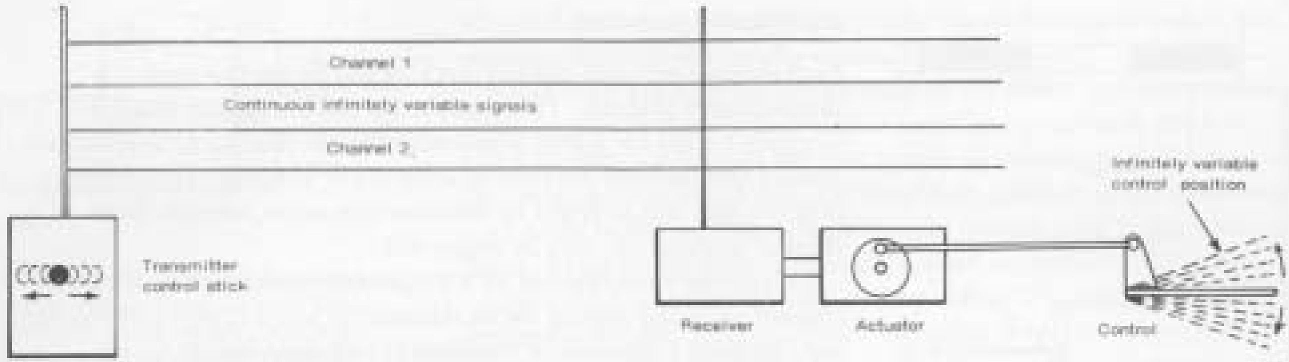
1.14 Single-channel signalling is either 'ON' or 'OFF' and the actuator can only follow this switching to provide control movement ON-OFF in sequence.



1.15 The three conditions of a two-channel Tone transmitter are:-
Carrier Wave only (sent continuously, and corresponding to 'no command')
Carrier Wave plus Tone 1 (command 1 'ON')
Carrier Wave plus Tone 2 (command 2 'ON')
This means that opposite control positions provided by a multi-channel actuator can be selected at will. With no command (CW only), the actuator returns to the neutral position.

(Below) Proportional servos are designed for compact, easy mounting, preferably on rails or a board fitted inside the model.





1.16 With a true proportional control system the actuator is under continuous command from the equivalent of two signal channels and the control assumes a position corresponding to the position of the Transmitter Control Stick.

Proportional controls

Both single-channel and multi-channel working have one characteristic in common. Control response is either 'on' or 'off'. This can be allied to actuators which are self-centring (return to neutral on release of signal) or progressive (stop where they are on release of signal).

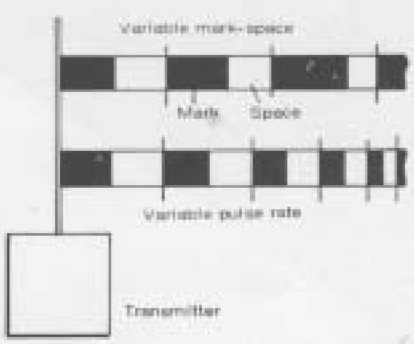
Self-centring actuators are used on main controls; e.g. rudder, elevators and ailerons on aircraft models. Control response achieved is thus either full rudder movement (or full elevator, or full aileron), or centralised. This has become known as a 'bang-bang' control—full movement to one extreme or the other with no possibility of selecting intermediate movements.

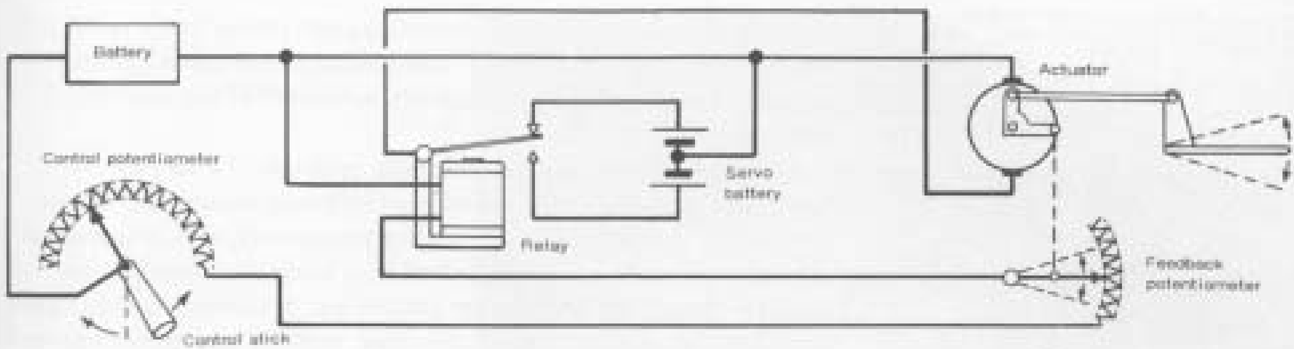
With progressive response, controls can be 'inched' to a particular position; then inched on a bit farther, and so on, up to the limit of movement. Further 'inching' then moves the control in the opposite direction. This is not suitable for main control services since there is no means of telling the exact position of a control at any time (except by judging the response of the model, which is an unreliable guide because of the time lag involved). It is, however, the type of movement required for a throttle control, and some secondary services.

Proportional controls aim at producing a control movement exactly proportional to the movement of a control lever (typically a 'joystick') on the transmitter. This demands a more complex method of signalling since the command must both initiate movement in the required direction and at the same time signal the degree of movement called for. There must also be some means of ensuring or measuring the control movement to check for proportionality.

Proportional control can be obtained with single-channel signalling by *pulsing* the transmitter signal. Here the tone signal is superimposed on the carrier in a series of discrete pulses, rather than continuously, with the opportunity of varying the *width* of the pulses (or mark-space ratio), or the *rate* of pulsing, or both (*figure 1.17*). Either, or both, can be utilised to produce a form of proportional response, and various systems have been devised to operate on this basis. Those employing single tones are basically still single channel systems and are described in detail in Chapter 8. They retain a basic simplicity, but have a number of functional disadvantages—not the least being the inability to 'sense' the control movement and compare it with the original command.

1.17 Sending a pulsed signal is one method of providing 'multiple' intelligence via a single channel. This can be done by varying the Mark-Space ratio of the pulses (the signal on-signal-off ratio in a complete pulse); or by varying the actual rate of pulsing. The bottom signal shows variable pulse rate with a 50:50 Mark-Space ratio.





1.18 A circuit demonstrating the working of an Analog Proportional control. The Feedback Potentiometer is driven by the actuator and generates an 'error signal' when the actuator movement has not exactly followed the Control Stick movement. The presence of an 'error signal' causes the actuator to continue moving until this signal falls to zero.

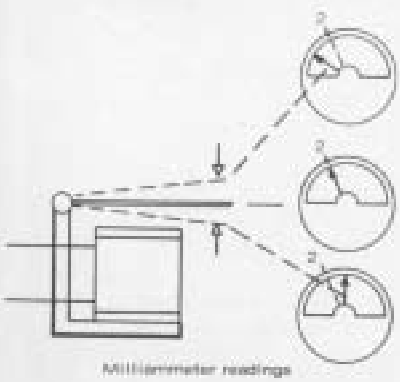
True proportional systems are based on *closed loop* servo circuits where the output provides some form of feedback which compares the position of the control with the input signal. Any difference produces an *error* signal, which is used to reposition the actuator to its true proportional position and render the error signal zero.

This can best be demonstrated with a typical analog circuit, as shown in *figure 1.18.* The actuator in this case is an electric motor, the switching of which is controlled by a relay. The actuator will drive in either direction, depending on whether the relay armature is pulled in or dropped out. With the armature in the mid position the motor circuit is broken and thus the actuator remains stationary.

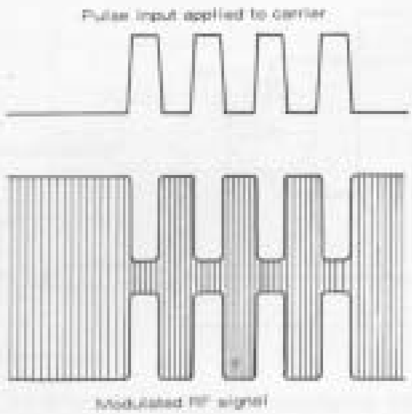
Assuming that the relay is adjusted to pull in at a current of a little over 2 milliamps and drop out at a little under 2 milliamps, a 2 milliamp input signal to the circuit will maintain the relay in a 'null' condition with the armature mid-way between the contacts, this condition being set up by appropriate adjustment of the control potentiometer.

If now the control potentiometer is moved to decrease the resistance in circuit the current will rise, pulling the relay armature in and completing the circuit for the motor to run in one direction. Coupled to the motor movement is a second potentiometer of similar value to the first, but connected the other way round. Thus as the motor drives the potentiometer in the direction initiated the resistance provided by the second potentiometer increases, until a point is reached where the increase in resistance exactly balances the decrease in resistance given by movement of the control potentiometer. At this point the relay current will have fallen to 2 milliamps again, giving a 'null' condition for the relay and switching off the motor.

1.19 Current flow through the Relay in the analog circuit of Fig. 1.18 and corresponding relay armature positions, controlling the switching of the Actuator.



Basically, therefore, such a circuit is stable (stationary) only with 'null' conditions for the relay. Any movement of the control potentiometer will induce an 'error signal' due to change of resistance in circuit causing the motor to drive in one direction or the other. This movement is used to operate the feedback potentiometer, coupled in such a way as to compensate for the original change in resistance and restore the circuit to its 'null' condition again. Thus the feedback control provides *proportional* movement of the actuator relative to the *actual* change in input signal (or actual movement of the control potentiometer). The actuator will then remain at this commanded



1.20 Almost all modern radio control systems are based on Digital Proportional. Intelligence is encoder at the Transmitter in the form of pulses of variable width, giving a Modulated RF Signal of the typical form shown. Compare this signal with that of simple Tone Modulated RF shown in Figs. 2.6 and 3.9.

position as long as the control potentiometer remains in the position it has been set. Thus any position from neutral to full throw in either direction can be set up by appropriate movement of the control potentiometer.

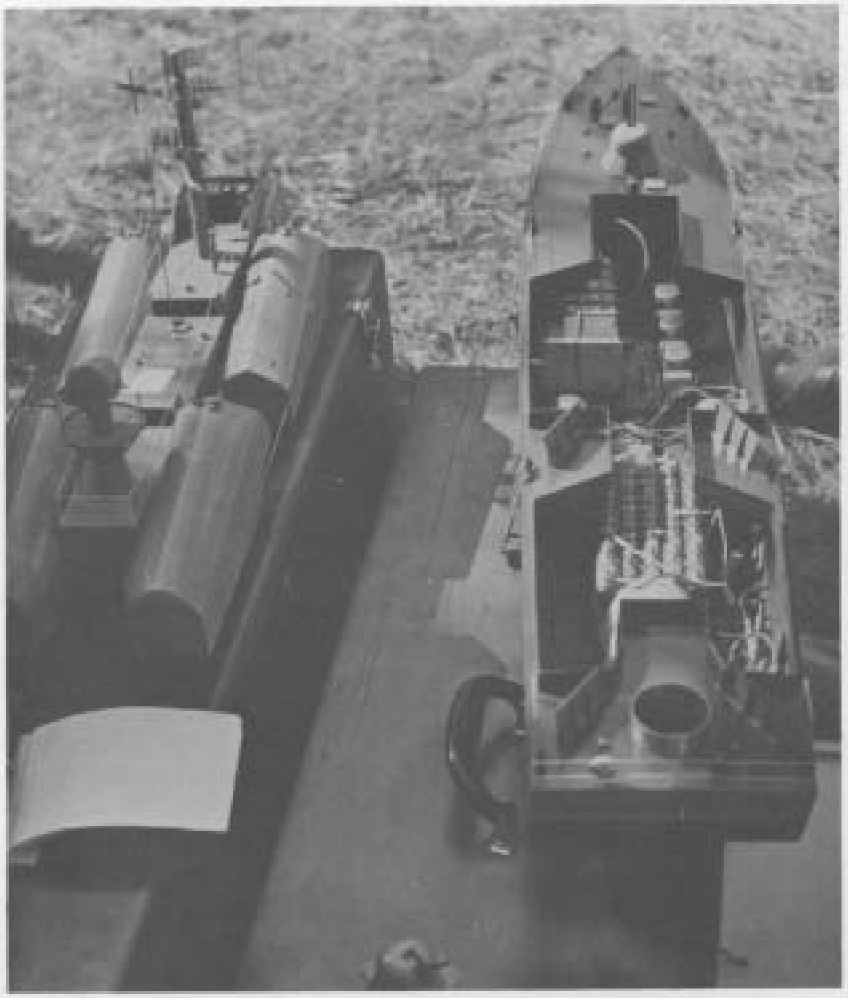
All analog systems work on this basic principle of a varying 'command' resistance (equivalent to an infinitely variable DC voltage imposed on the circuit by control stick movement), with proportional movement of the control determined by a feedback potentiometer. Separate transmitter and receiver circuits are, of course, involved rather than the simple integral circuit described, with the intelligence encoded by the transmitter and decoded by the receiver and actuator(s) (see Chapter 10).

Digital systems work on a similar basis of closed loop servo circuits with feedback, but the method of originating the command and providing feedback differs considerably. Basically the transmitter encodes the signal in terms of pulses of variable width, which are decoded at the receiver end in terms of 'pulse count' (again see Chapter 10).

Proportional control systems represent the ultimate in model radio control requirements. They can readily provide for multiple controls (simultaneously operable as necessary) and infinitely variable positioning (with true proportionality of movement ensured). Multiple controls are essential for *complete* control of many types of models, particularly aircraft. Proportional control response is also so much more desirable than bang-bang movements that modern proportional systems have completely replaced all original multi-channel systems.

At one time it was thought that the considerably greater complexity on the electronics side would inevitably mean that the cost of proportional systems would be several hundreds of pounds, and thus well outside the means of the average radio control enthusiasts. However, intensive development and large scale production (particularly in Japan), brought prices down to be directly comparable with reed and tone filter multi-channel outfits. The latter then ceased to be competitive on a price basis, which was their sole hope of survival against fully proportional systems, and manufacture of multi-channel equipment was discontinued. It had served its purpose of showing the great value of multiple controls—which enabled great advances to be made in the design and performance of radio controlled models.

The proportional transmitter is usually distinguished by a control stick capable of providing proportional control signals on two channels simultaneously. A separate trim control is also provided for each channel—seen to one side and under the stick.




22

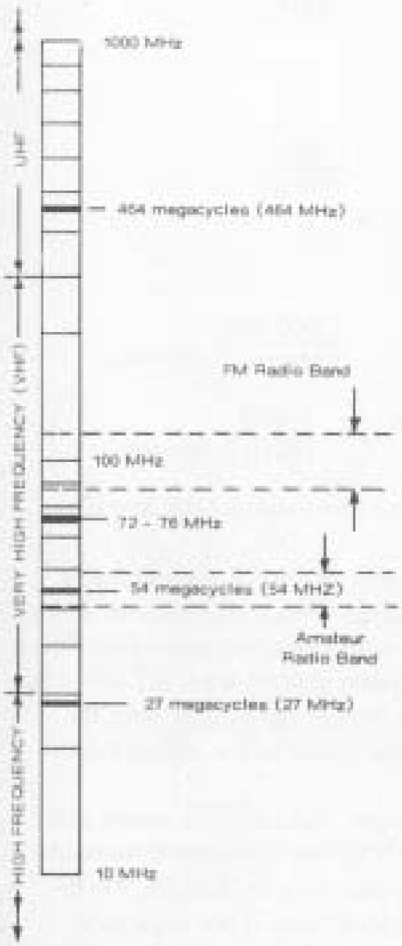
Model radio control signals have only a limited range due to the low power transmitters used, but this is quite acequate to control model aircraft in flight within the range of visibility. Note pennant on transmitter aerial identifying the 'spot' frequency this transmitter is operating on. (Radio Modeller photo)

2 BASIC RADIO FACTS

Radio waves travel with the speed of light—about 186,000 miles per second or 300,000,000 metres per second—and can be generated by any radio frequency (RF) current flowing in a circuit. RF is an alternating, rather than a steady current, and the *frequency* is the number of complete waves generated by the source in one second. The correct description is 'cycles per second', for which the abbreviation cps or cycles/sec was originally used. This is now replaced by the term Hertz, abbreviated Hz, meaning 'cycles per second'.

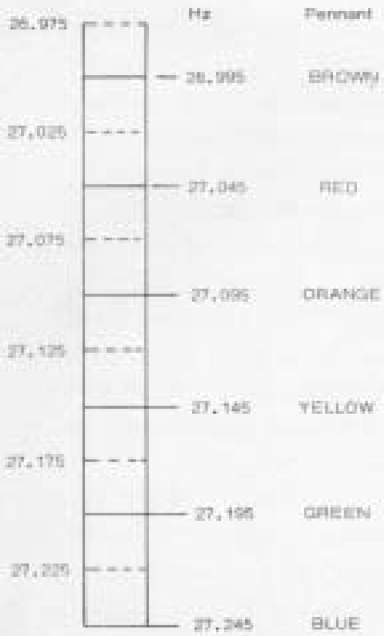
Radio waves are generated at very high frequencies, ranging from about 15,000 Hz up to 100,000,000 Hz and beyond. To avoid quoting large numbers of zeros abbreviations are normally used—kilo or k for 1000 and mega or M for 1,000,000. Thus the range above would be written 15 kHz to 100 MHz.

This spread, or radio frequency spectrum, is roughly divided into low frequency (long wavelength), medium frequency (medium wave), high frequency (short wave), very high frequency (VHF) and ultra high frequency (UHF), all of which are used for various broadcast applications. Specific narrow frequency ranges or *bands* are allocated for amateur broadcasting, transmitting on which requires an amateur licence, qualification for which requires passing both a written examination on radio technology and a practical test in Morse code transmission and reception. One specific band, however, is allocated for general use by radio control modellers in the United Kingdom: the 27 MHz band with a specific width from 26.995 MHz to 27.255 MHz. Transmission at frequencies within this band is permitted, for radio control purposes only, by holders of a special licence which can be obtained on application, without examination or any other type of qualification. This radio control band is further subdivided into internationally recognised standard 'spot' frequencies. These are the specific frequencies at which crystal controlled transmitters should work, particularly when used with superhet receivers.



2.1 Portion of the radio frequency spectrum showing the position of the three radio control bands.

Twin or multi-engine power is perfectly practical with modern radio control.



2.2 'Spot' frequencies in the '27 megacycle' (27 MHz) radio control band identified on transmitter by a coloured pennant attached to the aerial.

The term *wavelength* has largely been abandoned as descriptive of the position of a particular broadcast frequency in the RF spectrum, although it is still quoted to some extent in connection with domestic radio broadcasts, e.g. long wave, medium wave and short wave. It is still of some technical interest, however, particularly in the design of aerials (see Chapter 5). The relationship between wavelength (in metres) and frequency f (in kiloherz) is quite straightforward:

$$\text{wavelength (m)} = \frac{300{,}000}{f(\text{kHz})}$$

If f is expressed in megaherz,

$$\text{wavelength (m)} = \frac{300}{f(\text{MHz})}$$

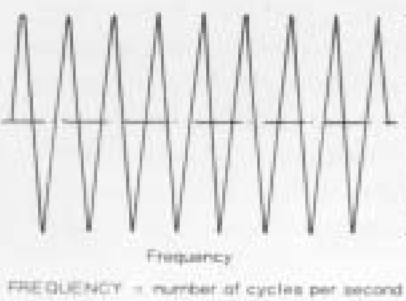
If the wavelength is wanted in feet,

$$\text{wavelength (ft)} = \frac{1{,}000{,}000}{f(\text{MHz})} \text{ approx.}$$

$$\text{or} = \frac{1{,}000}{f(\text{MHz})} \text{ approx.}$$

High frequency thus corresponds to a *short* wavelength, and vice versa.

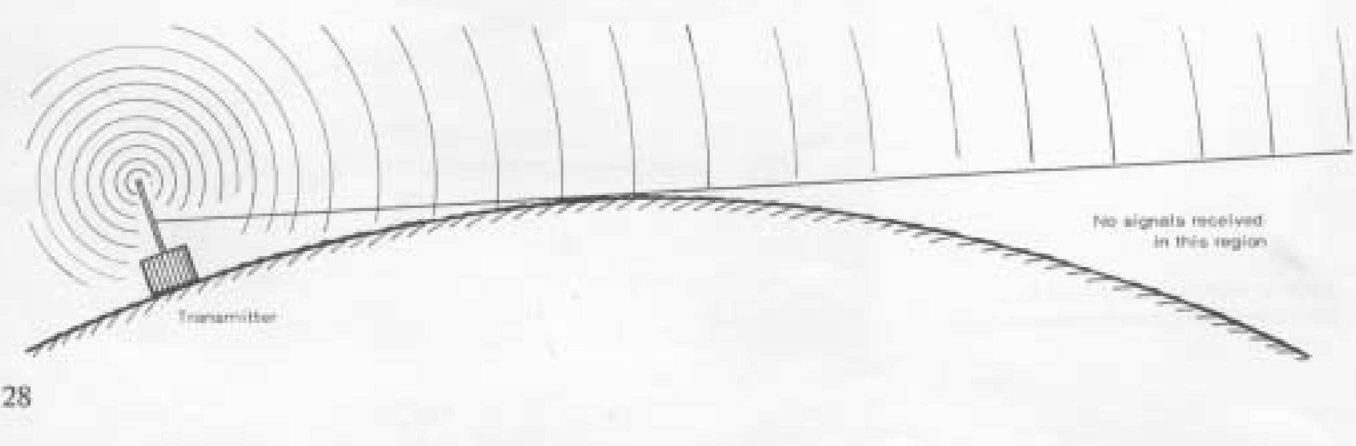
A basic radio transmission consists of a steady RF wave radiated from the transmitter aerial in all directions. This wave will have a fixed frequency—e.g. so-many kHz or MHz—and a constant amplitude (*figure 2.3*). At the frequency of interest for radio control work (27 MHz) the range of transmission will extend on a 'line of sight' basis, with the *power* of the RF signal decreasing as the square of the distance from the transmitter.



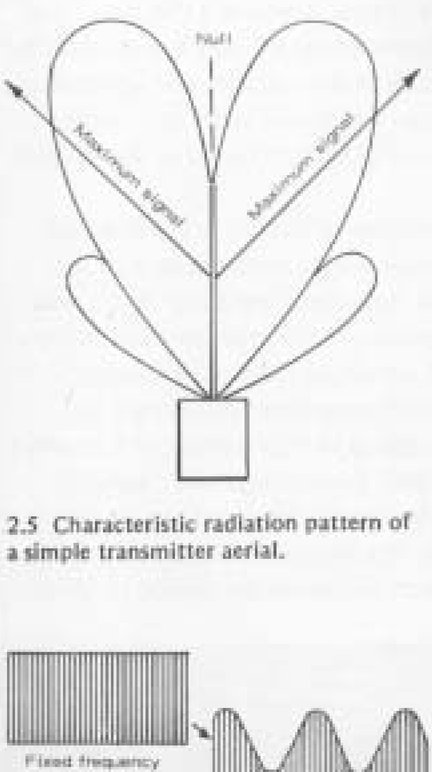
2.3 Constant amplitude radio frequency signal—frequency scale considerably expanded.

Even with high power, the 'line of sight' characteristic means that reception at a distance would be cut off by the curvature of the earth. Also, of course, power drops off quite rapidly with distance. Fortunately for model radio control work a long range is not necessary. Models must be operated within 'line of sight' anyway, and even with model aircraft a distance of about a mile is the practical maximum at which it is possible to observe what the model is doing.

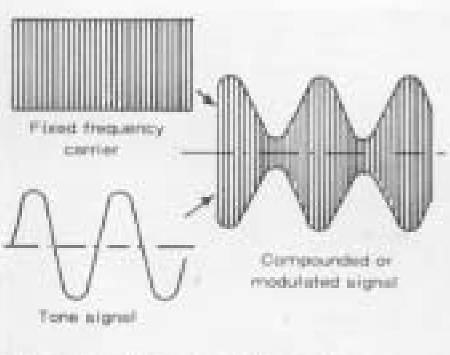
2.4 Radio control signal transmission is 'line-of-sight'.



Realism in miniature—thanks to radio control! This could be a shot of a full size aeroplane approaching a grass landing field—except that the figure is holding a transmitter, and is the 'pilot'.



2.5 Characteristic radiation pattern of a simple transmitter aerial.



2.6 A modulated radio frequency signal is made up by combining a 'tone' signal with a fixed frequency RF 'carrier' signal.

Radio control transmitters can, therefore, work on relatively low power; and need only have a maximum range of a mile or so. In many applications, e.g. control of model boats or cars, only a very short range is necessary for satisfactory operation. Range is also affected by the radiation pattern of the aerial. With the type of aerial normally employed on radio control transmitters, maximum power is radiated in an outward and upward direction (*figure 2.5*). This means that the ground-to-air range is generally appreciably greater than the ground-to-ground range—a useful feature again for model aircraft control.

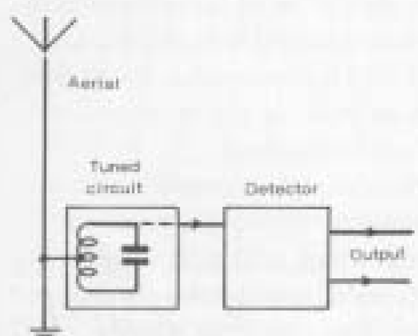
Transmitter input power can range from as high as several watts, to as little as 100 milliwatts or less, depending on the design, type and application involved. Low powered transmitters, used with suitable matching receivers, are suitable for all types of model radio control, provided the transmitter has a reasonably high efficiency. Only a proportion of the input power is transmitted as RF output power; the higher the proportion the greater the efficiency of the transmitter, and vice versa. This is a matter both of transmitter circuit design and 'peaking' the RF output transmitter by adjustment of the aerial and/or tuned circuit.

A rather better type of signal for transmitting purposes is obtained by modifying the fixed-frequency constant-amplitude RF signal with a much lower frequency signal superimposed on it. This combined or *modulated* signal takes the form shown in *figure 2.6*. The original RF signal has its amplitude modulated at the frequency of the lower frequency signal. The original RF signal is known as the carrier wave (CW), and the combined signal as a tone modulated CW or just a tone signal. The description 'tone' is used because the lower frequencies chosen for applying modulation fall within the range of frequencies which are *audible*. They are generally called audio frequencies or AF. These range from about 30 Hz (a very low, deep note) up to about 16 kHz (a very high pitch whistle). Tone frequencies used for model radio control work usually range between about 350 and 1000 Hz, with 650 Hz being a typical average value.

This principle of tone modulation is, in fact, exactly the same as that used in normal broadcasting. Transmission of speech or music is simply audio tones or AF superimposed on a carrier wave. The tones in this case are much more complex, however, and there are many more of them.

For model radio control transmissions, both straightforward CW and tone modulated transmissions can be used. As will be seen in later chapters there are advantages in the use of tone signalling for even the simplest form of radio link. For more complex working further tones can be used to increase the degree of intelligence or 'command' transmitted, and the individual tones themselves further modified, if necessary. Regardless of the type of transmission employed, however, it is the carrier wave which sets the transmitting frequency, and to which the receiver has to be tuned. In other words, however a CW signal may be modulated, it is the carrier which remains at RF and is picked up by the aerial of the receiver at a distance. Smaller voltages and currents of exactly the same *pattern* as the original signal, but with very much smaller amplitude, are induced in an aerial system tuned to the original carrier frequency.

A basic receiver consists of an *aerial, tuned circuit,* and a *detector* (*figure 2.7*). The aerial and tuned circuit together comprise a circuit which will be *resonant* to a particular frequency, meaning that it will extract RF signals present at that frequency with maximum response, and show little or no response to RF signals of other frequencies. In the case of a radio control link the transmitter operates on a single frequency, so the receiver need only be tuned to that particular frequency. The tuned circuit components need only therefore provide suitable adjustment for the electrical characteristics of the aerial circuit to produce 'peak' tuning. Once tuned in this manner it can be left, unless something happens to the circuit which can cause the tuning to 'drift'.



2.7 Basic receiver comprises an aerial, tuned circuit, and detector.

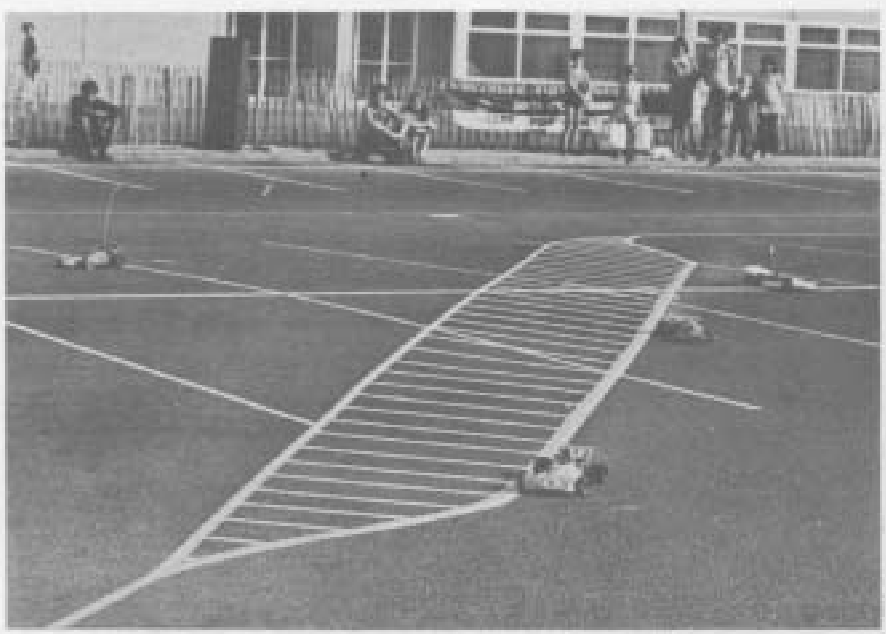

Model boats are another popular choice for radio control. Safer than model aircraft, since they are far less likely to suffer damage from 'pilot error' or malfunctioning of equipment.

Tuning controls are thus basically for initial adjustment and setting up to match a particular transmitter.

The purpose of the *detector* is to make use of the signal received by decoding any intelligence contained in the signal, and providing some sort of output. The simplest case for radio control purposes is where the detector merely has to determine whether the signal is being transmitted or not, (e.g. transmitter signal 'on' corresponding to a command being given; and transmitter signal 'off' corresponding to no command). The output to correspond to this simple type of command is an on-off switching function.

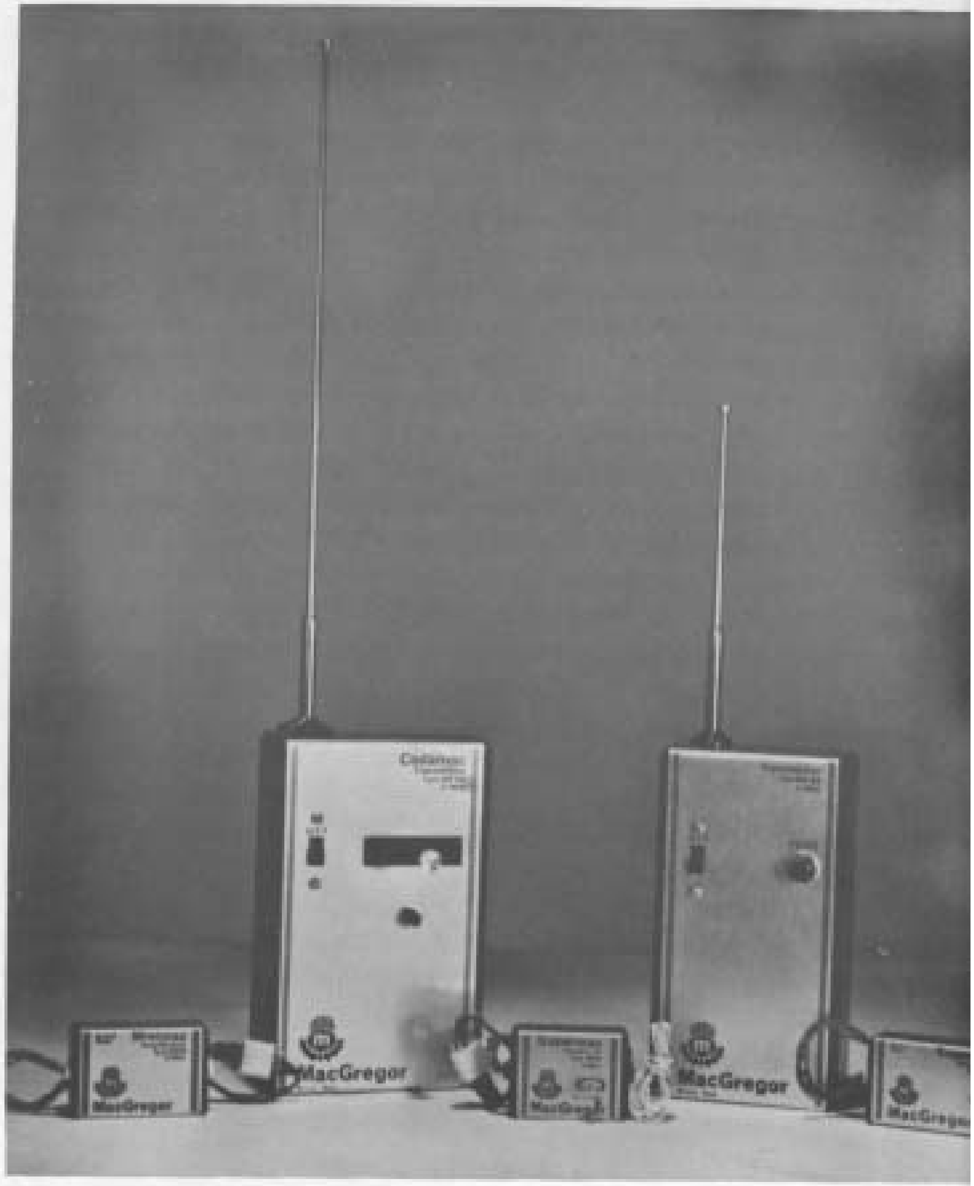
This can be made quite satisfactorily by employing a transistor (or valve) in what is known as a superregenerative circuit which is set up to near-oscillating conditions. The working point of the transistor (or valve) is moved in and out of oscillation, depending on the presence or absence of RF signal in the aerial/tuned circuit. A change of working point produces a change in current flowing through the circuit, which current change can be used to operate a relay to work as a switching element.

Early valve receivers worked on nothing more than this set up, as single stage superregen receivers responding to CW signals on an 'on-off' basis. The subsequent evolution of single-channel superregen receiver design can be studied in more detail in Chapter 4. *Superheterodyne* (superhet) receivers, which provide far greater selectivity, are also described in Chapter 4. These two receiver types—*superregen* and *superhet*—are the standard for model radio control working.

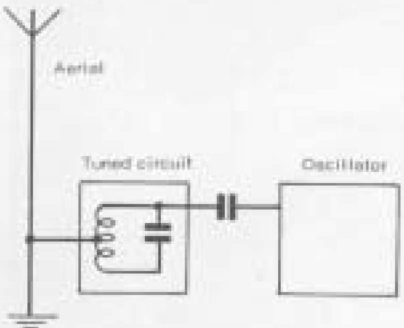


Road vehicles are less popular for radio control—but can present tremendous scope. (Radio Modeller photo)

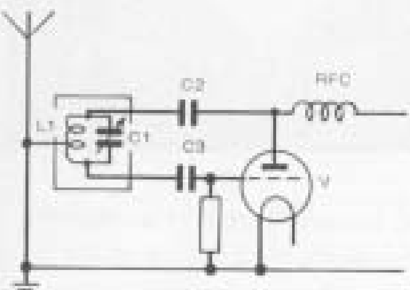
Examples of modern single-channel all-transistor transmitters, shown with alternative receivers. Fewer and fewer manufacturers now produce single-channel equipment, 'proportional' having taken over.



3 SINGLE-CHANNEL TRANSMITTERS



3.1 The basic elements which go to make a transmitter.



3.2 Circuit diagram of a basic valve transmitter. Symbols used are those normally employed for model radio control diagrams and not the same as BS symbols.
C2 is capacitor 'blocking' the HT. C3 is the grid capacitor. The radio frequency choke (RFC) is the anode load for the valve (V).

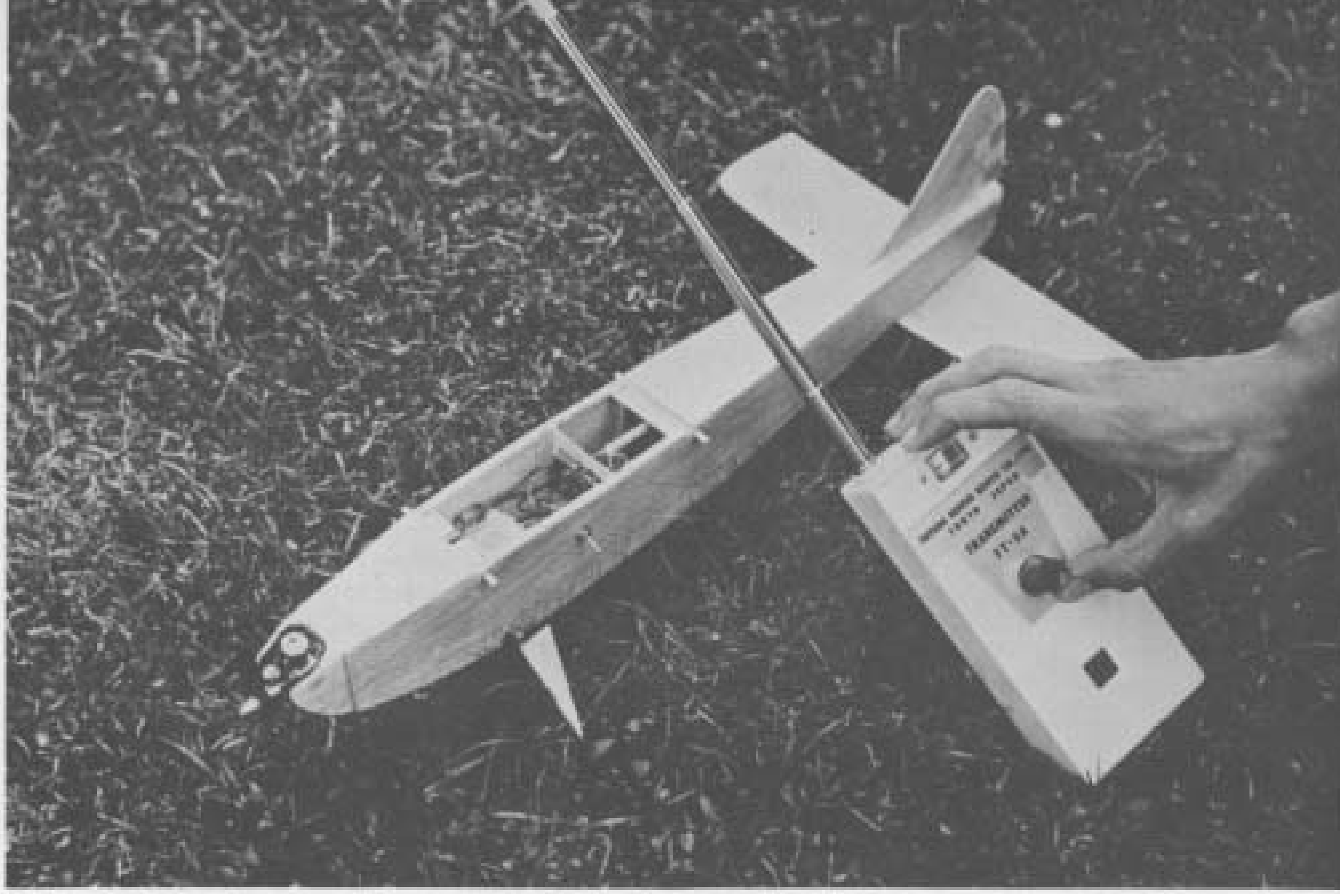
The basis of any transmitter is a radio frequency (RF) oscillator. This is a relatively straightforward circuit involving a suitable valve, or transistor, the object being to generate an RF signal at the required frequency which can then be radiated from a matching aerial system. As noted in Chapter 1, such a signal can be used directly for carrier wave (CW) operation of a transmitter-receiver combination, merely by arranging to switch the transmitted RF signal 'on' and 'off' to produce corresponding switching response in the receiver tuned to the original signal.

Early transmitters did, in fact, operate entirely on this basis, using the type of circuit shown in *figure 3.2.* The triode valve in this mode of working acts as an amplifier to any signals fed to the grid, but at the same time the amplified signal is returned to the grid. Provided the operating conditions for the valve are suitable, this will result in self-generated and continuous oscillations being developed in the valve circuit.

Operating conditions are set by the *grid capacitor* and the *grid resistor* (grid leak), biasing the valve to the working point where it will oscillate. Component values must thus be chosen to suit the valve used. The *frequency* of oscillation is then determined by the *tuned circuit* (comprising the tuning coil L1 and the capacitor C1). Component values, again, are chosen to provide an oscillation frequency of 27 MHz.

The other important components involved in this circuit are the radio frequency choke (RFC) between the anode of the valve and the HT + supply; and the blocking capacitor C2 in the connection between the valve anode and the tuned circuit. The RFC choke provides the necessary anode load for the valve (V) to work. It needs to be a choke

Typical example of a hybrid (valve-transistor) single-channel transmitter. Note the two batteries and high voltage HT required for the valve circuit.



The all-transistor transmitter works off a single low voltage battery and can be made extremely compact. Japan was a prolific source of single-channel equipment during the latter 1960s.

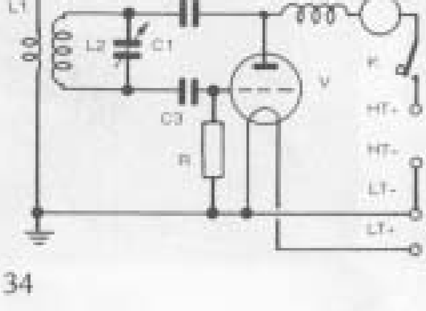
rather than a plain resistor to allow DC to pass (from HT+ to the anode), but to stop the RF signal from passing in to this leg of the circuit. The blocking capacitor works the other way round by stopping DC passing beyond the anode of the valve into the tuned circuit, but at the same time allows the oscillating RF current to pass into the tuned circuit.

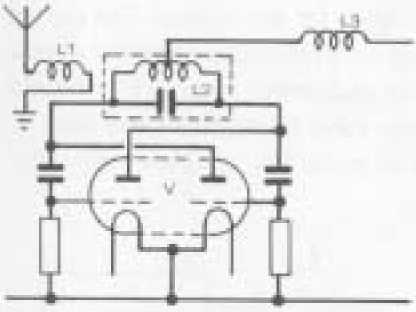
To provide 'on' and 'off' signalling it is only necessary to insert a key in one of the battery leads. The usual place is in the HT + lead. A further switch can be inserted in the common negative lead to act as an on-off switch for the batteries. This could, in fact, also serve as a signalling key (dispensing with the other key), but since a more sensitive type of switch than a simple on-off switch is required for precise signalling a separate *microswitch* is invariably used for 'keying' or signal-switching.

A practical circuit of this type, together with component values, is shown in *figure 3.3.* It is simple to construct and can readily be made to work, but it suffers from a number of limitations, particularly as regards low efficiency (relatively low RF output power in proportion to the input power supplied by the batteries), and lack of stability. Nevertheless this type of transmitter circuit was popular in this country right up until the mid-1950s, both for amateur and commercial productions.

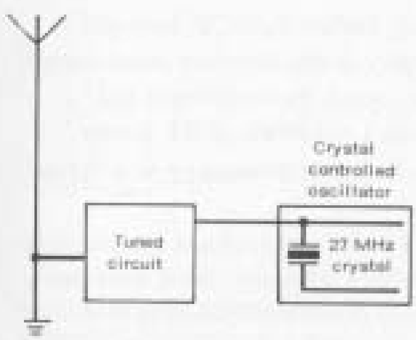
Both inherent performance limitations could be overcome to some extent. Thus instead of using a single valve, the use of two valves (usually a twin valve in a single envelope) in push-pull oscillator configuration considerably increased the RF power output obtainable, but at the expense of further increase in battery drain. The basic circuit

3.3 Practical valve transmitter circuit. Coil L2 and variable capacitor C1 form the tuned circuit. Typical component values:
C2—500pF
C3—500pF
R —100K
RFC—2 millihenries
Valve (V)- 3A4
L1 is aerial coupling coil





3.4 Circuit diagram of a basic push-pull valve transmitter. The (British) DCC90 or (American) 3A5 valves were the usual choice.



3.5 Block diagram of crystal-controlled transmitter (the crystal fixing the frequency of the oscillator).

remained very much the same (*figure 3.4*). Lack of stability, or the tendency for the frequency of the tuned circuit to 'drift', could be countered by incorporating a crystal in the tuned circuit, the crystal restricting oscillation to its specific resonant frequency or a harmonic of that frequency.

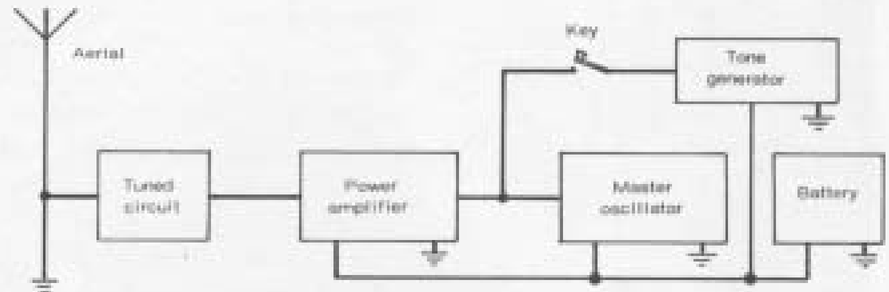
Crystal control

The crystal control of transmitters was, in fact, obligatory in the United States right from the beginning of radio control development. No such requirement applied in Britain and crystal-controlled valve transmitters remained comparatively uncommon right up to the time they were superseded by transistor circuits. There were a number of reasons for this. Originally crystals with a resonant frequency of 27 MHz were virtually unobtainable, necessitating the use of overtone crystals of an even fraction of 27 MHz. These had to be used in a doubler or tripler circuit to produce the stabilised transmitter frequency required, which was not always a satisfactory solution. More important still, all single-stage transmitters (i.e. straightforward RF oscillators) operated on a 'brute force' basis to achieve required levels of RF power, which meant that the crystal was driven very hard (and likely to be subject to drift through heating) and the whole circuit required very sharp peaking. The slightest change in operating conditions could thus cause oscillation to cease.

Single-stage valve transmitters continued in commercial production until about 1963 in the United States, and later in Britain, despite their numerous disadvantages. They were also used for tone operation, by combination with a tone generator circuit, which somewhat extended their useful life. The real answer, however, lay in the combination of an RF oscillator with a power amplifier. This means that the oscillator valve did not have to be driven hard, and so need only draw a relatively

low current, making the working conditions far less critical. The output from the oscillator was then stepped up by a following amplifier circuit.

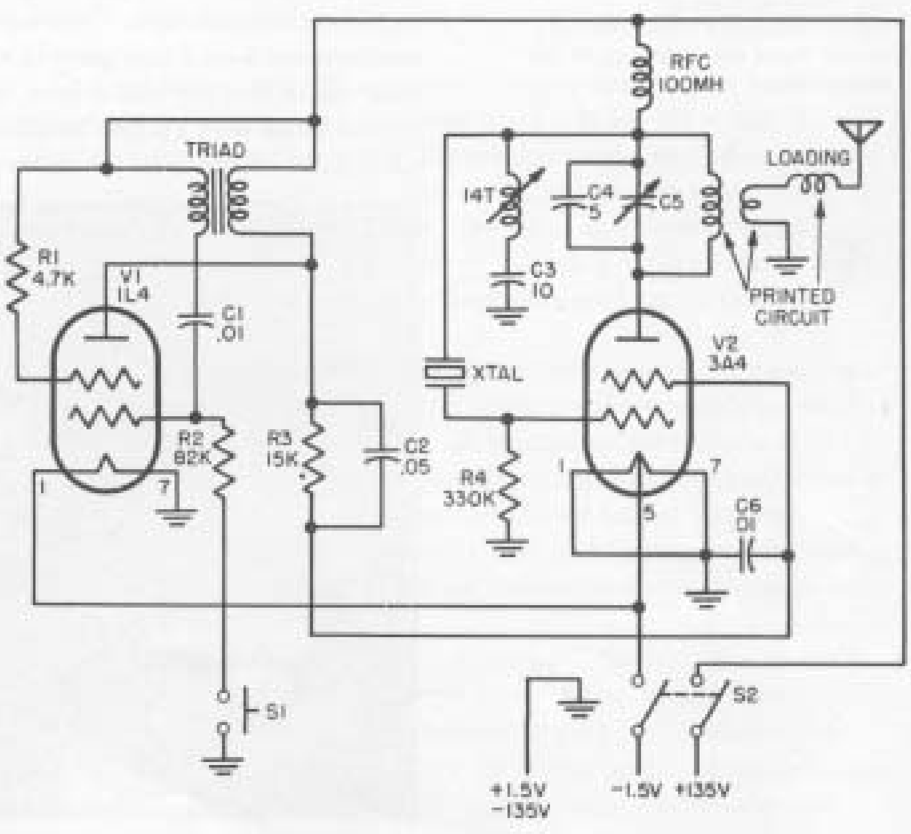
This combination of master oscillator and power amplifier, or MOPA circuit, was adopted by virtually all later valve transmitters and was largely responsible for the high degree of reliability achieved with such types.



3.6 Block diagram of a MOPA single-channel tone transmitter.

The general adoption of tone working, rather than CW, brought further improvements in reliability, largely in the inherent characteristic of a tone receiver to 'lock on' to a tone signal, thus making it less susceptible to interference; together with a reduction in RF power needed to establish a satisfactory radio link over a required or practical range.

The type of circuit shown in *figure 3.6* represents about the ultimate achieved in single channel valve transmitters, although there were many other circuits of comparable performance developed differing in detail design. Two major disadvantages remained with valve transmitters,



3.7 An American (CG) single-channel valve transmitter, with component values. This is fairly typical of the ultimate development of simple transmitter circuits using valves.

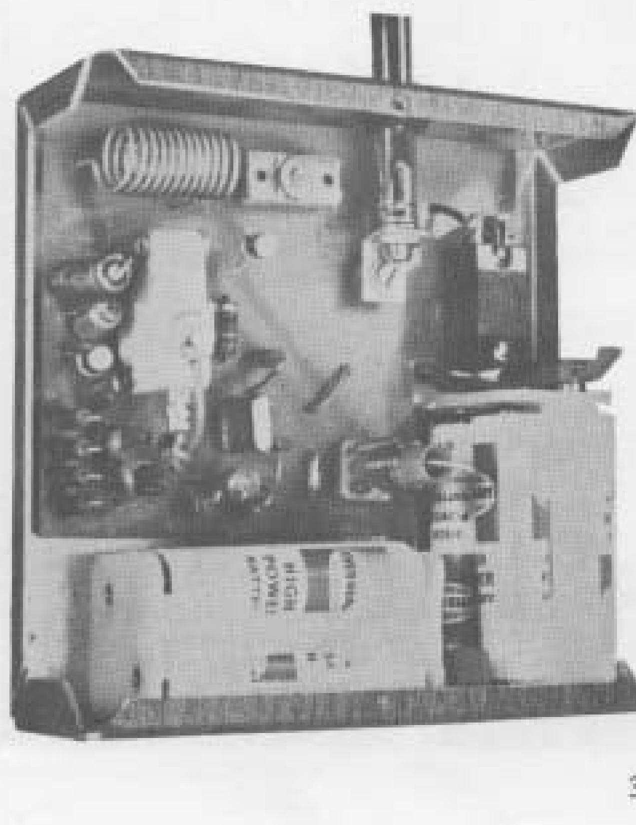
however. To accomodate adequate battery sizes they tended to be bulky and heavy for hand-held units (unless small batteries and short battery life was accepted). Also valve transmitters need both a high voltage (high tension) battery and a low voltage (valve heater battery). Only dry batteries were suitable for the former—providing a relatively short useful life at fairly high cost. It was inevitable, therefore, that all-transistor transmitters should eventually replace valve transmitters for virtually all model radio control applications.

Transistor transmitters

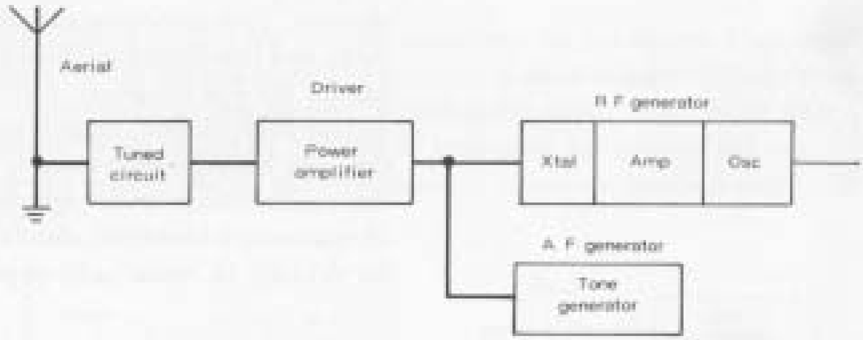
Exactly the same operating principles apply in the case of transistor transmitters: a master oscillator generating RF followed by one or more stages of power amplification, as necessary, plus a tone generator to impose modulation on the basic RF carrier in the case of tone transmitters.

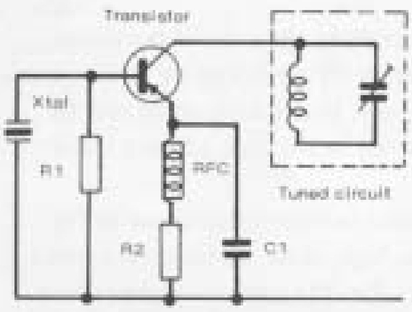
Transistors first appeared on the model radio control scene in the late 1950s, but originally their cost was high, their performance often temperamental, and their power ratings (i.e. the amount of electrical energy they could pass) generally low. Initially, therefore, their application was to amplifier circuits, first in receivers and then to the amplifier stage(s) in MOPA transmitters. As far as transmitter design was concerned this meant a hybrid circuit—a valve oscillator followed by transistor amplifier stages—which did not offer particular advantages, or any savings in battery requirements. (Hybrid circuits were a different story on receivers where transistor amplifiers reduced the bulk and weight of the unit, and the number of 'delicate' components susceptible to crash damage).

A very successful British design of all-transistor transmitter, intended for home construction. Components are widely spaced on the circuit board for easy assembly.



3.8 Block diagram of a modern transistorised single-channel tone transmitter.





3.9 Basic circuitry of a transistor oscillator with crystal control. There are various other configurations which can be used for oscillators

Increasing the number of amplifier stages to compensate for deficiencies in output of a low power transistor oscillator is not a practical answer for this can produce unwanted side effects. The practical all-transistor transmitter thus waited on the appearance of suitable power transistors, with stable characteristics, for the oscillator circuit, or driver stage as it is sometimes called in America. Actually this latter description can be misleading as a driver is more correctly the amplifier stage applied after RF amplication and modulation in a typical transmitter circuit, as shown in block diagram form in *figure 3.8* It is thus best to refer to the RF generator as an oscillator.

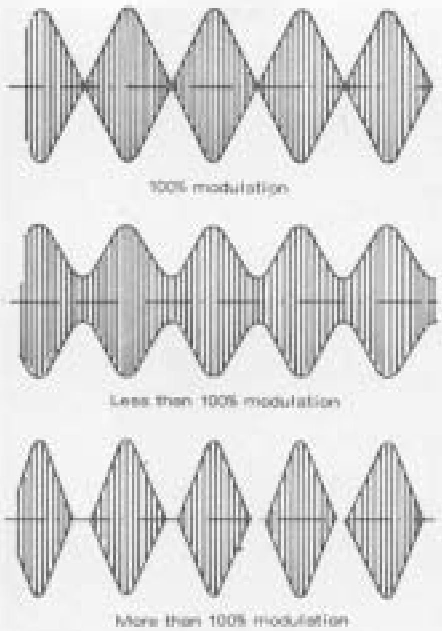
Basis of a typical transistor oscillator is shown in *figure 3.9* Numerous variations are possible in the bias circuit, which can control the quality of working. Where the oscillations are to be modulated, for example (tone transmitter) it is generally advisable to avoid 'bottoming' of the oscillator as this can result in considerable distortion of the modulated signal.

Large, heavy model aircraft were typical of the early single-channel era—when transmitters (and receivers) were bulky, too, and required high voltage batteries.

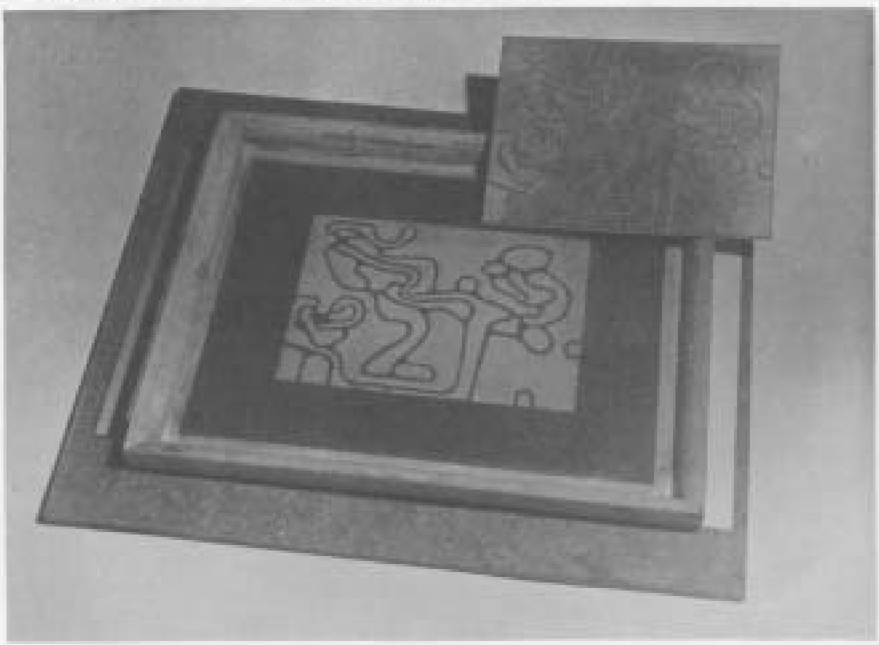
Degree of modulation

The degree of modulation produced by superimposing an AF (tone) signal on an RF carrier can vary considerably, which will show up in the shape of the combined waveform. Basically 100 per cent modulation is ideal since this provides the maximum amplitude change for detection at the receiver end. Over 100 per cent modulation will give the same amplitude change, but with 'gaps', equivalent to actual breaks in the transmission. Under-modulation results in reduced amplitude change. Neither of these conditions is particularly critical for single-channel superregen working, provided the amount of over- or under-modulation is not excessive. Under-modulation reduces the amount of signal change the tone receiver has to detect. As the distance between transmitter and receiver increases the signal strength decreases, i.e. the amplitude is reduced. Thus the effect of under-modulation which does not use the full amplitude change possible to start with is to reduce the range.

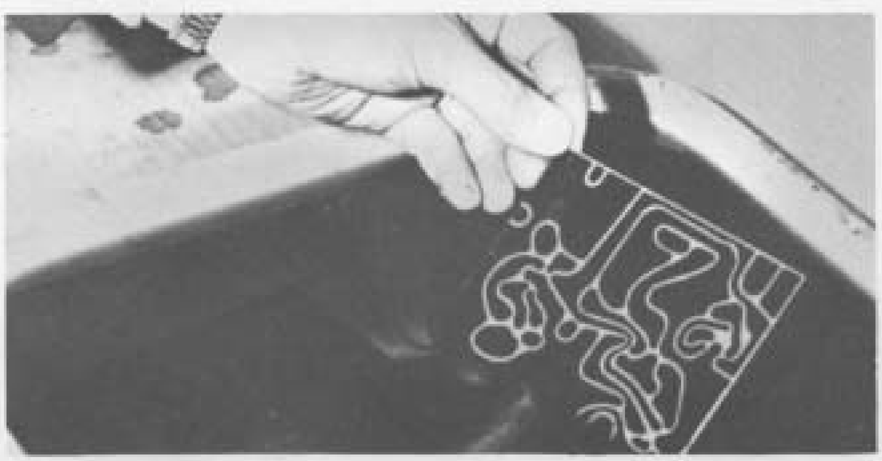
Under- or over-modulation can have a significant effect on the performance of a superhet receiver, however.



3.10 The degree of modulation affects the character of a tone signal.



Virtually all modern circuits are assembled on printed circuit panels. These start out as a drawing, transferred as a 'mirror image' to copper-clad Paxolin or glass fibre panels.

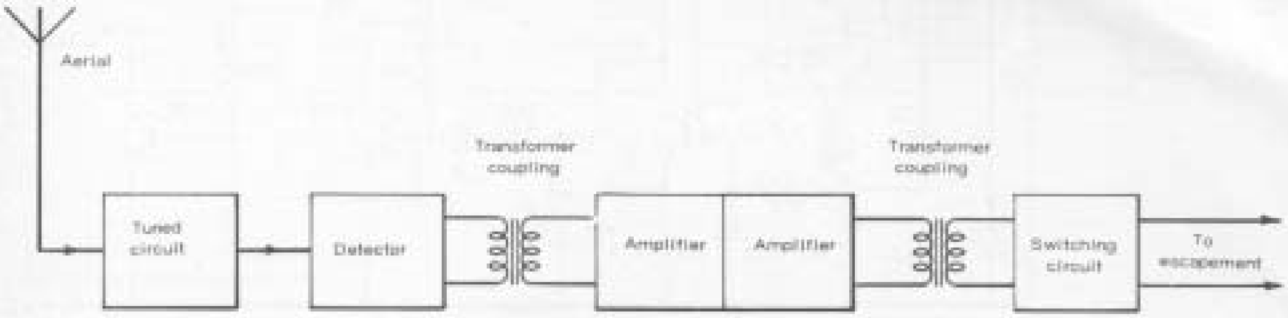


The printed circuit is produced by etching, which dissolves away unwanted copper areas and leaves the copper circuit.

Simple single-channel receiver with
battery box and escapement, all
prewired and 'ready-to-go'.

4 SINGLE - CHANNEL RECEIVERS

Single-channel receivers now invariably employ all-transistor circuitry, and (normally) printed circuit construction. In the case of a relayless receiver this can result in an extremely compact, lightweight 'solid

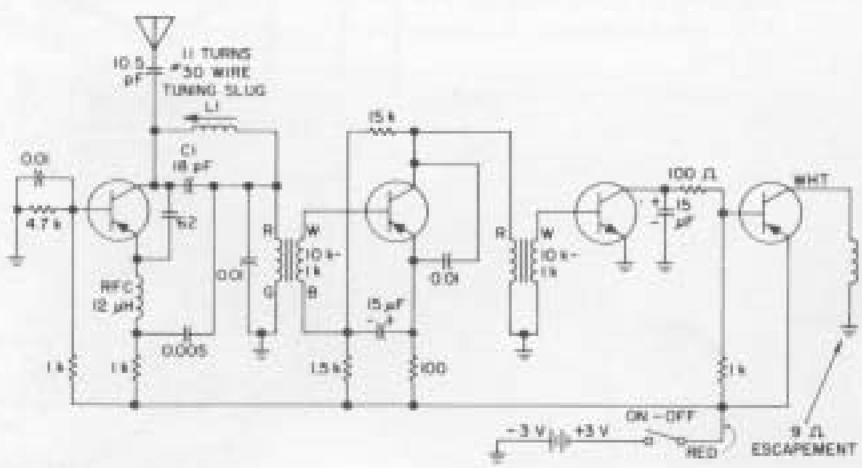


4.1 Block diagram of the ultimate development of the simple single-channel/relayless receiver superregen.

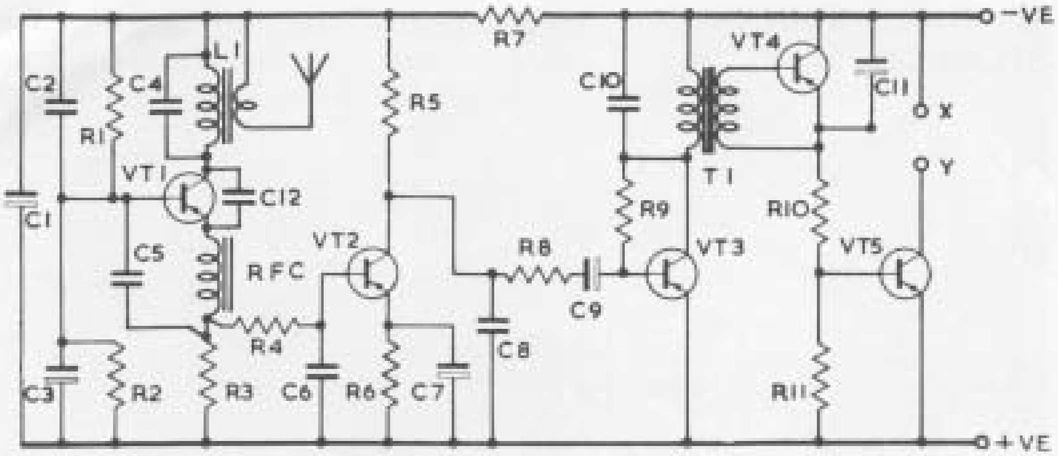
state' unit with a high degree of resistance to mechanical shock. In the case of a relay receiver, the relay is normally mounted on the printed circuit panel, although it can be a separate plug-in assembly. Because the type of relay used in modern circuits is a fairly rugged, low resistance type with non-critical adjustment, it can be sealed in a case to protect the contacts from dirt etc. This may be additional to the lightweight aluminium case usually fitted to commercial single-channel receivers.

Most modern all-transistor superregen receivers are based on the use of high performance, high quality transistors in fairly conventional circuits. The usual arrangement following the tuned circuit is a superregen detector transformer coupled into a two-stage AF amplifier. The output from the second stage of AF amplification is then transformer coupled into a switching stage (*figure 4.1*). The design matching load is normally a 9 ohm coil resistance escapement (relayless receiver); or a 30 ohm relay (relay receiver).

Two examples of superregen circuits are shown in detail in *figures 4.2 and* 4.3 The first is typical of American practice of the era and circuits of this type were widely copied, with detail modifications.



4.2 Circuit diagram of a typical American single-channel superregen receiver for relayless working.

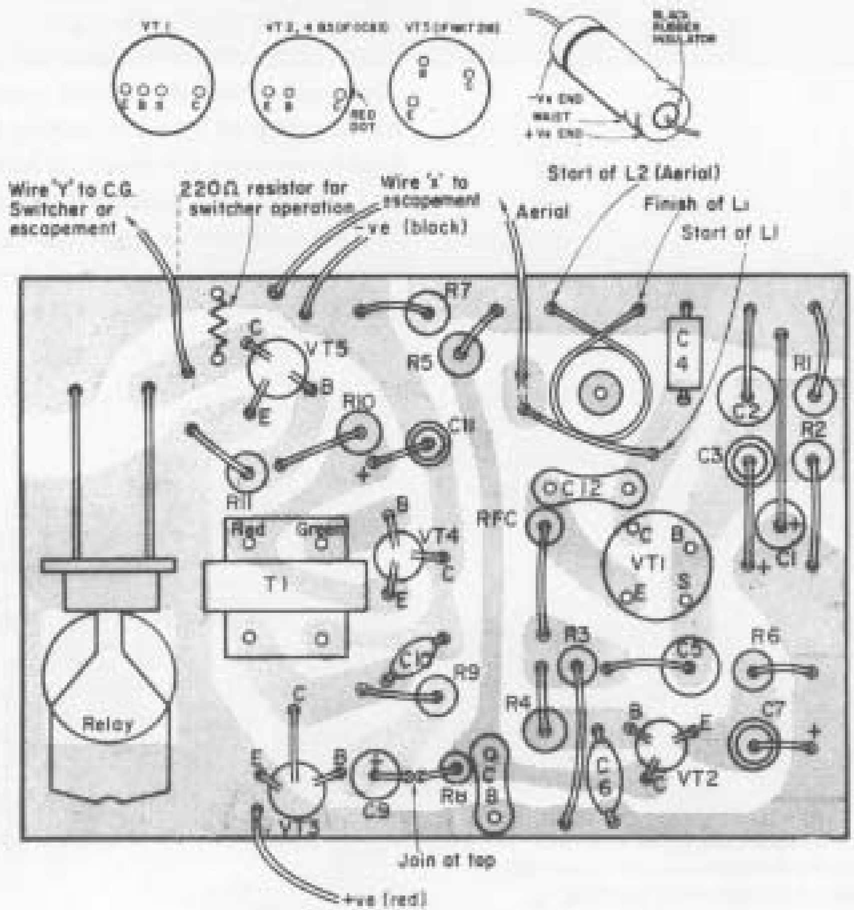


4.3 British superregen relayless receiver designed for home construction (courtesy of Radio Control Models and Electronics).

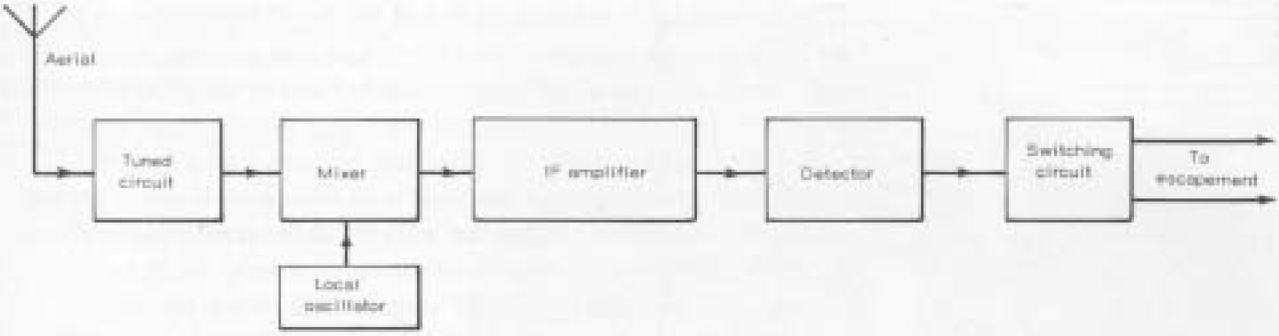
C1	: 25 μF electrolytic 6.4v				
C2	: .002 μF				
C3	: 4 μF electrolytic 10v				
C4	: 22 pF				
C5	: .002 μF				
C6	: 47K pF Disc.				
C7	: 25 μF electrolytic 6.4v				
C8	: .002 μF				
C9	: 2.5 μF electrolytic 6.4v				
C10	: 10 KpF Disc.				
C11	: 4 μF electrolytic 10v				
C12	: 22 pF				
R1	: 2.2 KΩ				
R2	: 1 KΩ				
R3	: 4.3KΩ	R10	:	150Ω	
R4	: 5.6KΩ	R11	:	470Ω	
R5	: 4.3KΩ	RFC	:	20 μH	
R6	: 2.2KΩ	VT1	:	OC170	
R7	: 1KΩ	VT2	:	OC44	
R8	: 2.2KΩ	VT3	:	OC45	
R9	: 560KΩ	VT4	:	OC45	
VT5	: OC83 or NKT 218				
T1	: D1001 Ardente				
L1	: 10 turns 24 swg				
L2	: 2½ turns aerial wire. Total length 32 ins. Cut bottom off R/S 7 mm former				
Relay	: OS 50Ω				

The second is a British circuit design, developed specifically for amateur construction. The circuit is non-critical, although satisfactory performance was dependent on using the types of transistors specified.

This, and other similar circuits, were marketed as kits, with ready-drilled printed circuit panel and all necessary components. Unfortunately, however, the practicability of 'kit' designs has become severely restricted by lack of availability of suitable transistor types for these earlier circuits.



4.4 Component layout of the receiver circuit given above, shown actual size.



4.5 Block diagram of a single-channel superheterodyne receiver.

Superhet receivers

The superhet receiver is a far more complex type, involving the use of more stages and considerably more components. A block diagram of a typical superhet is shown in *figure 4.5*

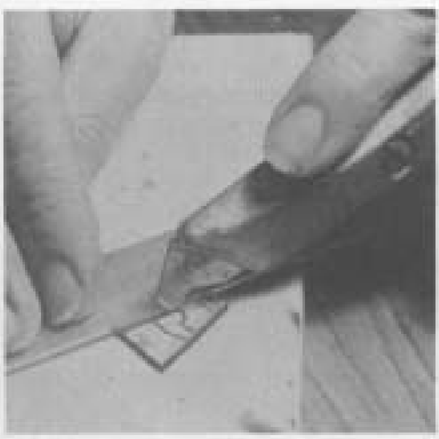
The basis of superhet operation is that the incoming RF signal is picked up by the aerial and tuned circuit in the usual way, and fed to a *mixer* stage. Also coupled to the mixer is a local oscillator circuit, crystal controlled to oscillate as a specific frequency above or below the RF signal frequency.

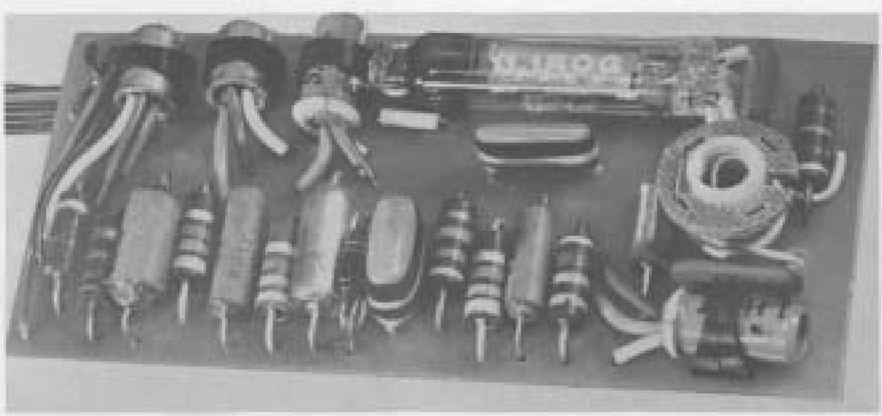
The mixer produces as an output a signal at the IF or intermediate frequency. This is then amplified by one or more IF amplifier stages. At some suitable point the audio tone present can be detected and the IF which is acting as the carrier discarded. The tone signal can then be subjected to one or more stages of AF amplification, as necessary to produce the required current to operate an actuator or relay direct. Detection and audio amplification may be achieved in one stage (e.g. with a single transistor working both as a detector and amplifier); or by a diode followed by transistor amplifier stage(s).

Such a circuit can achieve superior *selectivity* of signal for a number of reasons. The main one is that the original RF signal disappears at the mixer stage, and an IF signal is passed on.

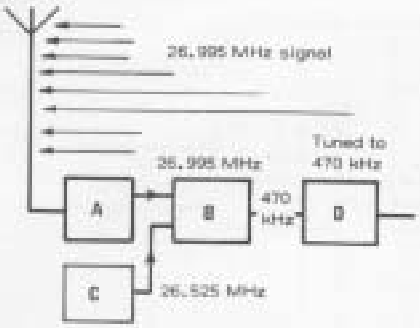
The value of IF adopted is normally 470 kHz (or 455 kHz in America). It is usual to work the local oscillator at this difference frequency *below* the transmitter RF frequency. The mode of working can then be followed from this numerical example.

Simple printed circuits for switchers can be cut on printed circuit material instead of etched.

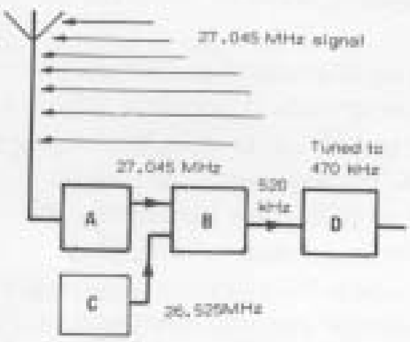




Early Thyratron valve receiver with transistor amplification.



4.6 In a superhet receiver the tuned circuit (A) accepts the incoming signal and passes it to the mixer (B). The local oscillator (C) generates a fixed frequency signal (typically 470 kHz below the incoming RF signal to which the set is tuned). The mixer passes on the 'difference' or IF signal to a detector circuit tuned to respond only to this signal.



4.7 A different incoming signal frequency means that the signal passed to the detector is different to that to which it is tuned to receive. Hence it rejects this 'difference' signal.

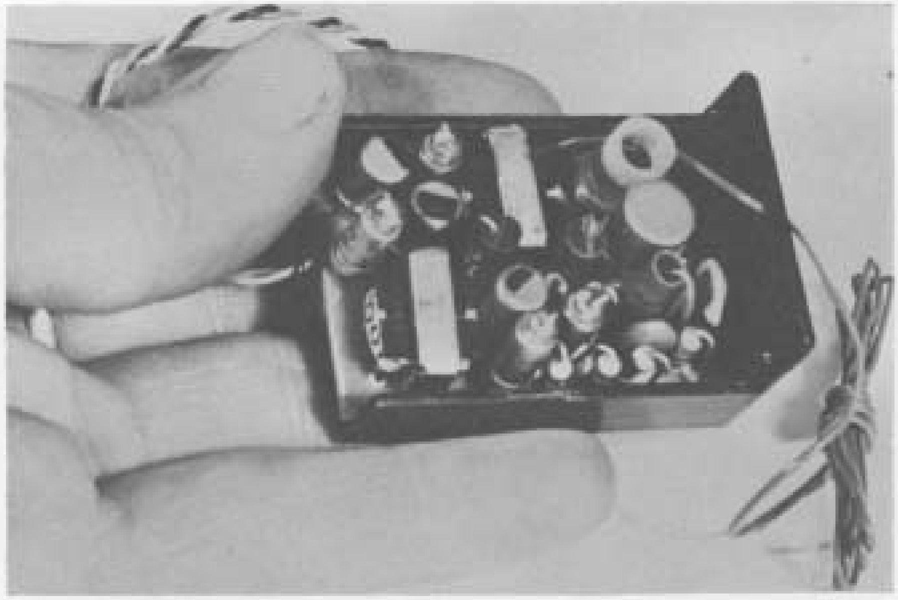
The transmitter is working on one of the 'spot' frequencies in the 27 MHz. Suppose the frequency used is the first one available, i.e. 26.995 MHz. The receiver local oscillator frequency will be set at 26.995 minus 470 kHz or 26.525 MHz to produce the design intermediate frequency, and the mixer will pass on this difference frequency of 470 kHz.

The next 'spot' frequency available is 27.045 MHz. If this is present (possibly from another transmitter working at the same time) and picked up, the difference relative to the receiver local oscillator frequency will be 520 kHz. The IF stages which follow the mixer are tuned to the IF frequency (470 kHz). The 'difference frequency' in this case is 50 kHz above the frequency to which the IF stages are tuned, or over 10 per cent.

Compare this with superregen working, where the receiver tunes directly to the RF frequency. The difference in this case is only 50 kHz above 26.995 MHz, or less than 0.02 per cent. On this basis, therefore, the superhet is something like 500 times better off as regards discriminating between the two signals.

A further advantage is gained from the fact that since a relatively low frequency is passed to the IF stages, very sharp tuning is possible in these stages (together with amplification of the IF). This tuning is so sharp as to make alignment of the IF stages critical, particularly as selectivity get even sharper with each stage. Once initially aligned, however, and providing the circuit design is stable, no further adjustment should be required on the receiver. Tuning adjustment (except for initial trimming which may be necessary) is eliminated by the fact that both the transmitter and receiver local oscillator are crystal controlled; the former at the specified 'spot' frequency for operation, and the latter at this 'spot' value less the intermediate frequency. Such crystals are referred to as 'matched pairs'. It follows that if the transmitter

Small single-channel receiver takes up hardly any room, even in a small model.



Commercially produced single-channel receivers crowd the components on a printed circuit base panel to save bulk and weight. Here, for example, components are mounted vertically.

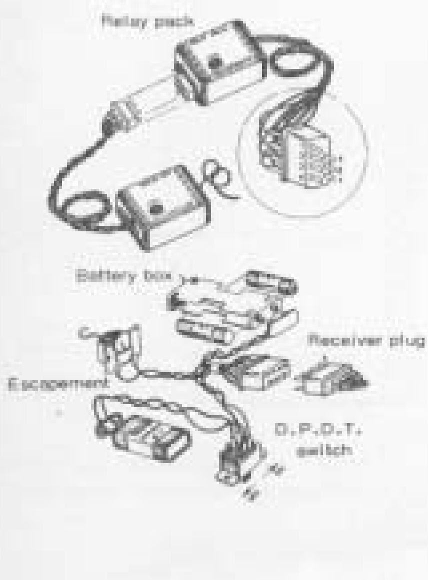
'spot' frequency is changed (e.g. by changing to a crystal of different value), the receiver (local oscillator) crystal must also be changed for the equivalent of the new 'pair' in order to preserve the same IF to which the IF circuits are peak tuned.

A further advantage offered by superhet working is the possibility of introducing automatic gain control (AGC). The stronger the input signal the greater the gain in the IF stages. If excessive, this can lead to clipping and distortion of the AF content of the signal to the point where it may be eliminated entirely.

To prevent this happening the IF stages can be made self-limiting in amplification by rectifying part of the IF signal at the last IF stage and feeding it back as a DC bias to the input of the first stage. If the amplification of the IF tends to build up excessively, enough reverse bias is applied to the first stage to reduce its gain, and control overall response, i.e. the overall gain is automatically self limited to an acceptable proportion of the input signal strength. This is known as AGC.

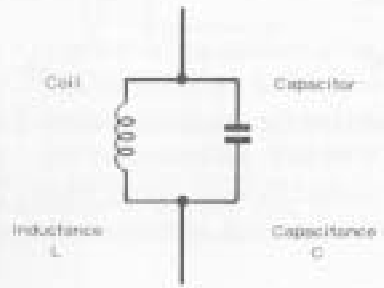
Automatic gain control may or may not be necessary with single-channel receivers, depending mainly on the characteristics of the transmitter used. Most tone transmitters produce 100 per cent modulation, when clipping and distortion is not likely to be harmful. AGC may, however, be very necessary where the transmitter signal has less than 100 per cent modulation, even for single-channel working.

4.8 Typical example of the ultimate development in single-channel receivers. A small, light relayless receiver prewired to a plug. This connects either directly to a receiver wiring harness, incorporating battery box, switch, and escapement type actuator; or to a relay pack for connecting to a motorised actuator. Wiring harness shown provides for separate receiver and escapement batteries.



Modern transmitters invariably have a telescopic aerial which should be fully extended for normal use. (Some transistor circuits can be damaged by operating with retracted aerial). Receiver aerial is usually a 30'' length of wire.

5 TUNED CIRCUITS AND AERIALS



5.1 A tuned circuit is usually based on a coil (with Inductance) and a capacitor (Capacitance) connected in parallel. The 'old fashioned' symbol for a coil is still used in model radio control diagrams.

Model radio control transmitter/receiver combinations are operated on a signal frequency of 27 MHz (or more specifically at any individual frequency within the permitted working range of 26.995 to 27.255 MHz). This means that tuned circuits, employed in both the transmitter and receiver, must be designed to have a resonant frequency of this value.

A tuned circuit comprises, basically, an inductance (coil) and a capacitor, normally employed in parallel configuration (*figure 5.1*). The relationship between the resonant frequency of such a circuit and the value of inductance (L) and capacitance (C) is given by the formula

$$\text{resonant frequency in MHz} = \frac{1000}{2\pi\sqrt{LC}}$$

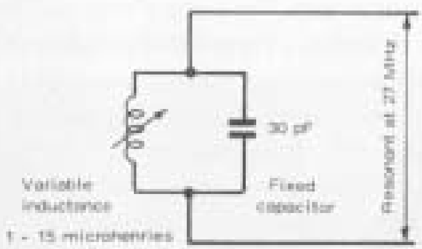
where L is the inductance in microhenries (µH)
C is the capacitance in picofarads (pF)

Substituting 27 MHz as the resonant frequency required, we get

$$27 = \frac{1,000}{2\pi\sqrt{LC}}$$

i.e. $\sqrt{LC} = 5.9$ approx
or $LC = 35$ approx

The latter is a suitable 'working' formula for circuit design. It means that to give a resonant frequency of 27 MHz the value of the inductance of the coil used (in microhenries), multiplied by the value of the capacitor used (in picofarads) should equal 35, as a close approximation.



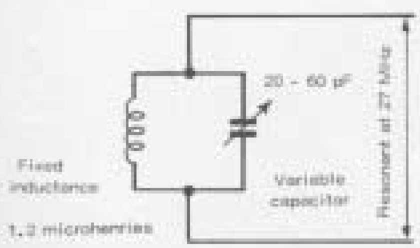
5.2 Inductive tuning with variable inductance (coil wound on former with iron dust core).

It is, of course, possible to calculate the exact values of L and C required to give a specific or 'spot' frequency in the 27 MHz band. This, however, is not a practical approach. A close match only is required when, by making one of the components variable, the final circuit can be *tuned* to the exact frequency required. Either the capacitor can be the variable component (i.e. employing a variable capacitor), or the inductance (e.g. by employing a coil wound on a former with an iron dust core which can be adjusted to vary the inductance of the coil). Both methods can be used; and in some cases both components may be made variable to provide even finer adjustment.

The simplest case to work out is that of a fixed inductance used with a variable capacitor (*figure 5.2*). A typical value for such a capacitor would be a 20-60 pF tuning range. Thus taking a 'centre' value of 30 pF, the required value of inductance required from the working formula is

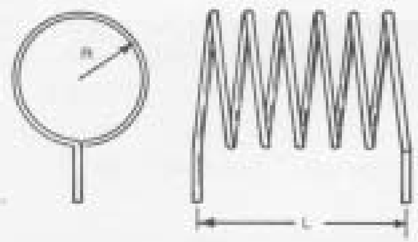
$L \times 30 = 35$
or $L = 35/30$ or a little under 1.2 microhenries

It now remains to design a suitable size of tuning coil to match.

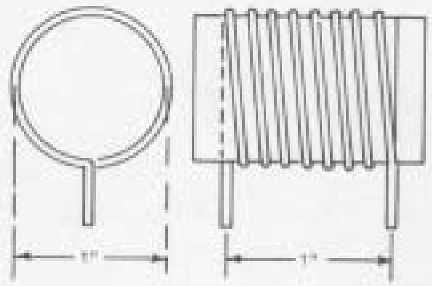


5.3 Capacity tuning, using a fixed inductance and variable capacitor.

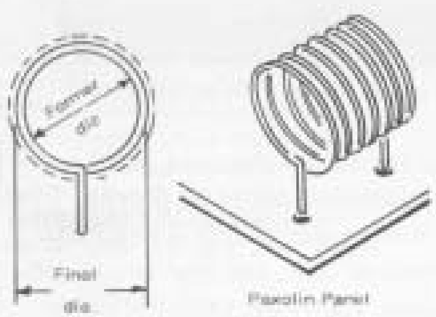
The simplest type of tuning coil is an 'open' winding of solid wire, as shown in *figure 5.4*. Such a form is known as an *air cored coil*. The



5.4 Length (L) and Radius (R) are the critical factors in designing an air-cored coil.



5.5 Typical air-cored coil winding.



5.6 Open-wound (air-cored) coil must be securely and rigidly mounted.

inductance can be calculated directly from the radius of the coil (R), the length (L) and the number of turns, viz:

$$\text{inductance, in microhenries} = \frac{R^2 \times N^2}{9R + 10L} \quad \text{(R and L are in inches)}$$

There are three variables, so two must be 'guesstimated' as being logical values, and the equation worked out to find the other value. This is much easier if simple values are selected for the coil geometry.

For example, suppose a coil length of 1 in. with a diameter of 1 in. (radius 0.5 in.) is decided on. The value of inductance required, from the previous calculation, is 1.2 microhenries (approx). Substituting in the equation

$$1.2 = \frac{(0.9 \times 0.5) \times N^2}{(9 \times 0.5) + (10 \times 1)}$$

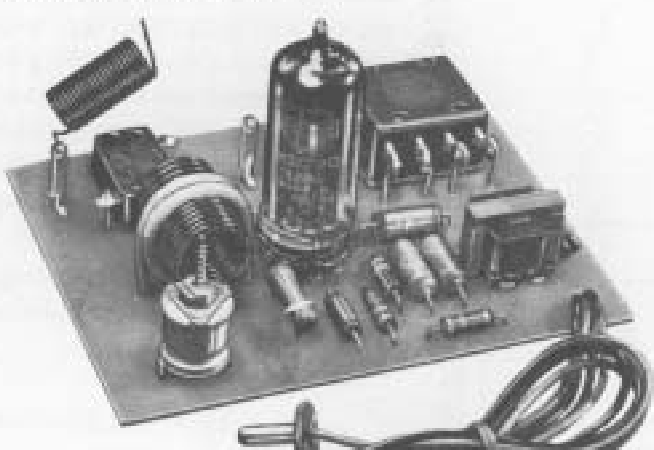
$$\text{whence } N^2 = 69$$

$$\text{thus } N = 8.3 \text{ turns}$$

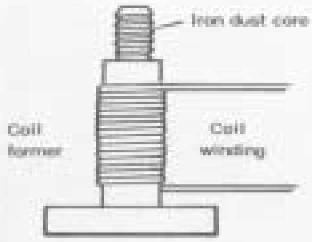
Actually an 8 turn coil, 1 in. diameter and opened up to 1 in. long would be a near enough match, the very small difference in inductance (1.1 microhenries as against 1.2 microhenries originally specified) would readily fall within the adjustment range of the variable capacitor.

The actual wire diameter does not come into the calculation. This would be chosen to give a nice rigid coil when wound. A typical choice would be 18 or 16 gauge enamelled copper wire. To make a neat coil 16 should be close wound on a dowel or cylindrical former of suitable diameter, i.e. of rather less than the final inside coil diameter required to allow for 'springback' when the coil is removed from the former (*figure 5.4*). The coil is then opened up to its design length, for mounting (usually through holes in a Paxolin panel, as shown).

Air-cored coils can be designed to required inductance values using this formula with reasonable accuracy, provided the coil dimensions (diameter and length are reasonably large. For smaller sizes of length or diameter the formula is less accurate as the actual wire diameter then starts to have an effect.



Early transmitters were based on valve circuits with open-wound (air-cored) tuning coils.



5.7 **Coil with variable inductance. Wire size and number of turns required to match a given coil former size are determined by practical tests, or wound to a given specification.**

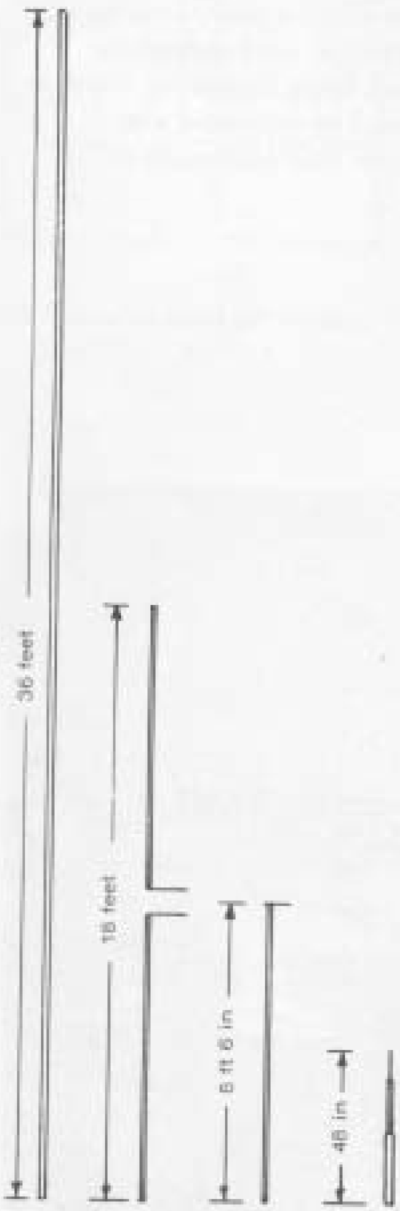
Iron-cored or 'tunable' coils are quite a different matter. These are normally wound on small (e.g. ¼in. diameter) coil formers which carry an iron dust core which can be screwed in or out to adjust the inductance (*figure 5.7*). It is difficult to calculate the required wire size and number of turns for a given former size. These are best determined on empirical lines. The table gives some suitable combinations to use.

Former-wound tuning coils have the advantage of being compact and fully supported. They are a logical choice for the tuned circuit of receivers, where space saving is important, and the whole unit may be subject to shock loads (which could distort an air-cored coil and change its inductance). This latter advantage also applies for transmitter coils. However, air-cored coils are still widely used for transmitters.

The most rigid type of tuning coil of all is that actually incorporated in the printed circuit panel. This is employed on some commercial circuits, both for receivers and transmitters. Being completely 'fixed' in characteristics, such tuning coils must always be associated with variable capacitors in the resonant circuit for final adjustment or trimming of the circuit.

Photo: Radio Modeller

All modern transmitters use a telescopic aerial extending to approximately 48" length.



5.8 Four 'standard' or resonant aerial lengths. Only the two smaller are practical for model use.

Aerials

Aerials are, in effect, another type of tuned circuit. That is to say their efficiency, either in radiating the RF signal in the case of a transmitter, or in the strength of signal picked up and fed to the following circuit in the case of a receiver, is very much greater if the aerial is of 'resonant length'. In this case it is the *wavelength* of the RF signal which is the parameter, although this is derived directly from the frequency, viz:

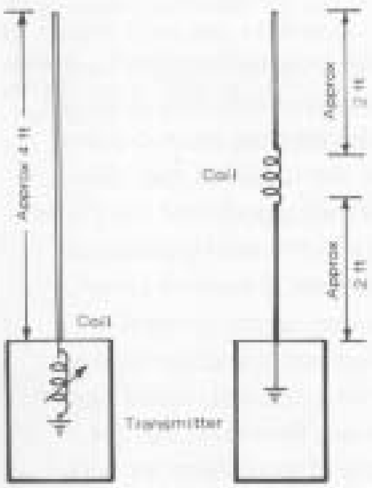
$$\text{wavelength (in metres)} = \frac{300}{\text{frequency in MHz}}$$

The *resonant length* for 27 MHz is thus 300/27 = 11.1 metres or 36 feet approximately. This is the optimum size for a transmitter (or receiver) aerial working at 27 MHz.

Obviously this is impractical to consider, so an even fractional length can be taken as the next best thing. A quarter-wavelength (9 feet) would be a logical choice and was the typical length used on older ground-standing transmitters. Since a physical aerial is subject to 'end effect' which tends to increase its effective length, a true quarter-wavelength (or quarter-wave) aerial would be more nearly 8 ft. 6 in. long, and 8 ft. a suitable size.

This is still too long for a hand-held transmitter, where the aerial length is normally half this size again—4 ft. (nominal). Actually sizes of anything between 30 in. and 54 in. appear to be used successfully on transmitters, but a 48 in. to 54 in. vertical aerial remains the best practical choice.

Fortunately there are methods of recovering some of the loss of efficiency resulting from having to use a shorter than optimum transmitter aerial for reasons of practicality. These involve 'loading' the aerial, and tuning it for optimum match to the circuit it serves.



5.9 (left) end-loaded aerial. 5.10 (right) centre-loaded aerial. Inductance of the latter is critical, since it cannot be adjusted. It must be accurately matched to the resonant frequency in the case of a crystal controlled transmitter.

Two alternative positions are possible for a loading coil, bottom loading being generally preferred since the coil can be mounted inside the transmitter case. Also it is easier to tune to an optimum match in the aerial circuit, e.g. by incorporating an aerial trimmer control as well (*figure 5.9*).

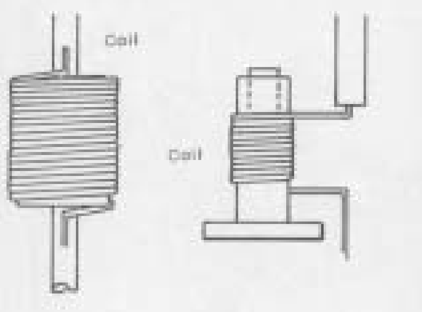
It is possible to get higher efficiencies with a centre loaded aerial (*figure 5.10*). This arrangement is more cumbersome, and also makes matching of the coil to the aerial more critical.

Typical specifications for aerial loading coils are shown in *figure 5.11*. Air-cored coils are commonly wound from 20 swg enamelled wire, embracing about 20 turns close wound of approximately ⅜in. diameter. The actual number of turns (or diameter) will vary with the length of aerial used. Miniature coils are close wound on ¼in. diameter formers, usually comprising 16 turns of 28 swg enamelled wire. The advantage of this type (for bottom loading) is that the inductance can be adjusted for optimum match by means of the core slug.

Aerial tuning can be quite critical on crystal controlled transmitters. This normally demands the use of a field strength meter to check the RF output (or some sets may have an output meter included in the circuit). RF output is 'peaked by adjusting the aerial tuning and/or the tuned circuit, depending on how many adjustments are provided.

In the case of a centre loaded aerial, the coil must be tuned individually to the aerial to match the frequency of the crystal used. Basically, therefore, a centre-loaded aerial can only be tuned to a particular spot frequency, which is against this type being used on transmitters with plug-in crystals which may be changed to work on different spot frequencies. With a properly matched centre loaded aerial, however, only the tuned circuit of the transmitter needs to be peaked for maximum RF output.

5.11 Typical aerial coil windings. Centre-loading coil is usually about 20 turns, close wound on ⅜" or ½" former. End-loading coil is typically 16 turns on ¼" former, with iron dust core for adjustment.

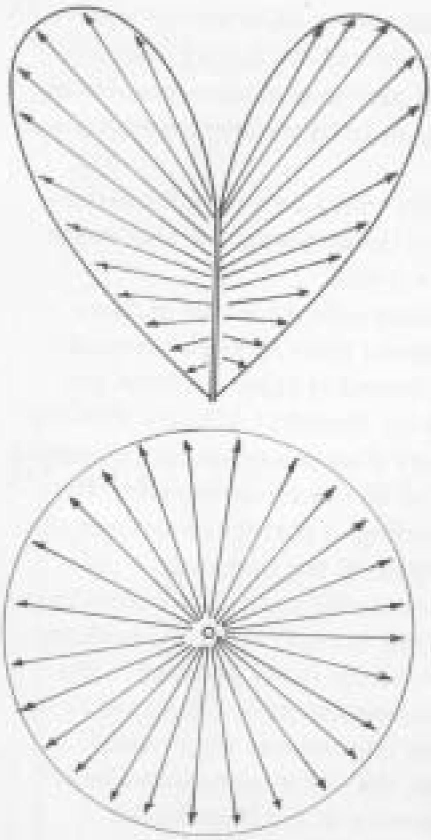


Usual mounting for the aerial on a model aircraft is to lead the wire to the top of the fin.

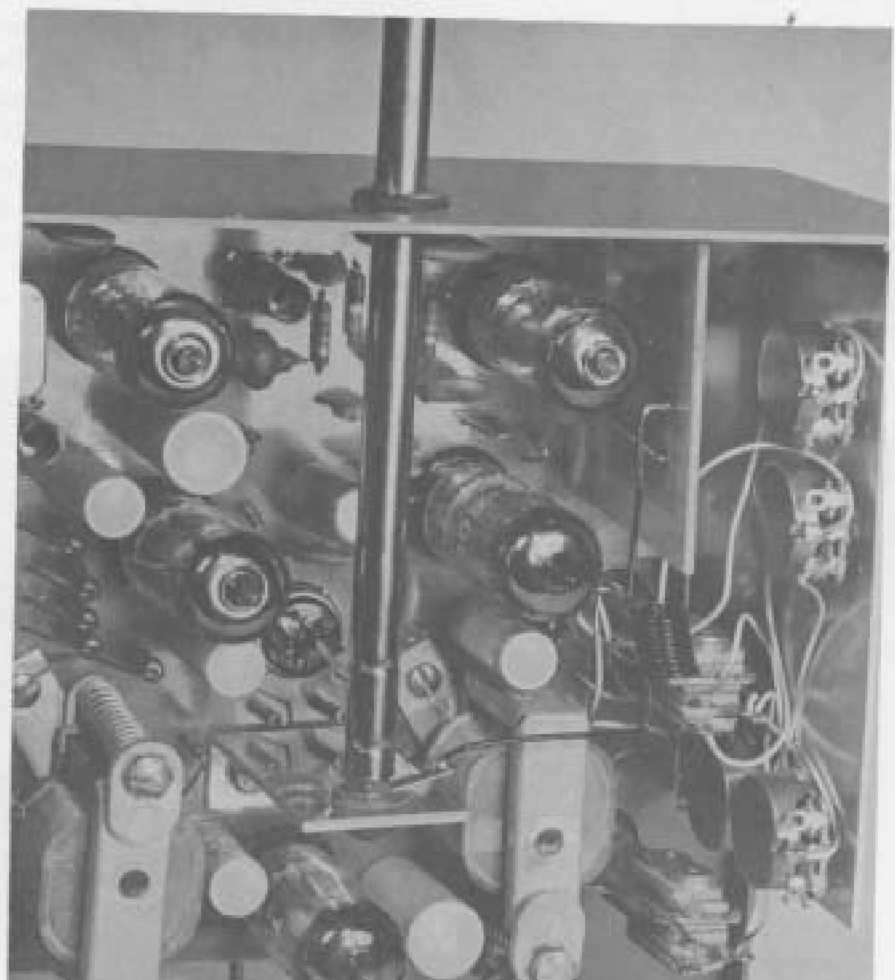
Radiation patterns

The ideal radiation pattern of a (nominal) quarter-wave dipole aerial* is shown in *figure 5.12*. The actual pattern achieved is usually distorted, however, often containing sidelobes and exaggerating the null point immediately above the aerial. In plan view, the radiation may also depart markedly from a circular pattern, showing preferred directions for signal strength, although the differences in this configuration are usually small enough to be quite negligible, even at extreme range.

The main fact that emerges is that maximum signal strength is radiated substantially at right angles to a rod aerial; and the weakest point for receiving the signal (it may even be a complete 'dead' spot) is directly above the top of the aerial. It follows, therefore, that for maximum range the transmitter should be held to position the aerial vertically upright. For close working, e.g. with a model aeroplane directly overhead at a good height, it may be necessary to angle the transmitter to one side to avoid the null spot and avoid contact. *Pointing* the end of the aerial at the model to be controlled will give the *lowest* range of all.



5.12 Basic aerial radiation pattern in side view (top) and plan (below).



End loading aerial coil can be seen on since it is an open coil (rather than wound on a former), and not rigidly supported.

*Although the physical length of a (nominal) 48 in. aerial is *one-eighth* of a wavelength, this type is known as a quarter-wave dipole since the 48 in. physical length represents only one half of the *effective* length of the aerial. The other half is made up from a 'mirror image' effect due to close proximity to the ground. This can, in fact, result in variations in radiation efficiency and radiation pattern, depending on the type of ground, how close the transmitter is to the ground, and even how a hand-held transmitter is held (the operator's body in this case providing the ground link). Such effects are not usually significant when operating a transmitter, but since they are present it is advantageous, when initially tuning a transmitter for maximum RF output, to hold the transmitter in the way it will normally be used, with the operator standing on a typical ground surface.

Radio-controlled model helicopter hovering in flight over a full-sized aircraft. The helicopter receiver aerial is a wire hanging down from the fuselage.

Aerial coupling

Inductive coupling is commonly employed between the aerial and tuned circuit. Optimum coupling is usually obtained by one complete turn in the case of transmitters using air-cored coils; and 2 to 2½ turns on transmitters or receivers using close-wound tuning coils on formers. In the case of receivers the coupling turns can be made from the aerial wire itself, taken around the tuning coil.

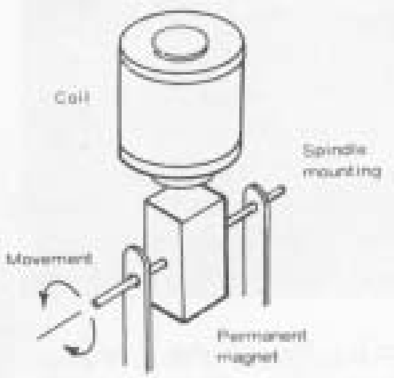
Alternatively, capacity coupling is commonly employed on receiver circuits, the aerial being connected directly to an appropriate point on the circuit via a capacitor.

Aerial design is considered non-critical in the case of receivers. Any thin flex is suitable (normally insulated), the usual length being 30 inches. On any installation the aerial wire should be taken away from the receiver as directly as possible and stretched out to its full length (e.g. in the case of aircraft, run through the fuselage to the top of the fin). The 'run' of the aerial wire should avoid close proximity to other circuit wires carrying alternating or fluctuating currents; and ideally should not lie parallel to current-carrying wires or lengths of metal linkages, etc.

Whip aerials (or even vertical telescopic aerials) are an alternative possibility—generally favoured for model boats, for example, where it is difficult to obtain a long horizontal run of aerial wire. Length may be reduced to 24 inches in the case of a whip aerial, if desirable.

Rubber-driven escapement-type actuator installed in model glider fuselage.

6 SINGLE - CHANNEL ACTUATORS



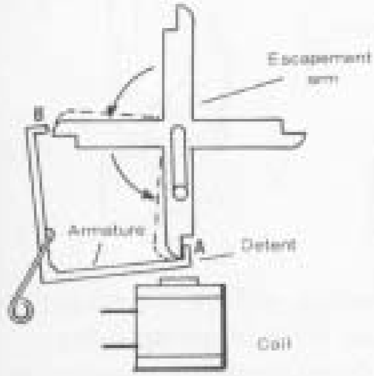
6.1 In the magnetic actuator a pivoted permanent magnet is made to rotate one way or the other under the influence of a coil. Power output available is very low.

There are two types of actuators or devices which convert electrical signals into mechanical output: (1) electro-magnetic devices based on an electromagnet controlling the movement of a mechanical system; (2) motorised actuators where the required movements are obtained directly from an electric motor.

The former type are divided into *magnetic actuators*, and *escapements*. A magnetic actuator consists of a permanent magnet surrounded by a field coil, one part (usually the magnet) being pivotally mounted, and spring biased to assume a certain position. If a current is passed through the field coil this now becomes an electro-magnet, attracting or repelling the permanent magnet, which rotates against its spring restraint (*figure 6.1*). This can provide output movement by virtue of the rotation of the spindle carrying the magnet, with 'power', or rather *torque*, proportional to the strength of the magnetic attraction or repulsion.

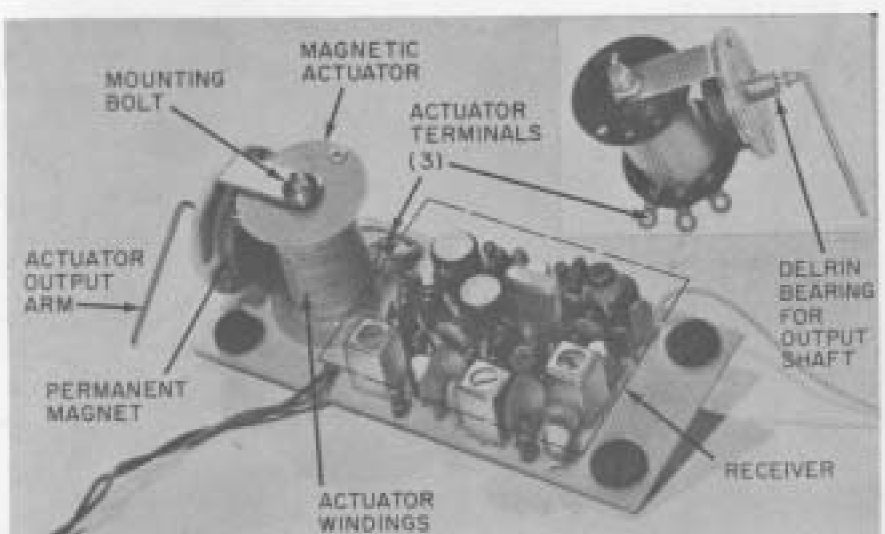
Although simple, and light, magnetic actuators have low power outputs and limited movement capabilities, normally just rotation in one direction, and then back again. They have little or no application for normal single-channel radio control, although they may be used in pulse proportional systems (see Chapter 8).

6.2 The principle parts of an escapement movement.

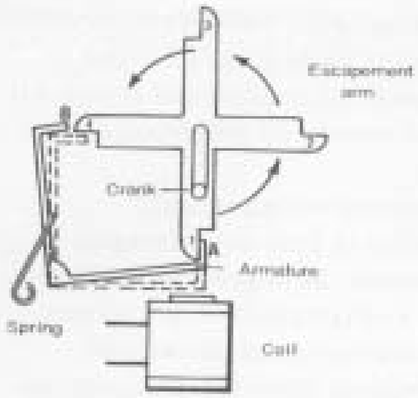


The *escapement* can again be made small and light in weight, but its mechanical design can provide a variety of different movements, leading to the development of different types of escapements. The basic operating principle is the same in all cases. An electromagnet is again employed, in the form of a single coil, which is used to work a pivoted armature with a rocking movement. This movement controls the position of an arm, to which some sort of external power is applied. This is usually a simple rubber-band motor, but can be clockwork. The mechanical output power available from an escapement is then the same as the amount of power applied to the arm. The power available from a two-strand rubber-band motor is sufficient to operate a control surface on a model aeroplane.

The operating principle can be further followed from *figure 6.3*



Magnetic actuator mounted on same panel as receiver. Actuator is shown separately top right.



6.3 Escapement action can be followed from this diagram.

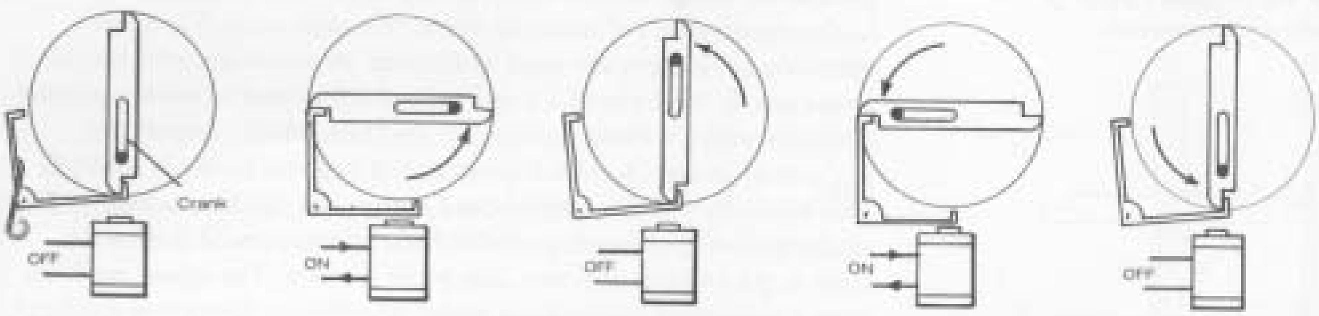
which shows the simplest form of escapement with a single (double-ended) arm. Output motion is derived by cranking the end of the spindle carrying the arm, to which a mechanical linkage can be attached. Rotation of the crank will then drive this linkage with a push-pull action.

In the 'idle' position the armature will be 'rocked' away from the escapement coil by a spring, the movement being limited as necessary by a stop. Since power is applied to the spindle of the arm it will be trying to rotate, but will be held in a certain position by end 1 abutting against end A of the armature. In practice, both the arm ends and the armature ends are specially shaped to provide optimum 'latching' and 'release' actions.

If the escapement coil is not energised (i.e. the actuator circuit completed or switched on, allowing current to flow through the coil), the armature will pull in and release the arm. The arm now rotates, but is brought to a stop after a quarter-turn by end 2 abutting against armature end B.

Release of signal will cause the armature to 'rock' out again, withdrawing end B from the end of the arm. The arm will thus make a further quarter-turn movement until brought to rest again by end 2 abutting against armature end A.

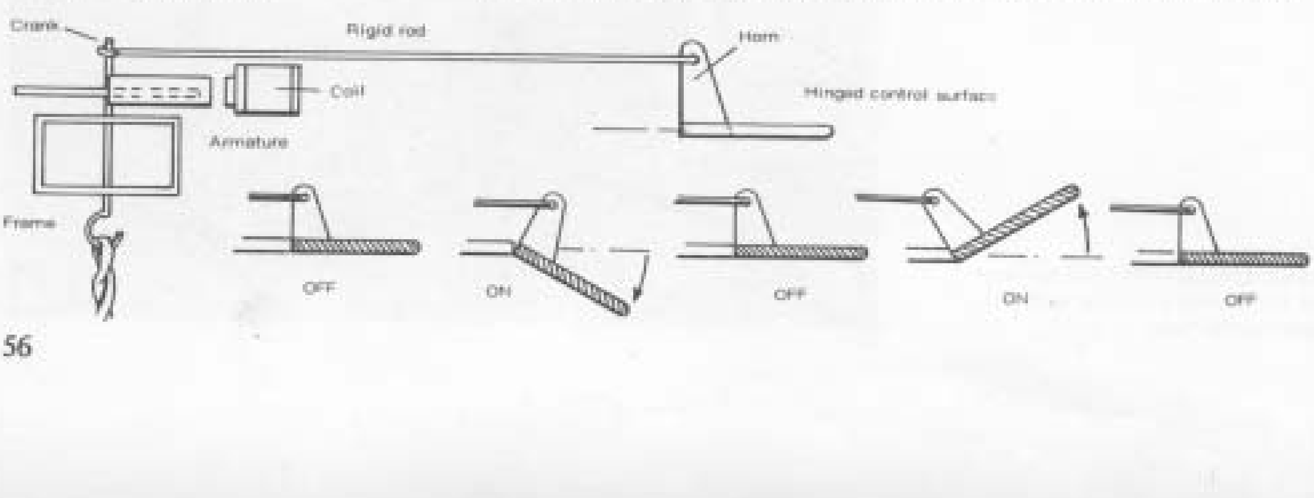
6.4 Sequence of escapement movement.

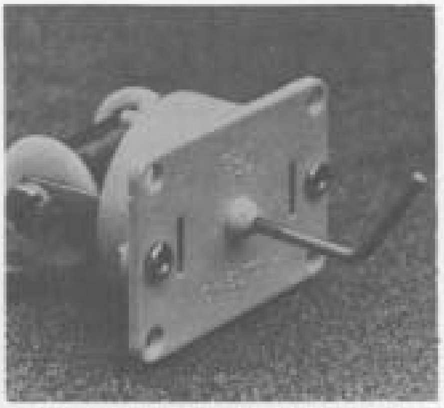


This sequence is shown in *figure 6.4*, together with the corresponding crank positions. To understand how this can produce corresponding movements of a control surface, suppose the escapement is mounted on its side, with the crank pointing upwards. Simple linkage as shown in *figure 6.5* coupling to a movable control, such as a rudder, would then produce the sequence of control positions shown in this diagram, namely:

(1) initial position (or no signal command present)—neutral rudder

6.5 Escapement movement allied to a movable control surface.





Typical example of simple magnetic actuator with cranked arm for deriving output motion.

(2) signal on (energising the escapement coil)—full rudder movement to one side
(3) signal off—rudder returns to neutral position
(4) signal on—full rudder movement to the other side
(5) signal off—rudder returns to neutral position.

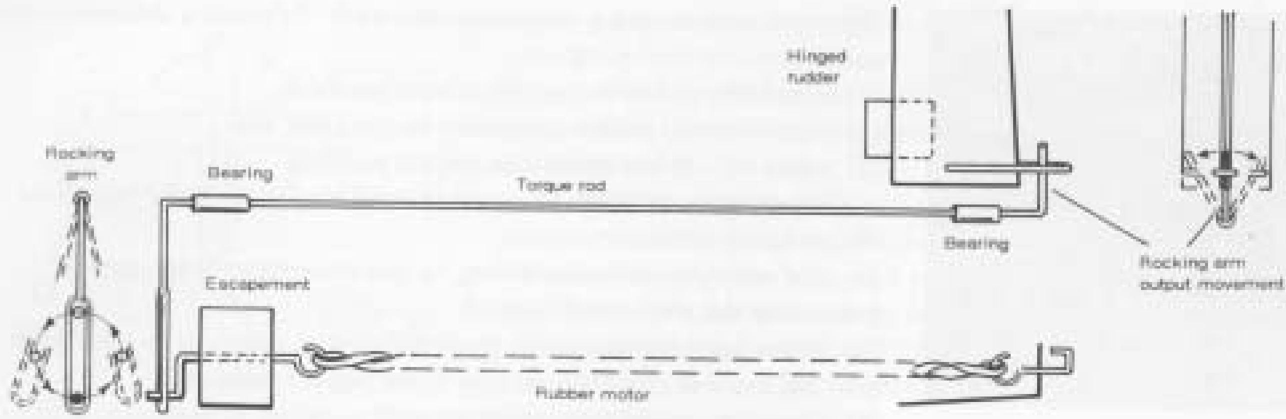
This sequence can then be repeated indefinitely, the three important factors being as follows.

(a) The control is self neutralising, i.e. always returns to the neutral position in the absence of a signal.
(b) When a command signal is given the control moves to its maximum position and will stay there as long as the signal is held on.
(c) Opposite control movements are only obtained in sequence, with a 'neutral' intervening. In other words, to repeat a particular control movement—say 'right rudder' after 'right rudder' was the last movement before the return to neutral—the escapement must be signalled through the sequence of 'left-rudder' followed by 'neutral' and then 'right rudder'.

This type of actuator is self neutralising (known as a S/N type), because it returns to neutral on release of signal. The facts that a signal has to be held on to produce a control position, that the movement involved is a 'bang-bang' type, and that control positions can only be signalled in *sequence* are all characteristics of simple single-channel actuators.

In a practical installation the actuator is usually mounted vertically and thus the crank rotates in a vertical rather than a horizontal plane. The necessary motion for operating a rudder control can then be obtained with a rocking arm type linkage, as shown in *figure 6.6*.

Transmitter, receiver and escapement, showing relative sizes. Simple escapements can be built smaller and lighter, but need precision manufacture.



6.6 Basic practical arrangement of transferring 'rocking arm' movement derived from escapement crank into rudder movement.

There are also alternative ways of coupling up control operating linkages to a vertically mounted escapement (see Chapter 12).

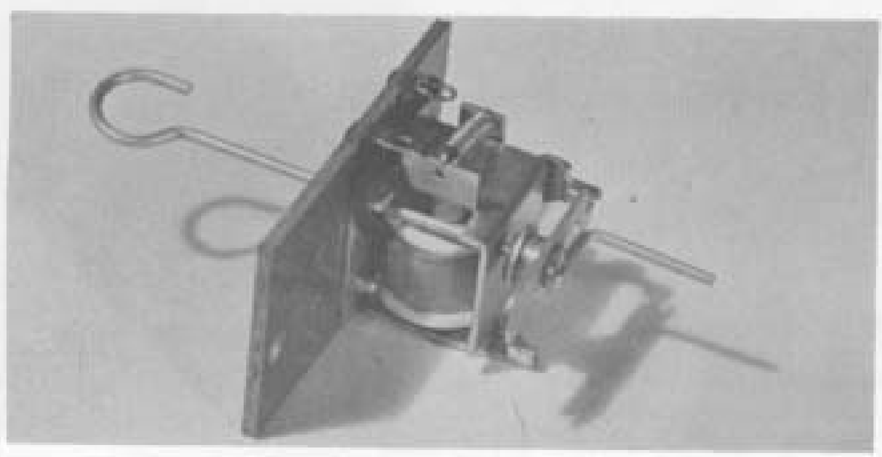
Because the action of an escapement is rapid—movement from neutral to a control position, or from a control position to neutral, only takes a small fraction of a second—it is possible to switch through a complete sequence, if necessary, without the 'opposite' control position having any effect. Also it is very easy to become thoroughly familiar with the sequence involved, so that signalling a particular position becomes instinctive.

If, for example, the direction of rotation of the escapement arm is such that the first signal gives 'right' rudder, either control position can be selected on the basis of operating the transmitter key in the following manner.

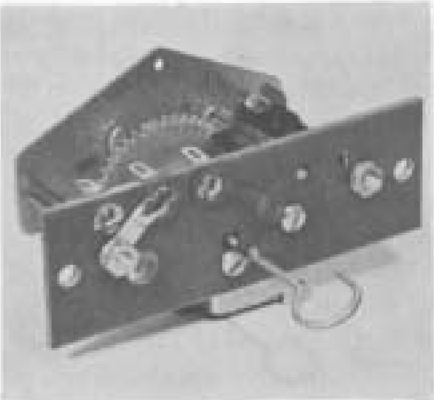
For *right* rudder—*press and hold*
For *left* rudder—*press-release-press and hold*

If a sequence is 'lost'—as can happen—it is only necessary to press and hold the signal and *observe* the response of the model to establish the true 'last' position of the escapement.

On some transmitters this type of sequence switching is provided for automatically, using a joystick control instead of a simple keying switch (microswitch). Movement of the stick to the right would then give a



Typical simple single-channel escapement assembled on Paxolin panel. This panel serves for mounting the escapement. Note use of single arm movement.



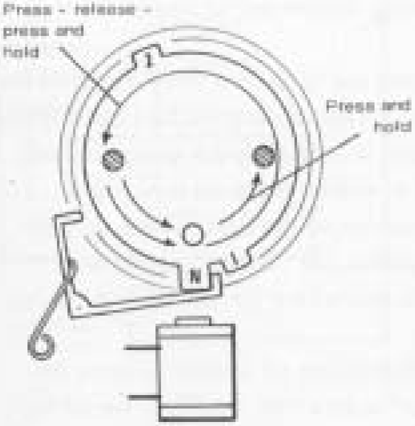
Toothed wheel is preferred on later type escapements, rather than cruciform arm.

single signal, held; and movement of the stick to the left a sequence of switch on-switch off-switch on and held.

Modern simple S/N escapements usually employ a cruciform arm instead of a single arm, one arm being 'short' and one 'long'. The advantage of this is that it enables the 'stop' and 'release' actions to be performed by a single detent on the pivoted armature. The actual sequence of movements is exactly the same. Alternatively the arm can be replaced by a disc with 'teeth' on the periphery, although this form is normally used with a *compound* escapement.

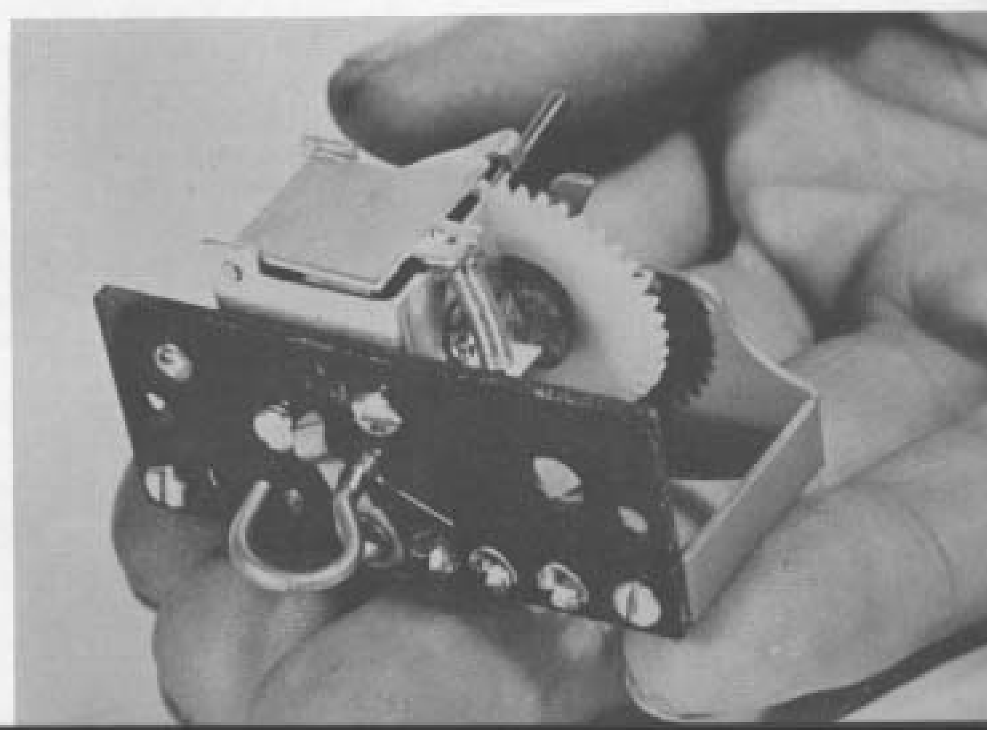
The compound escapement produces *selective* action in the design of the escapement itself. In its simplest form it employs a rotating disc with two 'teeth' diametrically opposed, with the original type of double-ended armature (*figure* 6.7). The first application of signal will release the disc, causing it to rotate through a quarter-turn (90 degrees) until it is brought to rest by armature detent B. On release the disc will rotate through three-quarters of a turn (270 degrees), to return to neutral, stopped by detent A.

If an 'opposite hand' signal is given—press-release-press and hold—the first signal pulse will release the disc, allowing it to rotate. By the time the first tooth has reached detent B position, however, the armature will have dropped out due to the release of signal and so rotation will continue. By the time the tooth has completed 270 degrees of rotation the armature will have been pulled in again, so detent B is now in the way to stop the motion after 270 degrees of rotation. This position is held as long as the signal is held. On release of signal, the disc rotates a further 90 degrees to neutral again.



6.7 Compound escapement with selective 'hold' positions 1 and 2.

This is the same as the simple S/N movement, the only difference being that controlled timing is built into the movement. This is usually done by adding a ratchet brake to the disc, deliberately slowing its rate of rotation to match normal 'press-release-press and hold' signalling times. The advantage over simple S/N working is that there is no need deliberately to stop and release on the 'opposite' control position to ensure that the sequence has been properly selected. Also the actual

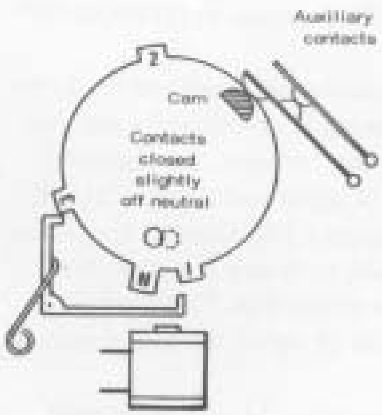


Compound escapement with auxiliary switching contacts. Toothed wheel is slowed by a ratchet-type brake.

'timing' of the press-release-press and hold signal is less critical because of the slower movement involved.

To produce ratchet braking the disc is normally made in the form of a gear wheel with fine teeth all around the periphery. At the top is mounted a loosely pivoted 'rattler' to work as a ratchet. The braking effect achieved is normally to reduce the rotational speed of the wheel to the order of one halt to one second per complete revolution. The 'teeth' for providing the stop-and-go action for the escapement are in the form of projections on the face of the wheel, the whole wheel commonly being a single moulding in nylon. The use of a metal wheel with a metal rattler must be avoided to eliminate the possibility of generating electrical 'noise' which could interfere with the receiver circuit.

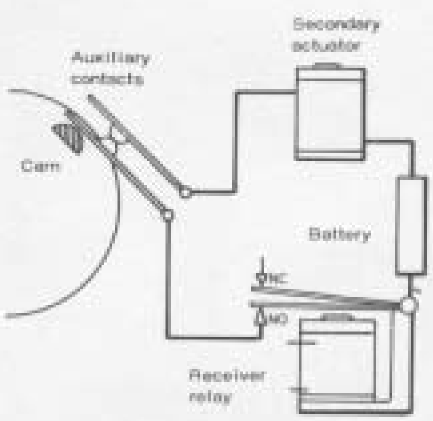
The same principle can be extended to provide a third 'selective' control position on the compound actuator movement. One basic method is to include a third tooth on the wheel, quite close to the neutral position so that when this position is held the main control linkage connected to rudder movement is not appreciably displaced (*figure 6.8*). This third position is then selected by the sequence signal: *press-release-press-release-press and hold.*
When this signal is received the disc rotates to a position where a set of auxiliary contacts are closed, these being connected to a secondary control circuit.



6.8 Escapement with auxiliary switching contacts.

There are, however, limitations to the use of such a third position for switching. The switching contacts are, in fact, momentarily closed every time the disc makes a complete rotation in selecting the main controls. This means that the secondary actuator will be given an unwanted momentary 'trip' signal with every rotation of the disc, which may or may not have an unwanted effect. It could, for instance, cause an escapement used as the actuator in the secondary circuit to 'trip' to its next sequence position each time.

This possibility can be eliminated in the case of a *relay* receiver by using the back contacts of the relay to 'isolate' the auxiliary switching contacts, as shown in *figure 6.9*. The secondary circuit is wired through the 'unused' half of the relay contacts (i.e. armature and NC contact). Unless the third position is deliberately signalled the condition of the receiver relay when the third-position tooth sweeps past the auxiliary contacts and closes them is dropped out. Thus the actuator circuit, taken through the now 'open' relay contacts, remains broken. Only if the third position is held will the relay be pulled in, and the secondary actuator circuit fully completed and switched on.

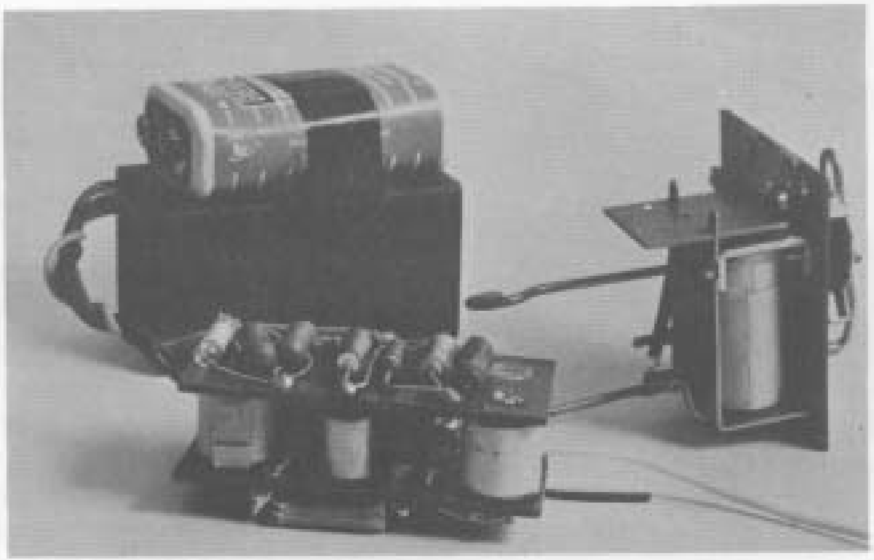


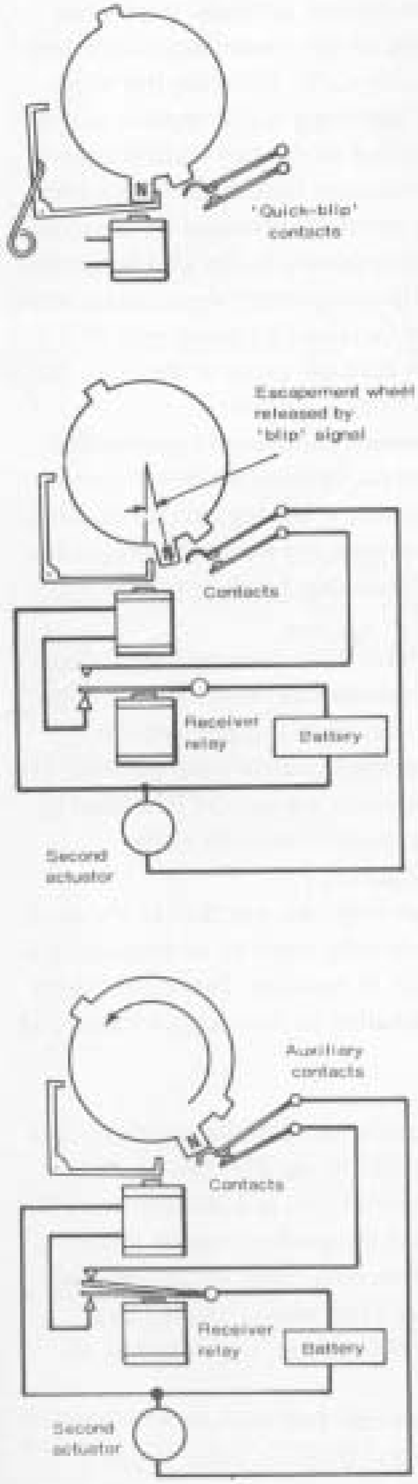
6.9 Wiring to 'isolate' the auxiliary switching contacts.

The method of signalling the third position is relatively cumbersome, however, and is normally replaced by 'quick-blip' signalling on modern compound actuators. The working of this can be explained in conjunction with *figure 6.10*.

A cam, or projection, on the disc is positioned as shown, so that a pair of contacts are momentarily closed every time there is movement away from the neutral position and immediately following it. These are wired through the relay contacts again, to provide 'isolation' of the

Special type escapement shown with matching receiver. Special escapements were often 'tailor made' to match different types of receiver systems.





6.10 Working of 'quick-blip' signalling.

auxiliary circuit when a main control position is signalled by ensuring that the auxiliary circuit is completed only when the relay is dropped out.

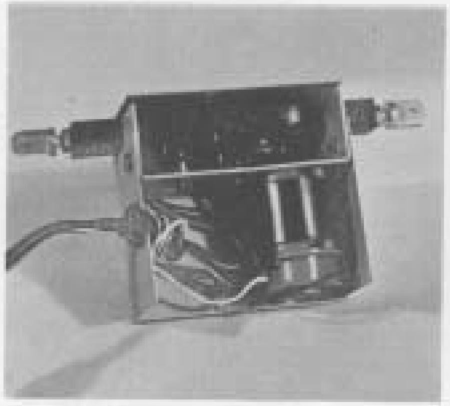
Either of the main control positions required will be signalled by a deliberate press (which may be followed by release and press again). Over the initial movement, when the auxiliary contacts are momentarily closed, the relay will thus be pulled in.

If, however, a very quick signal is given—a quick 'blip' followed by immediate release—this will be sufficient to release the disc, but the receiver relay will have dropped out by the time the movement has closed the auxiliary contacts, thus completing the circuit. This will give a trip signal in this circuit, sufficient to release a secondary escapement to move to its next sequence position. Meantime, of course, since the signal is released virtually as soon as it has been given, the main escapement disc will simply complete a full rotation, returning to its neutral position.

Timing of the 'quick-blip' is obviously important. If not quick enough (i.e. if held a fraction too long), the relay will remain pulled in as the auxiliary contacts are closed and the secondary circuit remains open. This is a 'safe' form of failure as nothing will happen on the secondary service; and a further signal can be attempted with a quicker 'blip' action.

Quick-blip signalling is provided as a separate pressbutton control on some transmitters, rendering this signalling independent of operator error. Pressing this button for any period merely trips a 'quick-blip' signal of the required time interval to suit a matching compound escapement.

At one time—particularly before the introduction of the 'quick-blip' signalling idea—when 3-position and 4-position sequence controls were widely used with single-channel, mechanical switching devices were allied to the transmitter to provide the correct sequence signal from a single movement of a control stick. Thus moving the stick to the right would initiate a 'hold' signal to give right rudder. Moving the stick to



Motorised actuator with linear output movement.

the left would automatically give a trip signal followed by 'hold', i.e. equivalent to press-release-press and hold on a conventional single channel key. Sequence signals for the other position(s) would then be initiated by up or down movement of the stick, or by pressing separate signalling buttons.

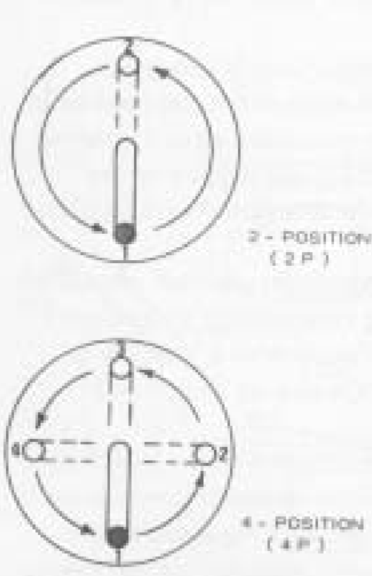
These devices were known as 'bleep boxes'. In theory, at least, they simplified sequence operation of single-channel controls. In practice they proved generally unreliable because of the consequence of a 'lost' sequence which could be generated accidentally, throwing the whole sequence out. The principle of 'direct' signalling is still applied to some transmitter designs, but generally restricted to the two main sequence positions (right or left rudder), with a separate button for 'quick-blip'.

The *third-position* signalling facility normally provided on compound actuators has been related only to relay receivers. It can also be applied to relayless receivers only in this case the escapement the actuator must incorporate both a pair of auxiliary contacts and a second pair of contacts controlled by 'position' which take the place of the relay 'back contacts' and provide the necessary form of isolation.

This is standard practice on most modern compound escapements since escapements are normally selected for lightweight installations, where a relayless rather than a relay receiver is the logical choice. Also, as previously noted, relayless receiver outputs are normally designed to match standard escapement loads as represented by their typical coil resistance of 8 ohms.

Self neutralising (S/N) escapements have been described first, since these are the normal choice for main controls—and essentially so in the case of aircraft rudder controls. The action of an escapement can, however, equally well be progressive, or merely move from position to position in sequence. Progressive escapements are usually described by the number of definite *positions* they provide—normally either 2-position (2P) or 4-position (4P) (see *figure 6.11*).

The other difference is that to change from one position to the next in the sequence a progressive escapement only needs to be *tripped* by a momentary signal, not signalled and *held* in position. This makes them suitable for use in secondary services signalled by momentary closure of auxiliary contacts.

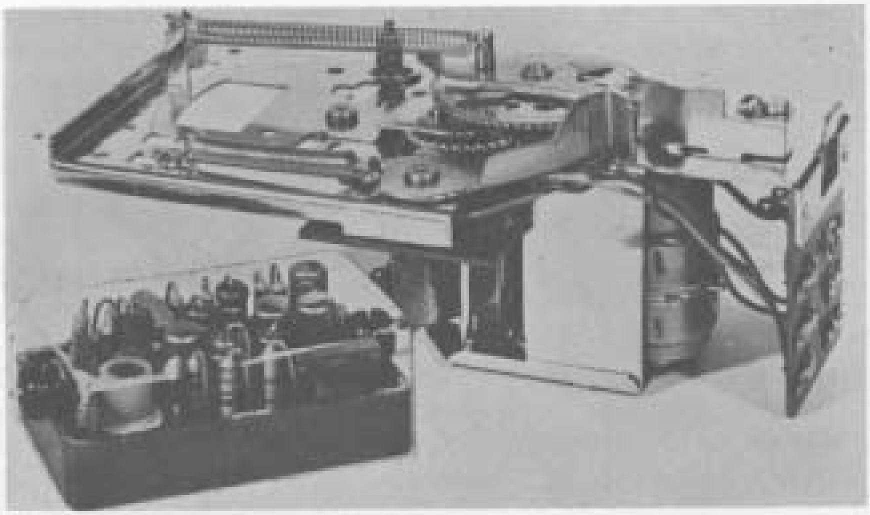


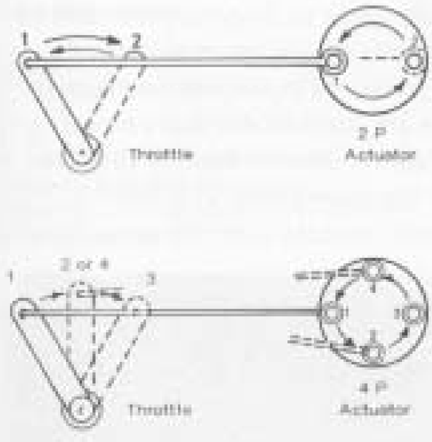
6.11 Two-position (2P) and four-position (4P) motions defined.

A 2P progressive escapement will provide two definite positions, but a 4P escapement will only normally provide three. This can be explained by considering the use of the two types as a throttle control, as shown in *figure 6.12*. The two-position escapement can be linked to move the throttle between extreme movements—slow or fast—and will move from one to the other in sequence. Thus when signalled as an auxiliary service it will provide throttle changeover, i.e. from fast to slow, or slow to fast.

The three-position escapement will provide two extreme throttle movements, with one intermediate position (realised twice in any complete sequence). The throttle control sequence available is thus: slow-intermediate-fast-intermediate-slow-etc.

Multi-function single-channel escapement with built-in switching action, specially designed for model boat controls.



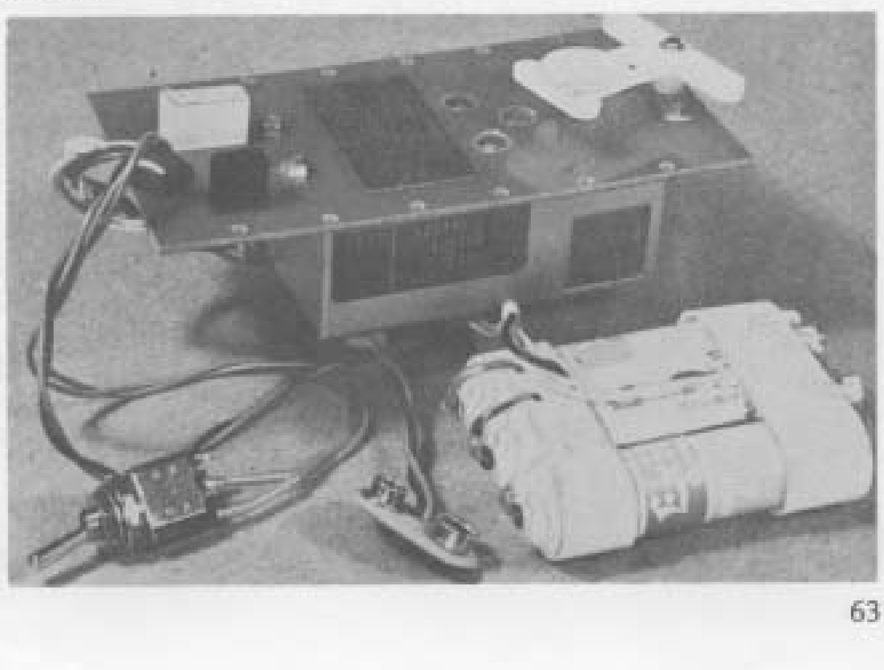


6.12 Throttle movement controlled by 2P and 4P actuators.

This has the advantage of providing an additional throttle position, but no *positive* selection. Thus if the control is in the intermediate position, the next signal may give either fast *or* slow. If the response was not what was required, then *two* further signals will have to be given to achieve the required control position.

Extension of use of actuators

One main escapement or motorised actuator is normally selected to provide the main control function required. A further switching facility on this actuator can be used to operate another service, or even services. The extent to which this is realistic in practice depends mainly on the application. The scope and extension of actuator services is, therefore, dealt with in appropriate chapters, for example Chapter 12 describes single-channel aircraft control systems, and Chapter 18 single-channel boat control systems. These show how single channel actuators may be further grouped or 'cascaded', and how other forms of single channel actuators, such as sequence switchers, may be suitable for particular services.



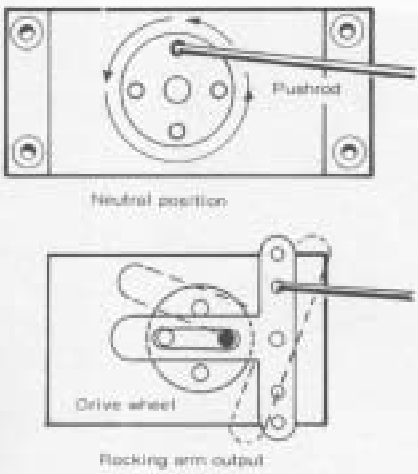
Modern motorised actuator. Even for single-channel working, motorised actuators eventually took over for escapements as being more powerful and more reliable.

In the case of cascaded actuators (either escapements or motorised actuators), best results are usually obtained with 'matched' actuators—i.e. two (or more) produced by a single manufacturer specifically for use in cascade. However, the manufacture of cascaded actuators (and single-channel actuators generally) has tapered off considerably since 1972, and such types may be difficult to find.

Motorised actuators

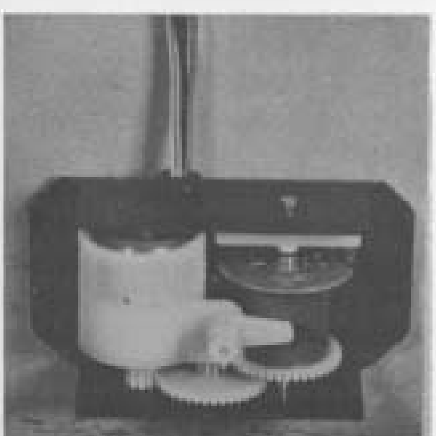
Exactly the same functions can be performed by electric motors controlled by suitable switching circuits swept by brushes controlled by the degree of motor movement. Such units are known as *motorised actuators*, or single-channel actuators (referring to the electro-magnetic types as escapements). The advantages are considerably more power output available; generally greater reliability (mainly because they are divorced from reliance on mechanical trip movements with their possibility of 'skipping' or 'binding'; and freedom from the necessity of

Photo: Radio Modeller



6.13 Rotating disc and rocking arm output movements.

Example of a three-position motorised actuator with disc type output movement. Cover and disc removed in bottom picture.



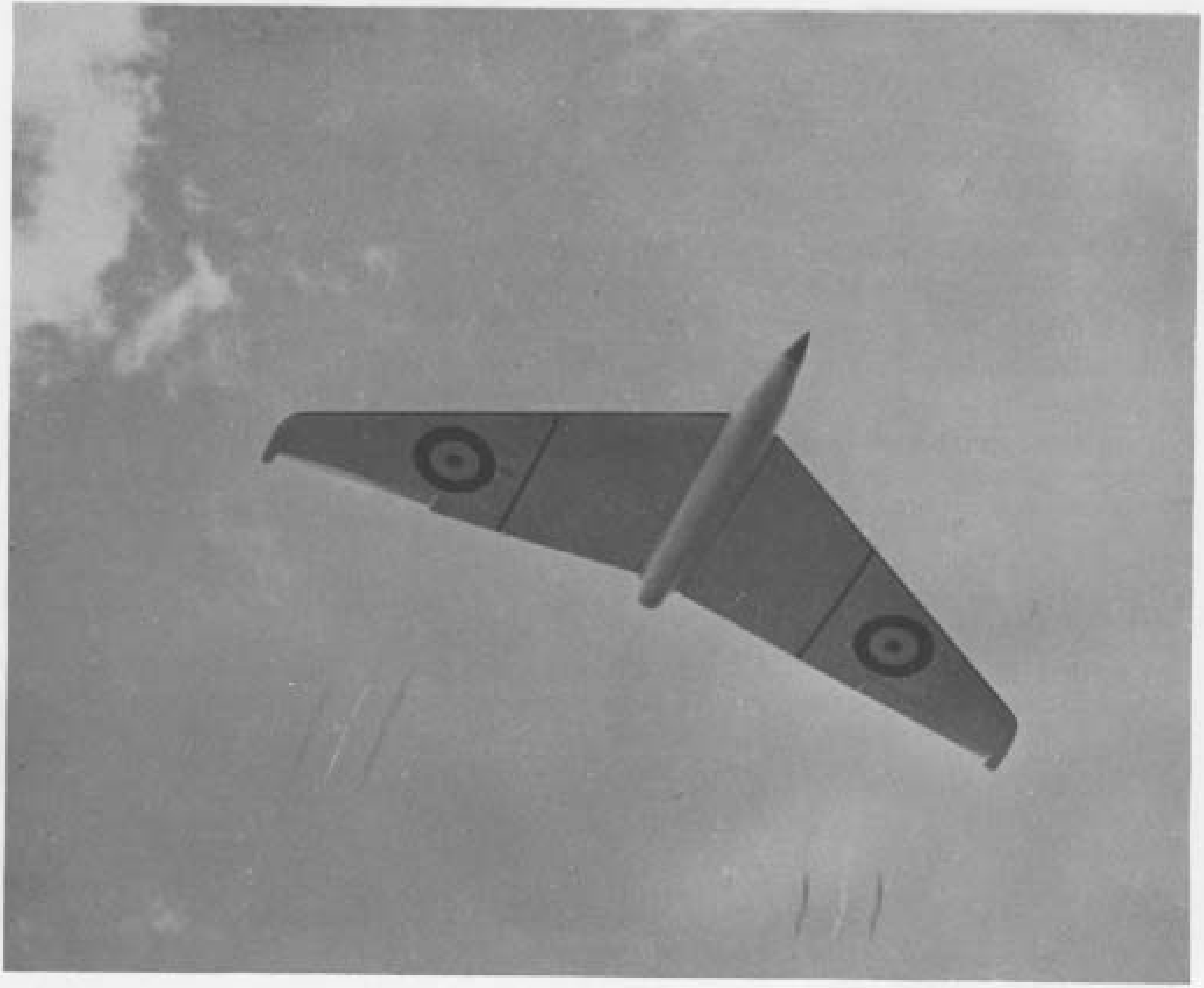
accomodating some 'external' form of power (e.g. the rubber motor normally used to drive an escapement). On the debit side they are bulkier and heavier, usually considerably more costly type-for-type, and have a higher electrical input demand. The latter largely excludes their use for direction connection to relayless receivers.

Motorised actuators would be a normal choice on all types of models where heavier control loads are involved, (e.g. larger aircraft and the operation of boat rudders). Mechanical output is usually presented in the form of a disc or arm with stop-and-go rotary movements to which push-pull linkage may be attached directly (*figure 6.13*). Alternative coupling positions provide a range of both output movement and force moment. The thrust output available can be quite high, even when a small electric motor is used, because reduction gearing is used between the motor spindle and the output movement to provide realistic transit times. This results in considerable torque multiplication.

Single-channel motorised actuators—meaning, basically, they provide bang-bang type control movements, responding to simple on-off signal inputs—are produced in all the same types as escapements: simple S/N, compound S/N, and 2-position or 4-position progressive. They are also more readily adaptable than escapements to multi-position (sequence) progressive actions, if required.

The main difference between a rotary output servo (rotary disc or rotary arm) and a linear output servo (push-pull action), is that the movement of the former is non-linear. Both the travel and rate of push-pull motion derived in the linkage decreases towards the end of the first 90 degree movement, and then increases over the second 90 degree or return movement. This is because the driving movement *is* rotary. With a linear output servo the output motion is driven through rack and pinion gearing. As a consequence the movement has a constant rate of travel.

In the case of cascaded actuators (either escapements or motorised actuators), best results are usually obtained with 'matched' actuators—i.e. two (or more) produced by a single manufacturer specifically for use in cascade. However, the manufacture of cascaded actuators (and single-channel actuators generally) has tapered off considerably since 1972, and such types may be difficult to find.



7 SINGLE - CHANNEL OPERATION AND TROUBLE - SHOOTING

It is an inescapable fact that the majority of radio-control 'faults' occur because equipment was never thoroughly checked and adjusted, if necessary, *before* attempting to fly or operate the model. Particularly in the case of aircraft—where radio failure can be disastrous—a model should *never* be flown unless all the controls check out as working satisfactorily and reliably. Symptoms of 'skipping' actuators or some other incipient fault will not 'come right' in the air. Almost invariably the reverse is true.

Wiring-up or connection faults are virtually eliminated with pre-wired commercial receiver-actuator-wiring harness installations (the latter incorporating battery connections or a battery box). The only likely fault is installation of the battery cells with wrong polarity in a battery box. If the installation has been wired up from scratch, however, it is essential to check the circuit through, wire by wire, before switching on for the first time. Mistakes in wiring up connections are very easy to make, and wrong connections could cause damage to the receiver transistors on switching on.

Commercial transmitter and superhet receiver combinations are factory tuned and aligned and need no further adjustment or tuning. Superregen receivers may also be factory-tuned, but provision is made for individual tuning, via a *tuning* control, and sometimes also a separate *sensitivity* control. Both controls are in the form of coil slugs, accessible from the outside of the receiver case, and with a slotted end which can be turned by a screwdriver. Where two separate controls are provided, adjustment is interdependent to some extent. Thus alteration of one may affect the response of the other. With most modern receivers, however, only a single tuning control is used, and tuning is generally straightforward. Explicit directions are normally supplied with the equipment.

The screwdriver used for turning a tuning control or sensitivity control must be non-metallic otherwise its proximity to the component would temporarily affect its behaviour. Alternatively a plastic knitting needle, a rod of perspex or Paxolin (sharpened to a chisel end), or indeed any suitable instrument of insulating material, may be used as a tuning tool. Some tuning slugs have a hexagonal hole for the tuning tool for which plastic tuning wands are available to fit. A metal Allen key must *not* be used in such cases.

Initial tuning, for convenience, is best done with the transmitter and receiver fairly close together, but not too close as otherwise the signal may 'swamp' the receiver and make it impossible to tune. Transmitter output, for initial or close-range tuning, is usually reduced by retracting the aerial. Tuning, basically, then consists of finding the *range* of movement of the tuning control over which the receiver responds to the transmitter signal—i.e. from one position to the other where the signal is 'lost' in each case—and then finally setting the tuning adjustment in the *middle* of this range as representing the optimum tuning position.

The easiest way to judge whether the receiver is 'working' or not is simply to connect up the actuator. In fact, with modern transistor receivers this is often the only way. The receiver is obviously 'working' or 'on tune' when the actuator responds to a transmitter signal, and so tuning is adjusted to the middle position of the 'on tune' range.

With a single-channel tone receiver tuning may also be done with headphones. Suitable tapping points for the phones may be indicated on the circuit diagram or provided for on the cable plug. With the receiver switched on but transmitter off, a characteristic hiss will be heard in the phones, indicating that the super-regenerative circuit is oscillating correctly. With the transmitter signal 'on' the receiver is tuned until the hiss stops. The tuning control is then turned further one way until the hissing starts again; then back in the other direction to the extreme point where hissing is heard again. The middle position between these two settings establishes the optimum tuning point.

A meter can be used instead of phones. The meter will show a nominal idling current which will drop on receipt of carrier signal. The receiver is then tuned for minimum idling current with the transmitter carrier on; and finally it is checked that when the 'tone' is keyed the receiver current rises to the specified value.

The use of phones in the circuit, incidentally, can be extended to listening for 'noise' generated by actuator linkage, etc. It is often quite surprising the amount of 'scratching' noise that occurs on operating a control. If bad, the source should be traced and the cause rectified (see later).

Tuning *must* then be re-checked at range, this time with the transmitter aerial fully extended and the transmitter in the normal position it will assume in use, e.g. held in the hand, or ground-standing. Model aircraft should also be held about shoulder high. Final tuning for boats *must* be done with the boat in water. Tuning procedure is exactly as before except that this time it will be found that the range of movement of the tuning control to stay 'in tune' will be appreciably reduced. Also the central position may be somewhat different from that found by initial tuning.

The distance at which the range-check is carried out is largely arbitrary. A 200-yard range is generally adequate for aircraft, with less for boats. It is important that a range-check *is* carried out, however.

A further check must now be undertaken with the engine running, to see if vibration is upsetting the receiver relay (in the case of a relay receiver) or the actuator, causing chatter; and that there is no mechanically generated 'noise' which could interfere with the working of the receiver. Ideally this engine-on check should be carried out at both short range and long range, but with the high reliability associated with modern equipment a short range check only is generally sufficient.

Should troubles show up, such as the actuator 'skipping', or failing to respond to transmitter signal, possible causes and cures are:

(1) Engine-receiver combination not suitable, i.e. the receiver is susceptible to vibration in the case of an i/c engine; or 'noise' in the case of an electric motor main engine.

Possible cures for vibration troubles:

(a) Try to reduce propeller vibration in the case of an i/c engine either by fitting a different propeller, clamping the propeller in a different position on the shaft, or balancing the propeller.

(b) In the case of a relay receiver, try a more flexible mounting for the receiver and, or, try the effect of positioning the receiver in a different way (e.g. at right angles to the first position).

(c) Try mounting the receiver in a different part of the model where vibration is less pronounced.

(d) The relay may be critically adjusted, with the possibility that readjustment will cure the susceptibility to vibration.

Possible cures for electrical interference and 'noise' are:

(a) Adequate suppression of motors or actuators.

(b) Spark suppression of relay contacts.

(c) Bonding or insulation applied to metal linkages.

(d) Locating the receiver as far as possible away from electric motors (e.g. servos or main drive motor(s)). This is no substitute for adequate motor suppression.

(e) Receiver aerial badly located. Reposition run of the aerial clear from other current-carrying wires, and avoid running parallel to such wires, or mechanical linkages.

Just how frequently tuning needs to be checked depends very much on the stability of the transmitter and receiver, and also whether either may have received mechanical damage or severe shock. Given good-quality equipment it is usually satisfactory to repeat a brief short-range check *before every outing*. If after the initial range check tuning the *extreme range* given when the transmitter aerial is retracted is found, future checks at just short of this range (again with transmitter aerial retracted) will confirm that tuning is in order. If this (aerial-retracted) range is found to be drastically reduced, then re-tuning is probably called for.

With some all-transistors operating with the aerial retracted or removed can result in overload and damage to the output transistor. This will normally be noted in the instructions for that particular transmitter. Short-range checks cannot be made in such cases.

A common cause of lack of range and/of sticky actuator action is low battery voltages, particularly when small sizes of dry batteries are used. In a majority of cases small dry batteries (and particularly those used as actuator batteries) are subject to current drains far in excess of their nominal rating. As a result they polarise rapidly and quickly lose voltage.

All battery voltages *must* be checked on load, i.e. when in the circuit and switched on. It is quite pointless to measure the voltage of a battery simply by putting a voltmeter across its terminals. Battery voltage on load should be measured when the circuit has been switched on for a minute or so (in the case of receiver and transmitter batteries); or during the operation of an actuator (in the case of actuator batteries).

Receiver and transmitter batteries have a nominal end-point voltage below which satisfactory performance will not be given. This does not mean that they can be used right up to this point. Range will decrease all the time with falling voltage and when the battery approaches its nominal end point it will be quite substantially polarised and likely to suffer a further voltage drop quite rapidly. As a general rule no dry battery should be used after its 'on load' voltage has dropped to 0.8 times the voltage it showed when new and fresh.

Do not overlook the fact that low *transmitter* batteries can be just as much a cause of lack of range as low receiver batteries. Receiver batteries are normally regarded as the 'weak link,' largely because they are of the smallest practical size to save weight and bulk. The current drain on hand-held transmitter batteries is quite high, however, and they need frequent checking.

Battery troubles are largely eliminated by using nickel cadmium batteries instead of dry cells.

Fault-finding

Fault-finding is not a subject which lends itself readily to general discussion. Many faults which can develop are characteristic of a particular receiver or actuator—or even the transmitter. Others may be specific to installation. The most common 'electronic' fault is low batteries, followed by dirty contacts. Provided the equipment is correctly set up and adjusted initially, these are the most likely 'electronic' troubles—short of mechanical damage following a crash or component failure. The latter usually requires expert knowledge to check and rectify, or the return of commercial equipment to the manufacturer for service.

Contacts on relays and actuators can get dirty and require cleaning. A more common source of 'dirty' contacts, however, is burning or pitting due to their being called upon to pass too heavy a current. This can occur if contacts are not fitted with arc suppression, or if the actuator controlled by the contact is operated on too high a voltage, deliberately chosen to get a more powerful 'action'.

Mechanical troubles which may arise are: sticking control linkages, either due to poor design and installation, or possibly as a result of crash damage; or excessive vibration or free movement due to wear on hinges or bellcranks. These, like structural damage, represent normal 'model maintenance' and should be dealt with as soon as the trouble shows up. It is more important to keep a radio-controlled model in first-class condition, regularly serviced, than its free-flight (or free-running) counterpart. It carries an expensive investment in time and money in its control gear. In checking the radio side at frequent intervals it is equally important to appreciate that the *model* also may require regular servicing.

Fault	Cause	Action
Does not work when switched on (No idling current shown on meter or as 'hiss' heard on 'phones used to check).	Connection fault	(1) Check batteries. (2) Check battery connections (especially spring pressure in battery boxes). (3) Check actual wiring to see if it agrees with instructions. (4) Check for broken wires or poorly soldered joints. (5) Check that switch is working properly and not defective due to dirt, etc.
	Circuit fault (component)	Faulty component.
Does not respond to transmitter (Idling current shown on meter when switched on, 'hiss' heard on 'phones but no tone).	Weak batteries	Check actual battery under load with suitable voltmeter, preferably after the battery has been on for 2-3 minutes. An absolute minimum load voltage for satisfactory operation is 0.8 times the nominal battery voltage (e.g. in the case of a 6 volt battery, 0.8 x 6 = 4.8 volts as measured on load). Replace batteries if approaching this minimum load voltage figure.
	Nickel cadmium Accumulators: Check voltage on load which should not be less than 1.1 volts per cell. Recharge if necessary.	
	Faulty tuning	Re-tune against transmitter (transmitter on) at short distance and at range. Do not attempt to tune near possible sources of interference, e.g. an iron shed or fence. In the case of aircraft: tune at range with the model held at shoulder height. In the case of boats: tune at range with the model in the water. In both cases the transmitter should be used in the normal operating position (e.g. hand held).
	Relay adjustment faulty	Check that relay *is* working by switching receiver on and off. If working, readjust to circuit specification or manufacturer's recommended 'pull in' and 'drop out.' If not working, suspect mechanical fault in relay.
	Transmitter fault	Transmitter batteries may be weak or transmitter faulty, transmitter aerial not connected or extended, or poor connection.
Relay or escapement 'chatters' (Motor not running)	Faulty relay adjustment	Check relay adjustment.
	Critical tuning	Check tuning at range
	Faulty tuning	Re-tune as above.
	Transmitter fault	Check transmitter for correct operation, e.g. from another transmitter.
	Outside interference	
	Escapement motor too strong—causes escapement to 'skip' under vibration.	Replace with smaller section motor or reduce number of turns supplied.
	Escapement motor wound wrong way	Immediately apparent as it occurs on winding the escapement motor.
	Escapement faulty	Pawl or detent not properly raked or set.

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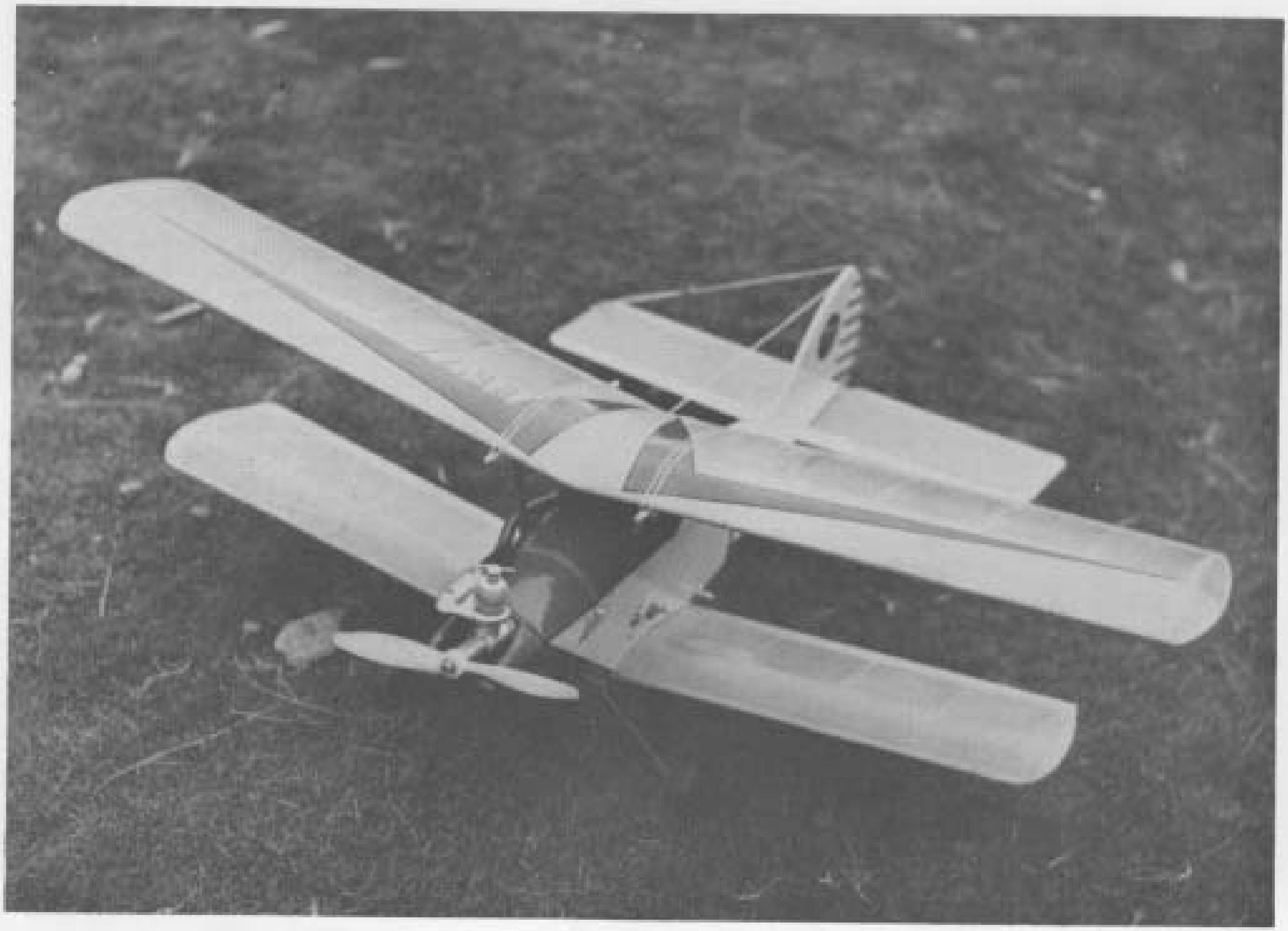
Fault	Cause	Action
Control surface or actuator sticks 'on'	Escapement motor too strong—locking escapment	Replace with smaller section motor or use less turns.
	Escapement motor unwound	Enough power for one movement but not return.
	Motorised actuators: (1) Motor fault	Possibly dirty or burnt commutator—clean to rectify
	(2) Switching circuit fault	Clean contact surfaces.
	Escapement fault	May be burr on pawl or detent. Check and adjust for proper action.
	Excessive friction	Check linkage for freedom of movement.
Control surface of actuator sticks 'off'	Escapement motor unwound	Check that it is rewound the correct way.
	Escapement motor too weak.	May stick 'on' or 'off'.
	Motorised actuators: (1) Faulty switching	Clean switching contacts.
	(2) Disconnected motor	Look for disconnected wire.
	(3) Motor fault	Clean commutator and/or replace bushes if necessary.
	Weak actuator batteries	Insufficient to energise coil. Replace.
	Excessive friction	Too much 'binding' for escapement motor to move linkage—so free up.
	Excessive aerodynamic load	Use aerodynamic balance to cure. Note : Excessive aerodynamic load at high speeds may equally well lock a control position 'on' by distorting the linkage and causing binding.
Controls do not operate	Weak actuator batteries	Check voltage under load.
	Actuator circuit fault	Isolate actuator circuit and check operation independently. (1) Possible wiring faults or disconnections. (2) 'Dry' solder joints. (3) Actuator coil fault.
	Dirty contacts	Check and clean as necessary. Re-adjust contact pressure.
	Damaged contacts	Contacts may be pitted, burnt or even welded by using excessive actuator voltages (this also includes relay contacts).
	Mechanical failure	Check for binding linkages, broken or seized hinges, etc.
Controls inter-act	Electrical interference	Suppression or bonding may be needed, if not already used.
	Weak batteries	Additional load to second actuator too much for battery capacity.

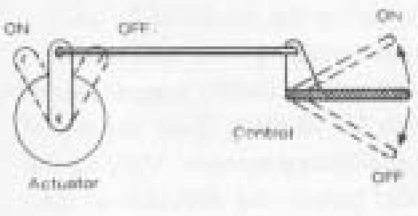
Relay or escapement 'chatters' (Motor running)	Engine/propeller combination	Check propeller balance or change propeller.
	Receiver mounting	Improve shock-resistant mounting of receiver or mount in a different attitude.
	Faulty adjustment	Relay adjustment may be faulty or weak batteries giving poor 'hold in.'
	Electrical 'noise'	Insulate or bond metallic linkages.
Lack of range	Faulty adjustments	Check relay operating points and differentials against recommendations. Specifically check top current at range (batteries may be weak).
	Critical tuning	Re-check tuning.
	Weak batteries	Check receiver and transmitter batteries under load.
	Change of aerial	Check that aerial length is correct.
	Transmitter fault	Check transmitter operation independently.

Fault	Cause	Action
Apparently no signal (No reading on field strength meter)	Faulty adjustments	Check against manufacturer's specifications.
	Circuit disconnection	Check for broken or disconnected wiring, fault in keying lead or switch.
	Circuit fault	Component failure (more difficult to trace without specialised knowledge. Return transmitter for check and service if necessary).
Weak signal or lack of range (Low reading on field strength meter and short range.)	Faulty adjustments	Receiver may not be correctly tuned to transmitter.
	Aerial fault	(1) Check that aerial is proper length (also that the loading coil is incorporated, where specified). (2) Check that aerial is properly mounted (e.g. good connection at base). (3) Check that joints are not oily or dirty on telescopic aerial. (4) Check that aerial is not earthing through faulty socket or moisture on socket.
	Weak batteries	Check batteries under load. See under Receivers.
	Unfavourable operating conditions	(1) Transmitter near damp ground with variable 'ground coupling' effect. (2) Output affected by presence of overhead wires, etc.



Example of a model designed specially for single-channel 'proportional' control. Only aircraft are suitable for this type of control. Photo Radio Modeller.

8 SINGLE - CHANNEL PROPORTIONAL



8.1 Control surface continually driven by an electric motor actuator.

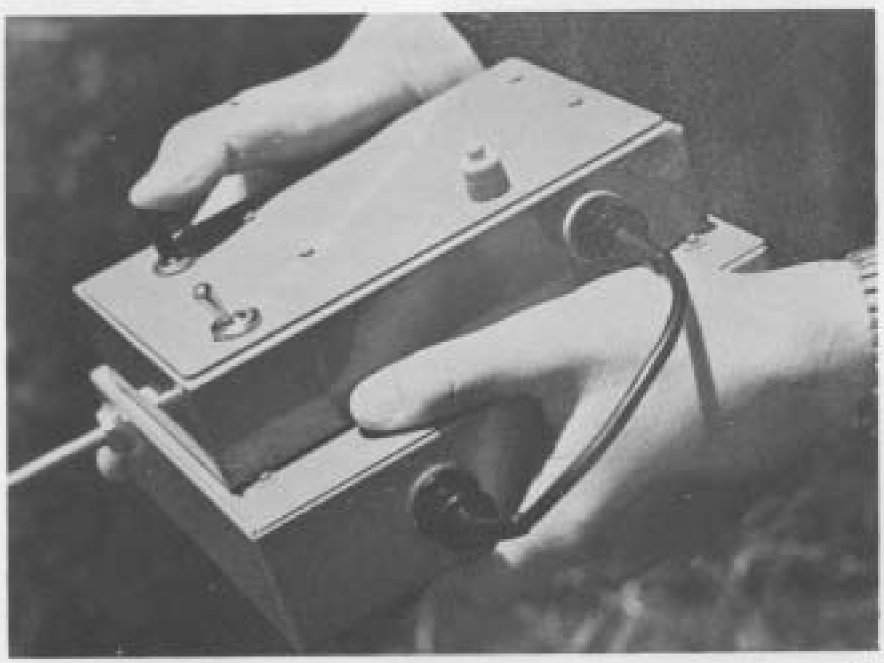
Single-channel proportional systems work on a *pulse proportional* basis, meaning that the command signal is sent in the form of pulses, the *length* of the pulses being varied in response to movement of a control stick on the transmitter to bias the actuator to a 'proportional' position. To achieve this it is necessary that the control surface involved oscillates continuously about a neutral position: a condition which may appear highly undesirable at first sight but, in practice, is quite acceptable for model aircraft control (and certain other types of model controls).

The principle of operation is as follows (see also *figure 8.1*). The actuator is basically a two-position type, so that 'on' corresponds to one extreme control position and 'off' to the other extreme control position. Sending the full signal will, say, thus give full right rudder; when switching the signal off completely will give full left rudder.

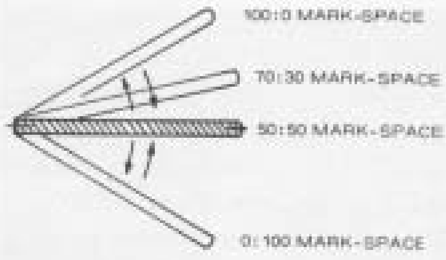
Instead of the signal being switched on or off as in normal single-channel working, however, it is transmitted continuously but chopped up into a series of *pulses*. The presence of a pulse is equivalent to signal 'on' and the absence of a pulse is equivalent to signal 'off'. This is referred to as a *mark* (pulse present)–*space* (pulse absent) form.

If the duration of the pulse is the same as that of the space (equal mark: space ratio) the 'command' is divided equally between right and left rudder. In other words, the rudder will oscillate equally about its mean position at the pulse rate of the signal. Changing the mark:space ratio will now produce a bias in one direction or the other. Thus if there is more mark than space, there will be more signal time present moving the rudder to the right than the left. As a consequence the rudder will oscillate about a new mean position biased to the right in proportion to the mark:space ratio present in the command signal. Similarly, more space than mark will bias the rudder to the left in corresponding proportion. Since the mark:space ratio can be varied

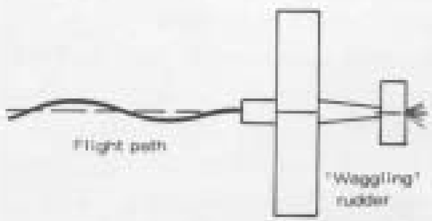
(Above) Simple pulse actuator with spring-centred arm and slipping clutch added to small electric motor.



(Right) Transmitter pulser made as a separate unit and used in conjunction with standard single-channel transmitter.



8.2 'Dwell' positions for oscillating control surface with different pulse mark-space ratios.



8.3 Flight path with waggling rudder.

from 100:1 (all mark) to zero (all space), this provides an infinitely variable selection of mean rudder position between these two extremes.

Considering this used as a rudder control on a model aircraft the effect of using a slow pulse *rate* would be for the model to fly an oscillating path, responding to the rudder wagging from side to side continuously. The model would still follow any rudder *bias*, induced by varying the mark:space ratio. Thus with 50:50 mark:space the model would fly a straight course, but in an oscillatory manner. Varying the mark:space ratio would make the model turn in the direction of the rudder bias induced, again oscillating about this course.

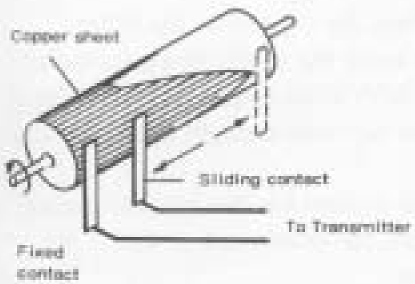
However, if the pulse *rate* is stepped up there will come a point where the model has not had time to react to movement of the rudder to one extreme position before the rudder has oscillated to the other extreme position, and so on. Thus although the rudder is oscillating continuously the model itself will fly without oscillation, and respond smoothly to any bias of the rudder position commanded by the mark:space ratio. Usually a pulse rate of 7 to 10 times a second (or higher) will achieve this smooth response in the case of an aircraft rudder control. A lower pulse rate could be used on a model boat rudder control.

Pulse transmitters

Virtually any single channel transmitter can be adapted for pulse proportional control. In theory, at least, pulsing the signal on and off could be achieved by manipulating the normal keying switch at the required speed (to achieve a suitable pulse rate), and dwelling at 'on' or 'off' to vary the mark:space ratio. Such a scheme is impractical, however. A separate *pulser* unit must be added in, or connected to, the transmitter circuit to convert to pulse proportional working. It can be applied to either a CW or tone transmitter. The latter is (almost) invariably the choice, when pulsing is applied to the tone signal, i.e. the pulser is inserted between the tone generator and modula or section of the transmitter.

Example of a proprietary pulser, for coupling to a standard single-channel transmitter.

High wing model aircraft with a wingspan of up to 48 inches are usually the best proposition for 'pulse-proportional' control.



8.4 Principle of simple mechanical pulser.

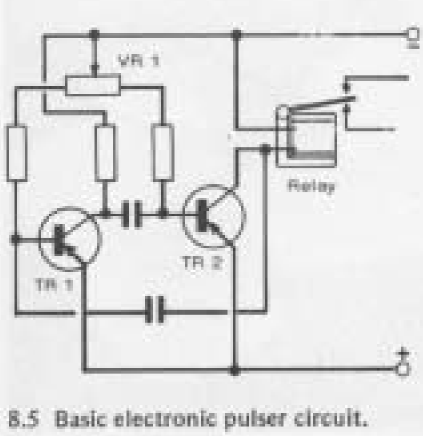
Pulsers can be either mechanical or electronic. Since the availability of commercial pulse proportional transmitters is more limited than other types, pulse proportional equipment is often home made. Modellers with limited knowledge or experience of electronics may thus tend to favour a mechanical pulser for home construction.

One of the early types evolved, which has proved quite successful as well as being easy to understand is shown in simple diagrammatic form in *figure 8.4*. It consists, basically, of a cylindrical drum of insulating material driven by a small electric motor at the required pulse rate (e.g. 10 revolutions per second or slightly more), the drum being covered by a tapering shape in thin copper sheet. Two contacts are arranged to rub against the drum. One is fixed at the 'full copper' end of the drum. The other is arranged to slide along the length of drum in response to the movement of a control stick.

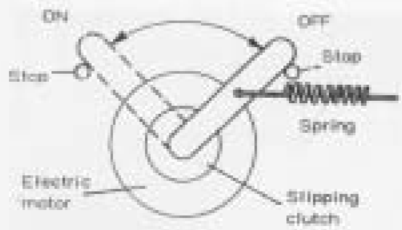
At one extreme position the sliding contact moves right off the copper area, corresponding to breaking the circuit or 'all space'. At the other extreme of its movement it reaches the full copper area, corresponding to direct connection to the fixed brush, or 'all mark'. At intermediate positions the mark:space ratio is determined by the relatively circumferential length of copper brushed by the sliding contact at that particular position.

More compact forms of mechanical switchers can be based on a rotating disc rather than a drum. Electronic pulsers are, however, generally to be preferred, based on conventional multivibrator circuits.

One such circuit is shown in *figure 8.5*. Transistors T1 and T2 are the heart of the multivibrator circuit biased by the variable resistor VR1. This is a potentiometer, adjusted by movement of the control stick. Component values for the circuit can be selected to give a fixed pulse rate, or a second variable resistor can be introduced to provide for adjustment of pulse rate. (Proportional systems can also work on variable pulse rate as well as variable mark:space ratio, as described later.)



8.5 Basic electronic pulser circuit.



8.6 Electric motor movement restrained by stops, with spring centering.

Receivers

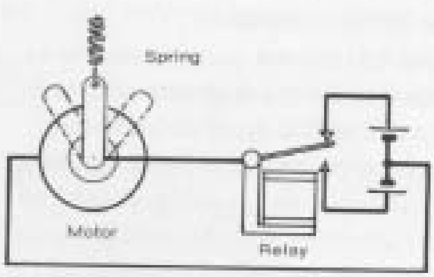
No special requirement is demanded of the receiver when using variable mark:space pulse proportional, other than an ability for the switching section to be able to follow the pulse rate used. However, since the actuator is usually based on an electric motor (and there are also advantages to be gained in having three switching contacts available), a *relay* receiver is normally employed (or a relayless receiver coupled to a relay to provide the switched output).

Actuators for pulse proportional

The simplest type of actuator for use with pulse proportional is an electric motor. This is coupled to a spring-loaded control, as shown in *figure 8.6*. Control movement is limited by mechanical stops at each end of the travel. With the motor switched 'off' (all space), the control is pulled to one extreme position by the spring. With the motor switched 'on' (all mark) the motor drives the control to the other extreme position against the stop. To avoid the motor being stalled at this control position it must be fitted with a slipping clutch, allowing it to continue rotation whilst the control has been brought to rest by the stop.

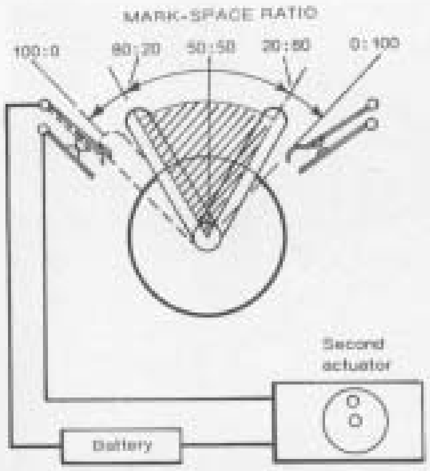
Such an elementary type of actuator system has distinct limitations. It may be used to control a boat rudder, for example, but would not really be suitable for an aircraft control.

The arrangement shown in *figure 8.7* is considerably better, again using an electric motor as the actuator, since the motor is driven in either direction, drive bias being provided by the relative dwell of the relay armature on the respective contacts, governed by the signal



8.7 Motor 'on-off' controlled through relay contacts, relay 'dwell' time corresponding to signal mark-space.

Another example of a model built for 'Galloping Ghost' control. Note relatively small rudder and elevator areas.



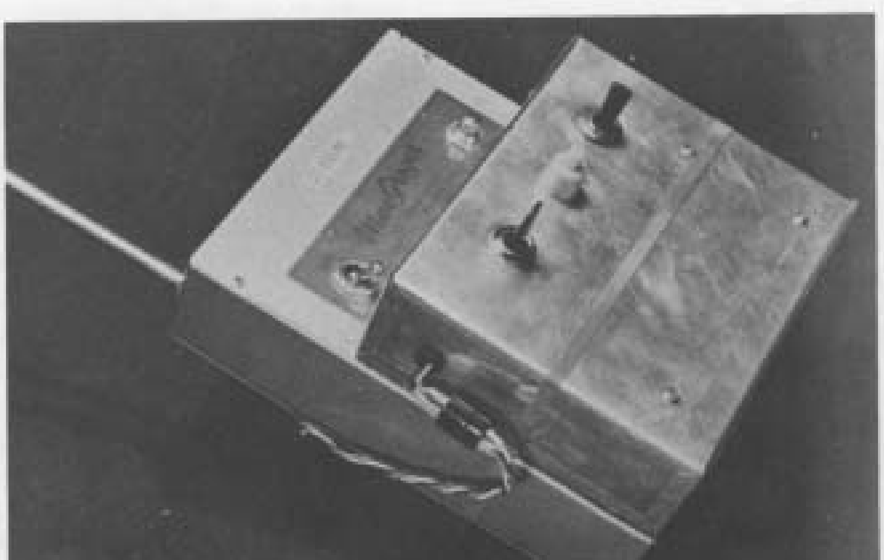
8.8 Utilisation of limit movement(s) for operating auxiliary contacts.

mark:space ratio. A slipping clutch drive is still necessary, but a self-centring action can also be added to the system by spring biasing the control to return to its neutral position in the presence of 50:50 mark:space ratio (when the motor is oscillating about its centre position).

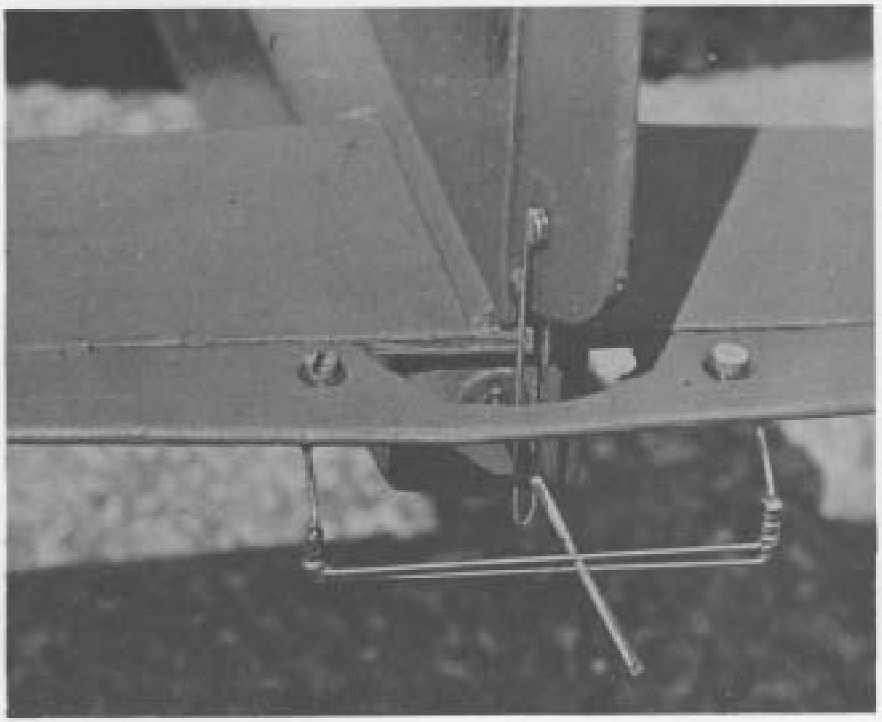
In practice specially designed (or individually constructed) pulse proportional actuators are used in this mode. These may be of magnetic type, or based on electric motors. Magnetic types are simpler, but generally suffer from the disadvantage of having a very low mechanical output force to operate the control. Their use is therefore limited to 'light' control actions (e.g. rudder control on a small glider). Motorised actuators are normally used with single-channel pulse proportional systems.

The services obtained from pulse proportional actuators can be extended in a relatively simple manner, by 'reserving' part of the movement for additional switching facilities. Thus if, for example, only the range between a mark:space ratio of 80:20 and 20:80 is utilised for driving the control over its required extremes of movement there is an immediate possibility of selecting two further positions at will: all 'mark' or all 'space' (see *figure 8.8*). These movements could correspond to closure of a switch controlling a separate service, e.g. a conventional single-channel actuator circuit. Selection of either of these switching positions is also direct and positive.

The one limitation that then arises is that these extreme positions can only be selected and held at the expense of holding the main control in one or other of the extreme positions. In practice this means that secondary services switched in this manner need to tripped by a brief signal, which can then be released. Thus the secondary service(s) would normally be based on a progressive single-channel actuator(s). One such service would be quite suitable for operating a throttle control (in steps) with the main proportional control function being rudder.


Home-made pulser attached to a commercial single-channel transmitter.

This photograph shows clearly the form of the rudder and elevator yokes associated with 'Galloping Ghost' control systems operating off a simple actuator (usually a modified electric motor).



'Galloping Ghost'

A rather more sophisticated system has evolved from simple pulse proportional control in which not only the pulse width but also the pulse rate is made variable (by the pulser unit applied to the transmitter). Whilst this still results in an oscillating drive to the control surface(s) this can extend proportionality to two separate functions. The most practical form of this 'double proportional' single-channel system is known as 'Galloping Ghost', or simple-simultaneous (simple-simul).

A basic form of Galloping Ghost actuator is shown in *figure 8.9*. An electric motor drives a crank through suitable reduction gearing. Rudder and elevator movements are mechanically linked to this crank by yokes. Spring tension is provided to 'centre' the movement (a rubber band is shown as the spring in the diagram, with stops also introduced to limit the crank travel.)

Under the influence of a pulsed signal the electric motor oscillates about its mean or 'centred' position. The *amplitude* of these oscillations will be directly dependent, or *proportional*, to the pulse *rate*. At a particular pulse rate—and bear in mind that the 'throw' each way will be equal—the mean position of the crank in the horizontal plane and working in the elevator yoke, will be equivalent to neutral elevator. *Increasing* the pulse rate from this condition will reduce the amplitude of crank oscillation, the effect being to lower the mean position of the crank and lower the elevator. *Decreasing* the pulse rate will increase the amplitude of crank oscillation, raising the mean position of the crank and raising the elevator. Thus starting with a pulse rate of, say, 6 pulses per second giving neutral elevator position, increasing the pulse rate up

8.9 Basic 'Galloping Ghost' mechanical set-up. Actuator is a slightly modified electric motor.

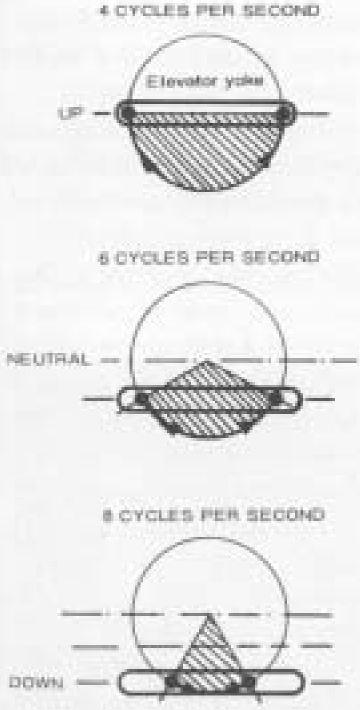
to, say, 8 pulses per second will produce up elevator movement *in proportion* to the actual increase in rate (8 pulses per second in this case being the maximum or full 'up' position). Similarly decreasing the pulse rate progressively down to 2 pulses per second will give corresponding proportional up elevator movement. In other words, *proportional elevator* control has been achieved via variable pulse rate as the command signal.

Considering the crank movement in the vertical plane, this produces the same effect as previously described, the proportional position being governed by the mark:space ratio of the signal. Thus a 50:50 mark:space ratio gives neutral rudder position. Any change in mark:space ratio will then give a mean rudder position to one side or the other, depending on whether the signal has more 'mark' or more 'space'. In both cases the mean position will be proportional to the mark:space ratio of the signal.

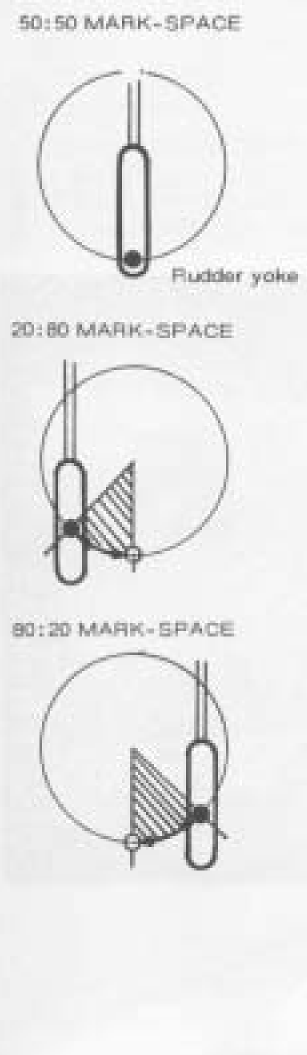
Both the elevator and rudder controls are, of course, continually oscillating under the drive of the electric motor. This will have little or no effect on the flight path of the model provided the *minimum* pulse rate used is not less than about 4 pulses per second. Proportional rudder or proportional elevator control can thus be selected independently, and simultaneously, simply by manipulating the controls at the transmitter end governing mark:space and pulse rate, respectively. Usually a single joystick type control lever is used, movement to one side or the other governing the mark:space; and movement up-and-down governing pulse rate. The stick has a universal movement so that any degree of mark:space can be selected with any degree of pulse rate.

The system does have certain limitations, particularly as regards the lack of true proportionality of the selected positions due to both mechanical and electronic interaction. Down elevator control, too, will always be more powerful than up elevator, because of the different amplitude swept by the crank in these two positions. For the same angle of movement there is more dwell time in 'down' than 'up'. To compensate for this it is necessary to arrange the mechanical set-up that the elevator has more up movement than down. Usually a minimum of twice as much movement is required. Also the power available for control movement is usually fairly limited, which restricts the size of aircraft models to which Galloping Ghost control can be applied successfully. The design of the model is also important. It must be 'tailored' to suit the type of control provided whilst remaining insensitive to the continually oscillating rudder and elevator movements.

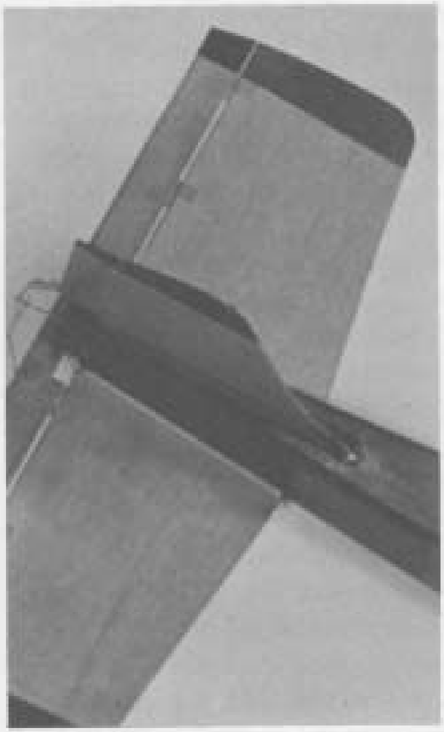
Ultimately the success of the system will depend on the performance and reliability of the actuator used, which must be a special type. Commercial actuators are advised rather than home made types, although their cost can be relatively high.



8.10 (Above) Elevator 'dwell' position is controlled by pulse rate.



8.11 (Left) Rudder 'dwell' position is controlled by mark-space ratio.



'Galloping Ghost' control linkage, as seen from above. Rudder and elevator are 'waggled' simultaneously by the actuator output movement.

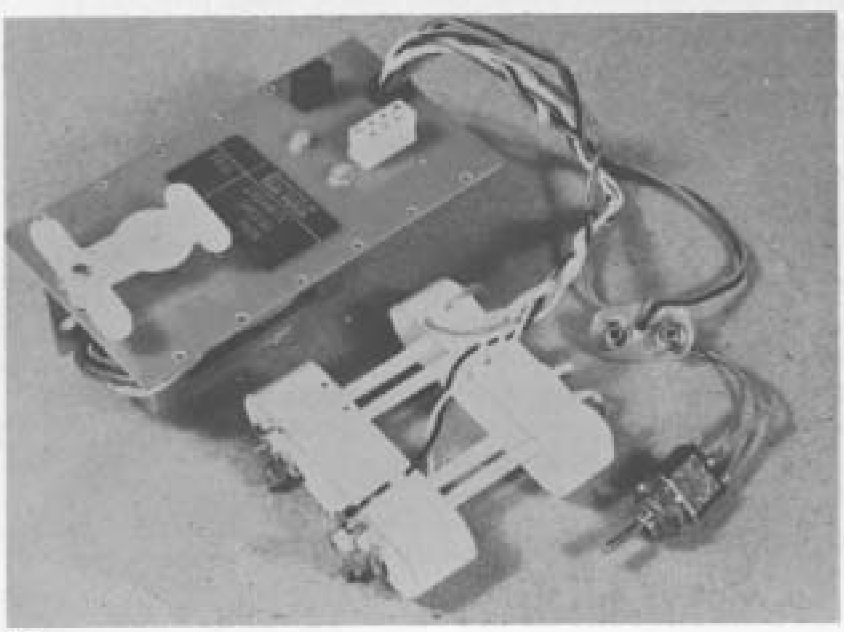
An outstanding example of a Galloping Ghost actuator is the Rand LR3 (*figure 8.12*). The crank-and-yoke motions which form the basis of the Galloping Ghost movement are accomodated on pivoted plates mounted on the actuator itself. Thus conventional pushrod linkages can be taken from the actuator to the rudder and elevators. The unbalanced elevator power previously mentioned is also mechanically compensated in the actuator movement itself, the elevator drive plate geometry providing a linear output response by amplifying the movement in the 'up' range.

As with the simpler pulse proportional systems, a separate switching control can readily be provided on Galloping Ghost actuators; e.g. limiting the range of mark:space or pulse rate required to produce the required mechanical movements and using one (or more) extreme position(s) to operate switching contacts. Only one switching service is really necessary, which could then provide (progressive or change-over) motor speed control using a secondary actuator, together with simultaneous proportional rudder and elevator control.

'Galloping Ghost' transmitters

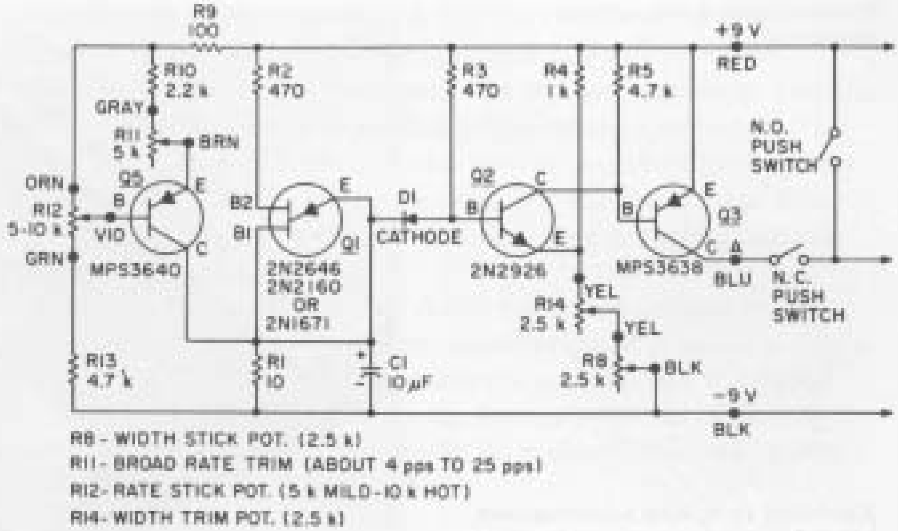
A standard single-channel transmitter can be converted to Galloping Ghost operation by the addition of a pulser providing variation of both mark:space ratio and pulse rate. The circuit requirements, however, are rather more demanding than those of simple pulsers, although these may have provision for varying pulse rate as well as mark:space.

8.12 Single-channel motorised actuator linked to battery box, with wiring harness incorporating on-off switch on battery connector.



Complete 'Galloping Ghost' system with 'pulse' transmitter and joy stick control, plus receiver with decoder circuit and Rand actuator mounted on the same panel.

8.13 Typical circuit of a pulse-width and pulse-rate pulser.



Combination of pulser and standard transmitter, by same manufacturer.

A typical basic circuit for a pulse-width and pulse-rate pulser is shown in *figure 8.13.* This can be built as a separate unit for connecting to a conventional single-channel transmitter of suitable type.

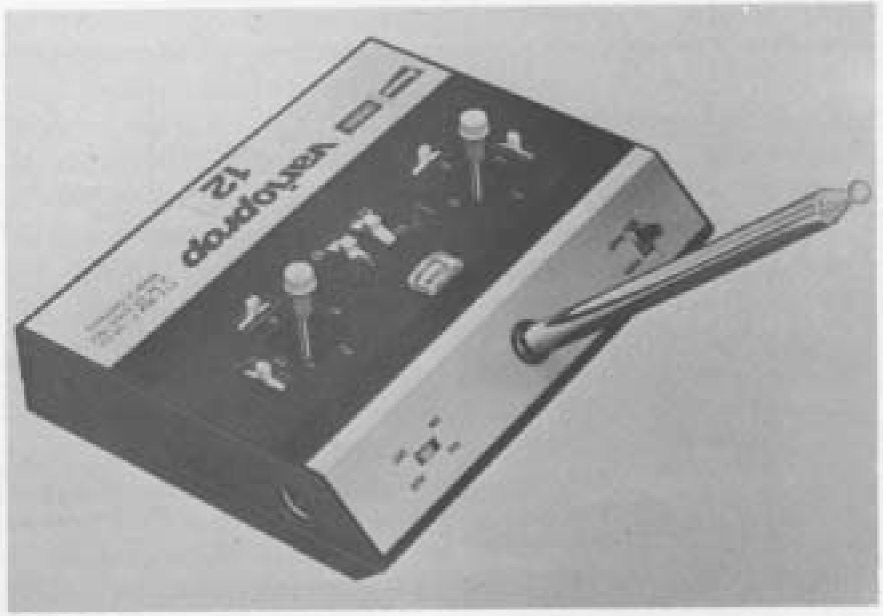
Electronic aids

Pulse proportional systems have so far been described in their 'minimal' form in which they first evolved, restricting the electronics to the signal coding at the transmitter end and deriving the output requirements at the receiver end by straightforward electro-mechanical and mechanical solutions. There are, however a number of ways in which electronic circuits can be used to simplify or improve the working of the system.

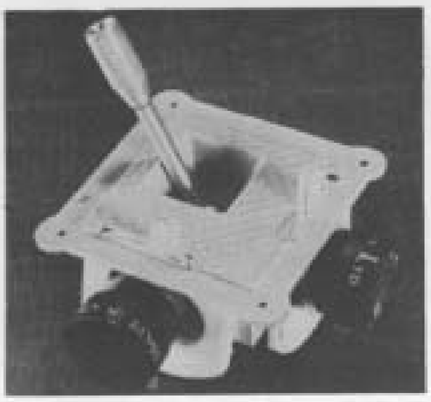
Electronic *switchers* for example, can take the place of the receiver relay, eliminating the relay contacts which can be a source of trouble or

Special 'Galloping Ghost' or pulse-proportional transmitter with matching receiver and actuator. Photo Radio Modeller.

Continental style proportional transmitter.



Assembled stick, with potentiometers which control the two different signals generated by the pulser.

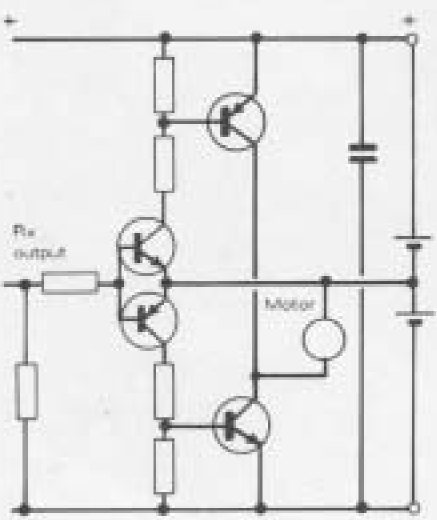


unreliability of action. (Not all relays fitted as standard to single-channel receivers, too, are suitably responsive to high rates of pulsing). Such a switcher, in effect, turns the receiver into a relayless type, with the switching output designed to match the particular type of pulse proportional actuator used. Equally, since the output from a relayless receiver is generally unsuitable for operating any form of motorised actuator direct, a switcher eliminates the need to employ a slave relay.

An example of a switcher circuit is shown in *figure 8.14*, matched to a typical Galloping Ghost actuator. The main problem as regards 'match' is in the power rating of the output transistors, which must stand up to the maximum current likely to be drawn by the actuator. The types shown in this circuit should have a current rating of 2 amps, which is likely to cover virtually all pulse proportional actuator requirements. The switcher circuit is also adaptable to most types of modern single-channel receivers, with the correct load and polarity of output.

The commercial production of pulse proportional actuators and other equipment virtually ceased by 1974 since the cost became almost the same as that of 1-function true proportional radio control transmitter-receiver combinations, and associated servo. Single-channel pulse-proportional, however, remains an attractive field for the amateur radio constructor. The following circuits are of particular interest.

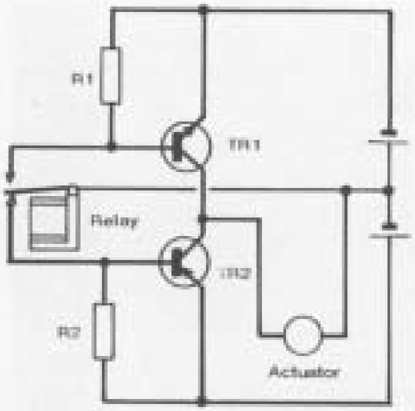
8.14 Relayless switcher circuit.



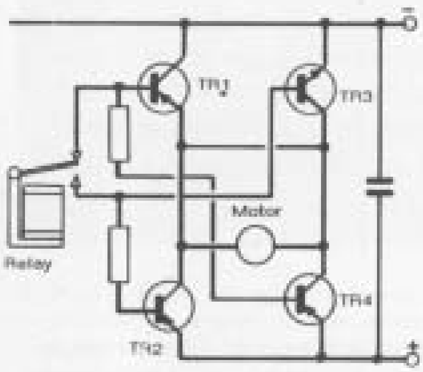
Relay followers

Where a relay is used as the switching element, a relay follower can be added to reduce the current carried by the relay contacts and thus minimise contact wear and arcing.

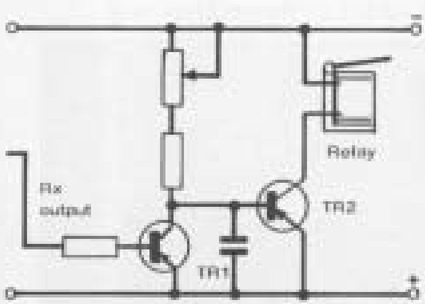
An example of a relay follower circuit used with a motorised actuator powered by a centre tapped battery is shown in *figure 8.13*. This is a straightforward circuit with the transistors acting as current



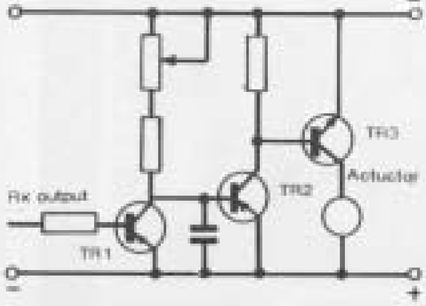
8.15 Transistorised relay follower circuit.



8.16 Relay follower circuit using single battery.



8.17 Pulse omission detector circuit.



8.18 'Mark' detector circuit.

amplifiers. The main requirement is that the current rating of the transistors used be suitable for the current demand of the motor.

Centre-tapped batteries (equivalent to a two-battery system) have the inherent disadvantage that if one half of the battery runs down before the other (e.g. through more use), the 'neutral' position of the actuator (e.g. signalled by 50:50 mark:space ratio) will drift to one side. This is more likely to occur with dry-cell batteries where the voltage output declines continuously with use.

Another type of relay follower circuit has been developed to overcome this possibility, combining the amplifier circuit previously described with a switcher circuit enabling a single battery to be used. The switcher section then provides the necessary reversal of battery polarity to drive the actuator motor in the required direction. A circuit of this type is shown in *figure 8.16*.

Pulse omission detectors

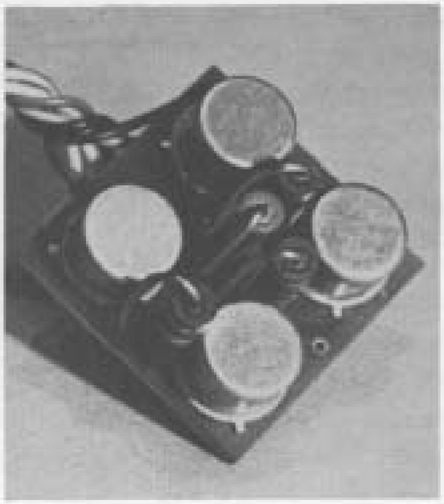
The additional switching function made possible by utilising a maximum actuator movement to operate a pair of contacts can also be performed electronically. This function can be commanded by 'all mark', or 'all space', or both. In practice, only one switching facility is normally needed, and the usual choice is the 'all space' signal condition. In other words, a signal in which the pulse is omitted entirely.

The omission of a pulse in the signal can be detected by a comparatively simple electronic circuit of the form shown in *figure 8.17*. This is basically a time delay circuit. Transistor TRI conducts in the presence of a pulse ('mark'), discharging capacitor (CI which effectively holds TR2 inoperative. During 'space', capacitor CI is charged, with TRI not conducting, the rate of charge being set by the value of the variable resistor VRI, and the pulsing rate. By choosing suitable component values it is possible to arrange that in the absence of a pulse (all 'space' signal) CI charges up fully, allowing TR 2 to conduct and operate the relay. The contact of this relay provide the switching elements for the auxiliary service.

The same circuit can equally well be used as an 'all mark' detector, merely by inversion (e.g. reversing the polarity and the types of transistors used). It can also be adapted for relayless operation, to work a secondary escapement, by adding a transistor driver stage, as in *figure 8.18*.

A pulse omission detector may also be employed to provide 'fail-safe' facilities. The secondary service switched by this facility can be a relay, the normally open (NO) contacts of which pass the common (centre tap) battery connection to the actuator. In the event of complete loss of signal there is obviously 'pulse omission', so the relay would pull in, breaking the battery connection to the motor which stops. The spring centring present would then return the control(s) to the neutral position (or at least substantially so).

If a further secondary service was also required from the actuator, then this would have to be derived from an 'all mark' signal.



Compact electronic pulser mounted on small panel of Paxolin.

Pulse omission coder

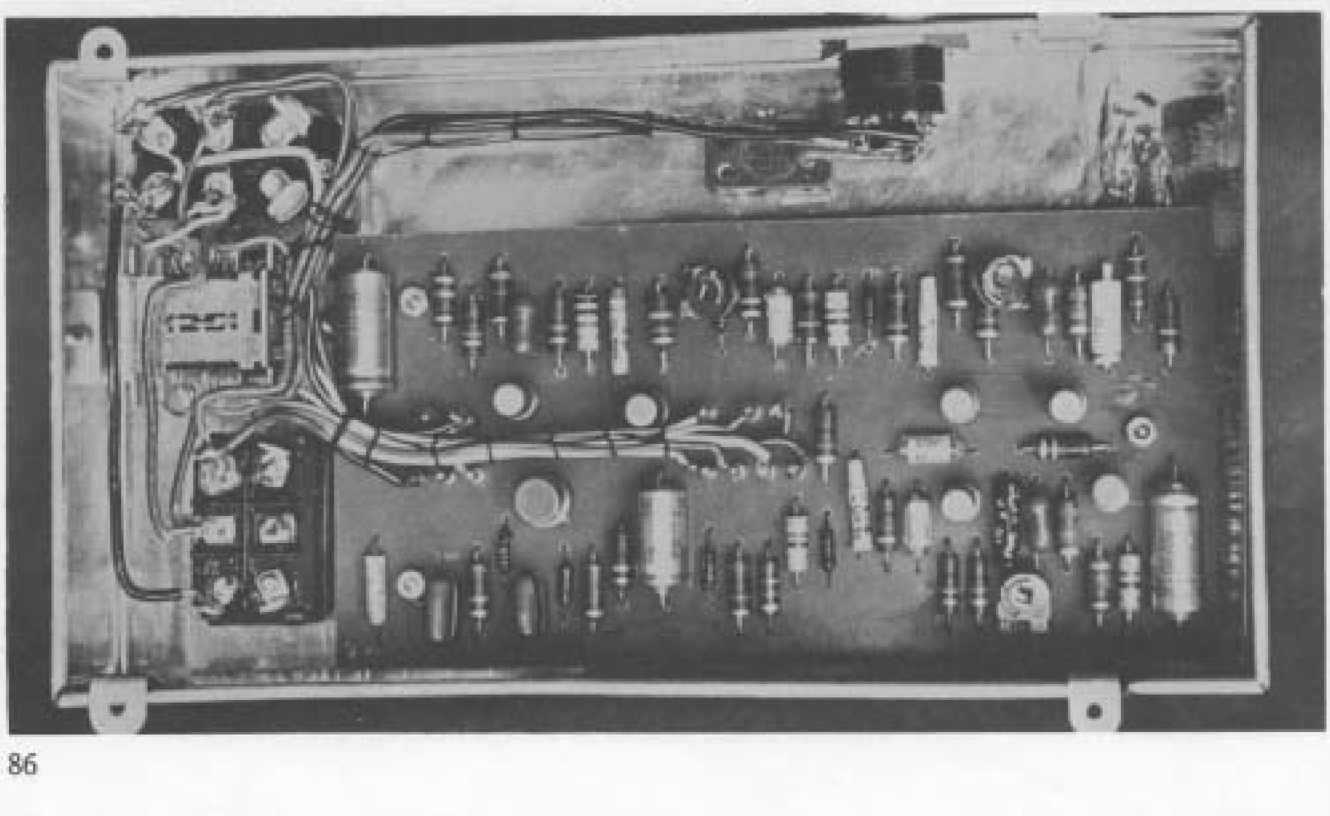
A pulse omission detector at the receiver end is often used with a pulse omission coder at the transmitter end. This is to prevent too long a pulse omission period being signalled which could cause certain types of secondary actuators to override. Such a circuit is designed to give an 'all space' signal of the same length when a separate control button is pressed, regardless of the time the signal is held on, in fact it is the equivalent of 'quick-blip' signalling used with simple single-channel working (and used with secondary actuator types designed to respond to quick-blip signalling).

Again this involves the use of a 'timer' circuit, which is shown in its simplest form in *figure 8.20.* This uses a minimum of components, but suffers from the disadvantage that there is a time delay inherent in the circuit. Operation of the command switch sets the circuit to the condition where the capacitor is charged up at a rate determined by the value of the resistance in circuit. At the same time the pulser output is turned off. When the capacitor is fully charged the transistor is positively biased to turn off and allow pulsing to resume. Releasing the command switch puts a short circuit across the capacity which thus discharges.

Other systems

The systems described by no means exhaust the possibilities of single-channel pulse proportional control, but cover the main *practical* systems developed under what is generally called simple proportional or single-channel proportional. There are many further possible variations, particularly if *decoders* are added at the receiver end.

Example of a transmitter circuit with special signal coding.



The latter then come under the general description of true *proportional controls* (see Chapter 10), normally used with proportional actuators.

No absolutely clear distinction is possible on this basis, however. For example, a pulse omission detector is really a decoder, but in the applications described in this chapter it is specific to simple single-channel pulse proportional. The type of signal used for Galloping Ghost, on the other hand, with variable pulse width (mark:space ratio) plus variable pulse rate, is really a two-channel signalling system and can be used, with decoders and pulse type actuators, to provide two-proportional functions.

Direct pulse proportional signalling, applied to a progressive type actuator, is a system which can be used successfully for model boat controls (e.g. rudder control). This is not suitable for aircraft rudder control. Equally, 'Galloping Ghost' is unsuitable for boat controls.

A wheel or rotary arm movement may be preferred on a pulser used for model boat controls, controlling response of a single-channel pulse-porportional actuator (not a 'Galloping Ghost' type).

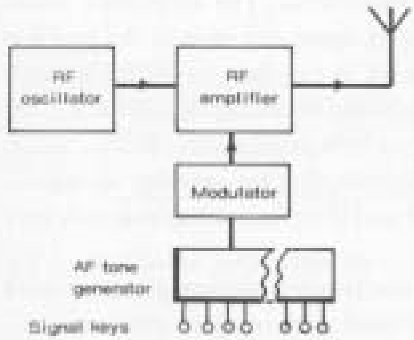
Single-channel pulse-proportional control is not suitable for controlling scale aircraft like this as it is never completely positive. Use true proportional control instead.

Although reed equipment is no longer made, equipment of this type can still be purchased at bargain prices on the secondhand market. It can be used for inexpensive multi-channel boat or car controls.

9 MULTI - CHANNEL CONTROLS

Multi-channel control systems based on the use of separate tone signals applied to a CW transmission and decoded at the receiver end by a reed bank or electronic filters are now obselete. A considerable amount of this equipment remains in use, however and technically the performance of such systems is sound and reliable, within the limitations of 'bang-bang' controls.

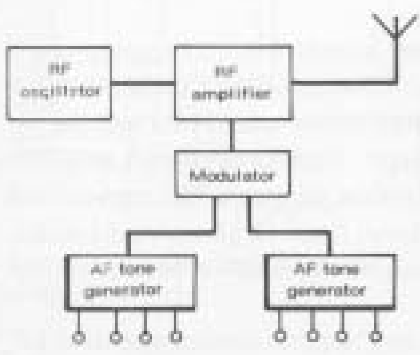
The transmitter is basically the same as that of a single-channel tone transmitter, except that the AF tone generator circuit is extended to provide a number of different tones, selected and applied to the modulator section by the operation of separate keys (*figure 9.1*). In the case of reed operation the typical tone range used is 330 Hz to 600 Hz (slightly less than one octave). Up to twelve separate tone frequencies may be generated with this range.



9.1 Block diagram of multi-channel tone transmitter.

An essential feature is that the audio oscillator is extremely stable, particularly where a large number of tones are involved. The most widely adopted method of stabilisation is the use of a toroid inductor of 4 to 6 millihenries. The tone generator itself is merely an oscillator which can be switched to work at each of the AF frequencies required.

A single AF oscillator unit can supply any number of individual tones, but only one at a time. To provide for simultaneous operation of two tones a second tone generator is required. The number of tone signals is then split between the two AF oscillators, when any one from each set can be operated simultaneously (*figure 9.2*).

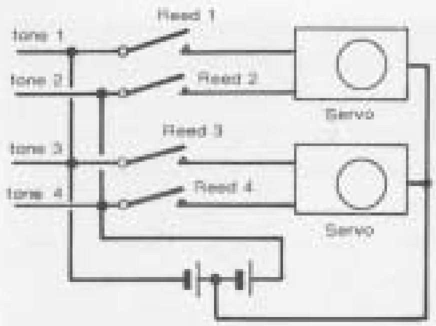


9.2 Block diagram of multi-tone transmitter with separate tone generators for simultaneous operation of two channels.

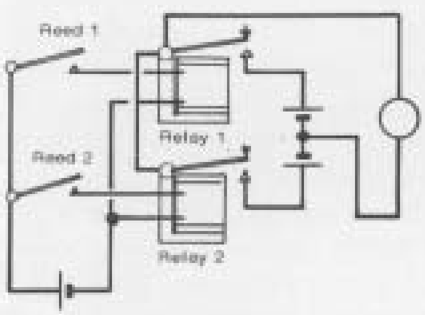
The receiver can be either a superregen or superhet type, the only difference (apart from cost) being the greater selectivity offered by the latter. It is 'matched' to a particular transmitter by having a reed bank designed to be resonant to the tone frequencies generated by the transmitter. This does not necessarily mean that the reed bank must have the same number of reeds as the transmitter has tones. Reed banks are made with three, four, six, eight, ten and twelve reeds. Transmitters are described by the number of separate tone signals they can produce, referred to as 'channels'. Thus a 4 channel tone transmitter would provide four tones for signalling; a 6-channel transmitter six tones, and so on. A 12-channel transmitter could be used with a receiver having 4, 6, 8, 10 or 12 reeds, provided in each case the resonant frequencies of the reeds correspond to the transmitter tone frequencies available (i.e. tunable on the tone circuits). Any difference between the number of transmitter channels and number of reeds in the receiver reed bank merely means that the transmitter has a surplus (and unusable) signalling capacity with that combination.

The only significance of this is that a single transmitter can be used with a number of matching receivers installed in different models. For functional requirements—or economic reasons—the number of working channels required in a particular model may be limited—say requiring only 4 channels. Another model may require 10 channels. A single 10-channel transmitter would then serve for both models, using a 4-channel (4 reed) receiver in one and a 10-channel (10 reed) receiver in the other.

Multi-channel receivers of this type are invariably used with



9.3 Two reeds switch an actuator direct with relayless operation.



9.4 With a relay receiver, two relays are required to switch each actuator.

motorised actuators, generally called *multi-servos* to distinguish them from single-channel actuators. Two signalling channels are required with each multi-servo, in order to provide *selective* response.

The basic principle of servo working is shown in *figure 9.3*. Each channel works as a switch or on-off control working the servo (motor) in one direction or the other. Thus by selecting the appropriate channel of the pair the servo responds with movement in the required direction. Two types of movement are then possible, depending on the design of servo. The servo may drive to its extreme position and stop there as long as the signal is held, then return to neutral on release of signal. This is a 'main control' or S/N multi-servo. The alternative mode of working is for the actuator to drive on signal and stop in the position it has reached when the signal is removed. It can thus be inched to any position within the limits of its two extreme movements. This is a progressive type multi-servo. Generally a S/N multi-servo can be modified for progressive action by disconnecting the internal wiring providing the self-centring action. S/N and progressive multi-servos may also be produced as separate types.

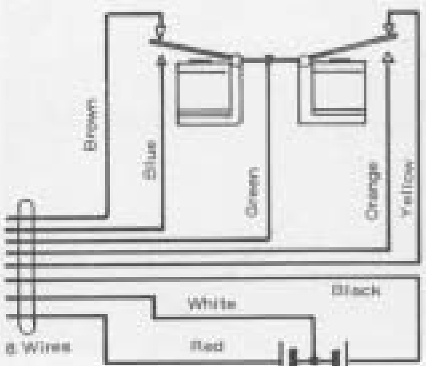
There is also a distinction between multi-servos designed for use with relay receivers and those which can be used with relayless receivers. In the former case the relay contacts produce the switching action controlling the servo movement in the type of circuit shown in *figure 9.4*. One relay is used in each channel circuit, and each circuit has its own battery supply with opposite polarity (usually drawn from a centre-tapped battery). The servo circuit is thus self-contained and merely controlled by the switching elements.

With a relayless receiver each channel output from the receiver is a switched *current*. This current is insufficient to operate the servo motor direct (or rather the demand of the servo motor would overload the transistors in the receiver switching stage). Additional current amplifiers thus have to be added in each side of the servo circuit. For convenience these are usually incorporated in the servo itself. Ordinary multi-servos can be converted for relayless operation by the addition of an amplifier (*figure 9.5*).

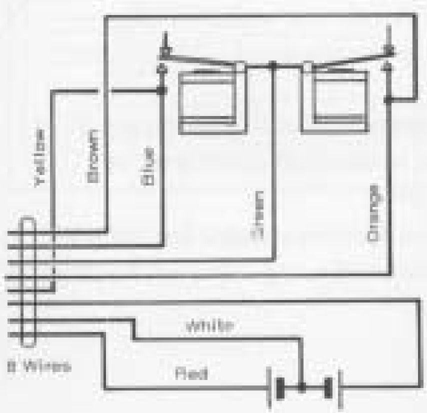
Wiring up is relatively complicated and requires careful attention to detail in order to avoid wrong connections. The majority of multi-servos used with relay receivers have eight wires emerging from the servo, identified by colour code. The American coding usually adopted

9.5 Transistor amplifier for converting a multi-actuator to relayless working.

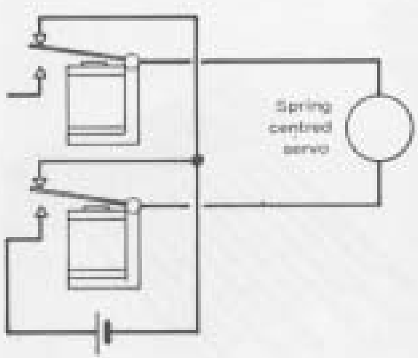
Transistor superhet receiver with reed bank. The diagrams can assist in sorting out the wiring connections needed when using secondhand equipment lacking the original instructions.



9.6 Typical 8-wire connections for self-neutralising action.



9.7 Typical 8-wire connections for progressive action.



9.8 Two-wire multi servo circuit.

(but not universally so) is shown in *figure 9.6* Five wires go to the two relays (one being a common armature connection); and three to a centre-tapped battery which provides power for the servo motor. This battery is common to all the servos in the complete system: regardless of the actual number of servos installed, all would connect to the same battery.

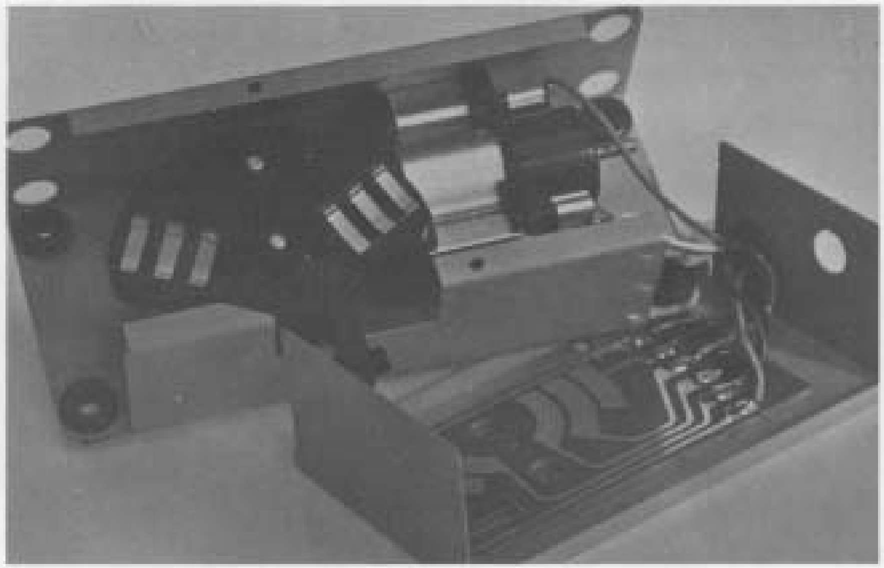
The wiring-up circuit is slightly modified in the case of servos which are to have progressive action since the back contacts of the relay (previously used to switch the self-centring action) are not used. The necessary modification to the wiring is shown in *figure 9.7*

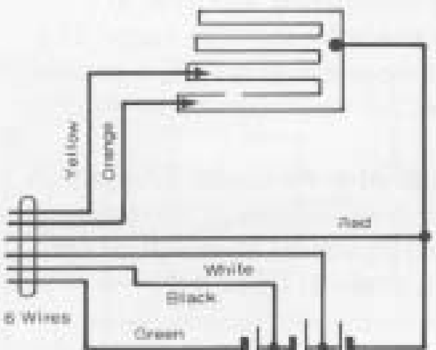
Some types of multi-channel servos for use with relay receivers incorporate spring return for self-centring action, thus dispensing with the switcher board and rubbing contacts necessary to provide electrical self-centring. This permits considerable saving in wiring, and the servo can be operated from a single battery. The basic circuit involved is shown in *figure 9.8* where only two wires are needed to connect the servo to the relays, and the battery is connected directly to the relay network.

A typical wiring circuit for relayless operation is shown in *figure 9.9* , again using the more conventional type of multi-servo with internal switcher board and electrical self-centring. Six wires emerge from the servo, three connecting to the reed bank and the other three

Earlier type of hybrid (valve-transistor) receiver with 10-channel reed bank.

Multi-channel servo showing wiper type switching and printed circuit switch panel.



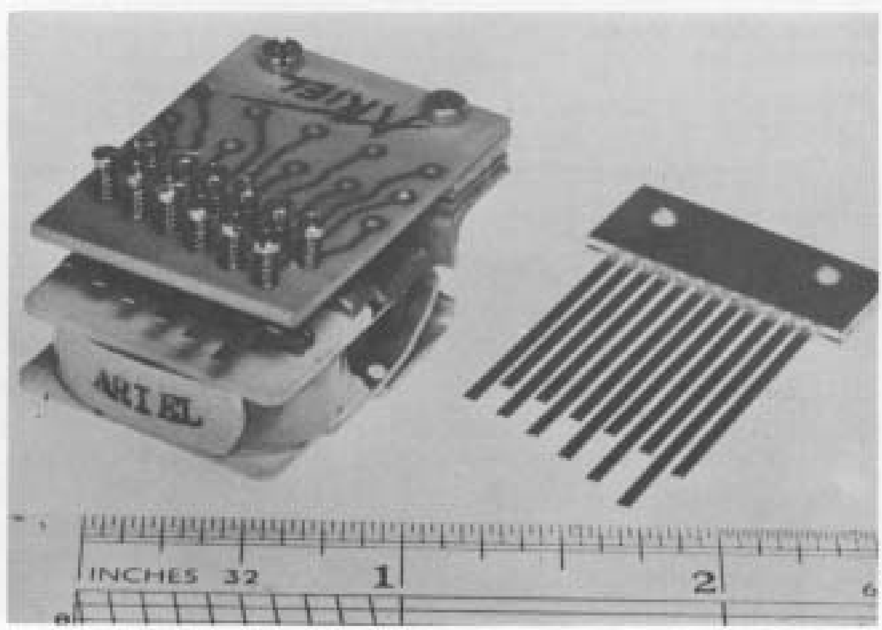


9.9 Typical 8-wire connections and colour coding.

to the battery pack. This is a centre-tapped battery as before, but with the addition of a further cell to provide a 'trigger voltage' for positive operation of the transistor switching circuit. This is not the invariable rule. Some designs of transistor amplifier do not require a trigger voltage, when the additional cell and green line connection can be omitted.

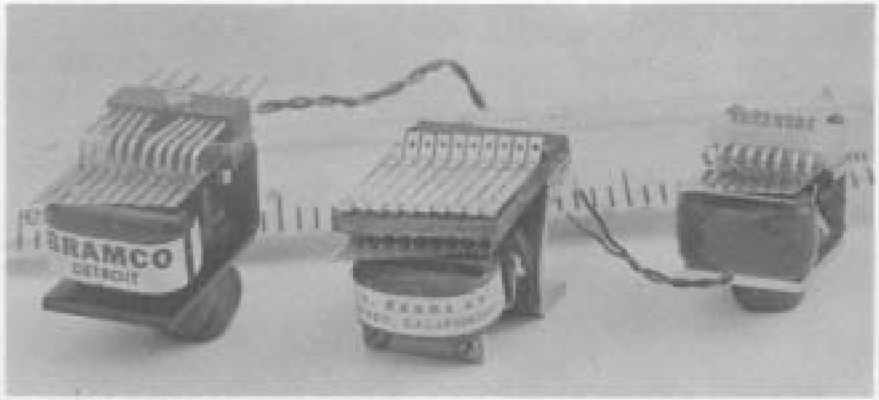
For progressive action, some internal modification of the servo circuit is required and the connection to the reed comb (red) is omitted.

Again there are simpler types of multi-servos suitable for use with relayless receivers with simplified wiring and a capability of working off a single battery.

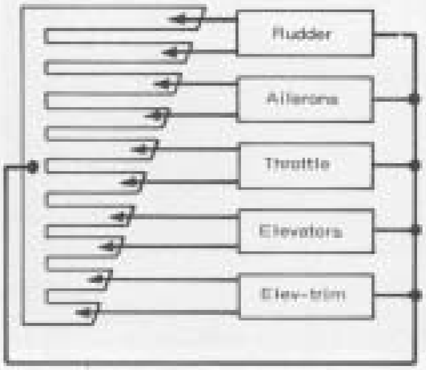


Example of a reed bank with staggered reed lengths.

More usual form of reed. Three different designs shown here. Best type is one with positive contact adjustment (centre).



Allocation of reeds



9.10 Typical reed allocation.

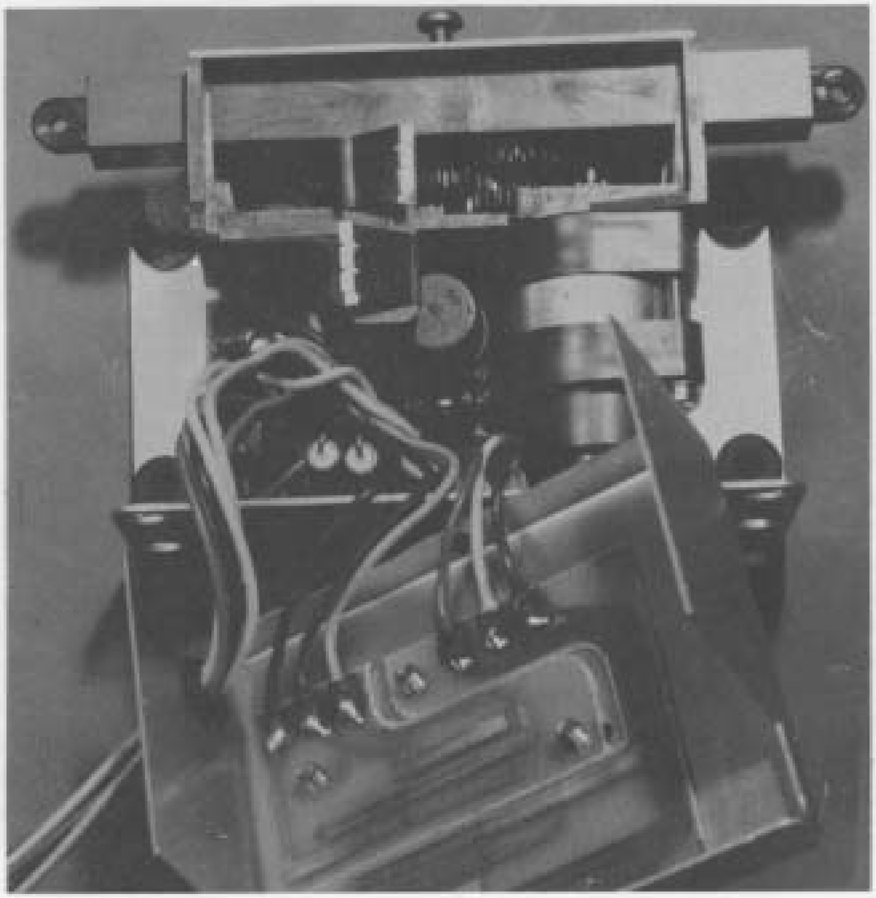
Selection of which channel to use for a particular service is largely arbitrary and there is no overall standard. Logically, and particularly with a large number of channels available, it would seem sense to separate 'paired' control signals by as wide a spacing as possible to avoid any possibility of interaction between adjacent reeds. Thus, for example, with a 10-channel, channels 1 and 6 would appear a good choice for rudder, 2 and 7 for elevator, and so on, giving the widest possible spacing between paired signals (i.e. signals controlling the same servo, but in opposite directions).

In practice, this is seldom done. One of the main reasons is that with 8-, 10- and 12-channel equipment, simultaneous control is usually made available in two groups of 4, 5 or 6 signals, respectively.* There is then a practical need to have certain controls in one group and certain in the other—virtually the controls which may *need* to be operated simultaneously. Since rudder and ailerons have a similar control effect, these can fall in the same group. Rudder and elevator, however, are the logical 'simultaneous' controls, and so these must lie in different groups. This rather restricts the allocation of any remaining services and so typical allocation of reeds to the various control services is as shown in *figure 9.10*. Of the alternatives, the simple numerical sequence is often followed (e.g. 1 and 2 for rudder, rather than 1 and 3, and so on). One particular reason for this is that the most likely point where 'overlapping' or interference between adjacent reeds could occur with simultaneous signalling is usually in the middle reeds of the bank. It is as well, therefore, to allocate these to control services which would normally never be operated simultaneously (e.g. engine throttle and aileron).

There may also be another reason for a definite pattern of relay allocation. The transmitter tone signalling on multi-channel work is normally done with lever-type switches arranged with left-right movement for turning controls (rudder and ailerons) and up and down movements for elevation and trim controls (elevators and motor speed). It does not always follow that *each* of the circuits wired to the various switches is tunable over the full range of tones covered by the reed bank. Thus by disregarding a particular manufacturer's instructions in allocating the relays it may only be possible to bring in a certain relay

*The reed bank may, in fact, be physically separated into two sections corresponding to such grouping to isolate one group electrically from the other. This can affect the choice of servos used. Some servos are designed to operate with split reed banks. Others may not work with split reed banks unless the two halves are electrically joined, i.e. making it an integral bank again electrically.

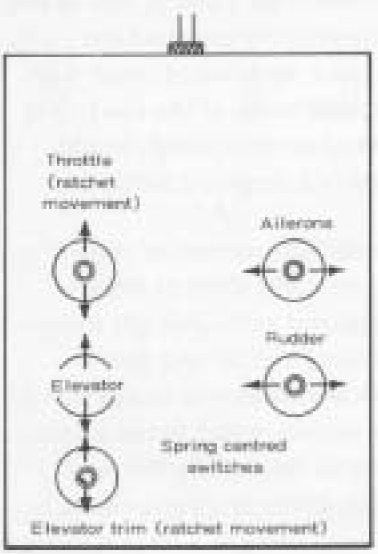
Internal components of a multi-channel actuator showing switching brushes and switch panel; also built-in transistor amplifier for operation direct from a relayless receiver.



(and associated control) in a 'wrong' position as regards keying from the transmitter.

Servo-allocation

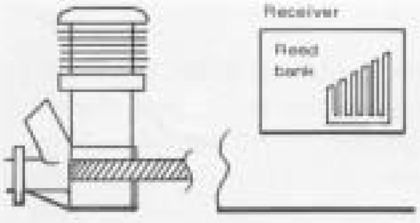
9.11 Usual mode of transmitter key allocation.



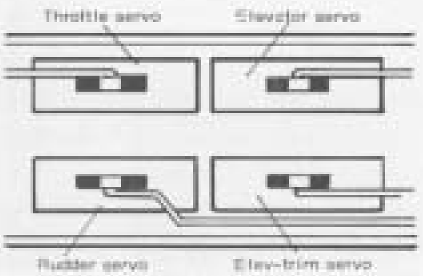
S/N servos are used for main controls, e.g. rudder, elevator, and ailerons on aircraft. The appropriate channels at the transmitter end are then normally keyed by two-position lever switches, with spring self-centring. A signal is physically held on against the spring action. On release the lever automatically returns to its central position, switching off the signal and allowing the servo to self centre.

Progressive servos are used for controls requiring 'inching' movements, such as throttle or 'trim'. These are normally operated by lever switches with a braked movement (i.e. by a friction brake or ratchet) so that the lever stays in the position it has been moved to when it is released.

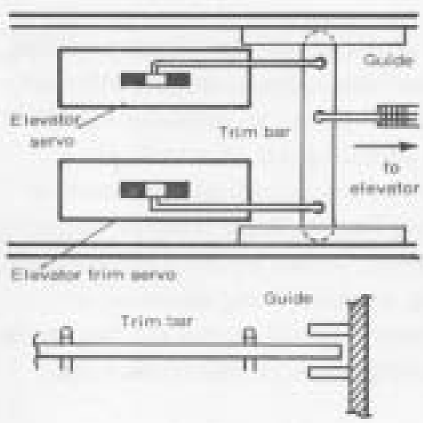
Switch positions can be chosen for 'natural' grouping of controls, and logical movements. The former is largely a mattèr of familiarity, however. A typical allocation for an aircraft system is shown in *figure 9.11*. Controls which respond to natural up-and-down movements would have switches arranged to work in a vertical plane; and those with natural side-to-side movements, horizontal switching.



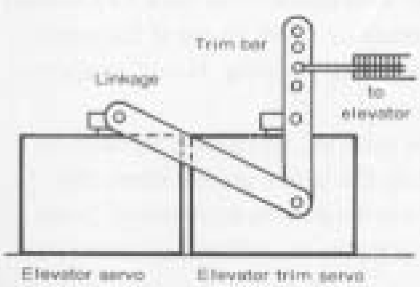
9.12 Reed receiver should be mounted with reed bank vertical to minimise effect of engine vibration on aircraft and boats.



9.13 Typical servo layout for 'multi' operation.



9.14 Use of two servos to provide 'trim' or differential output movement.



9.15 Alternative arrangement of 'trim' motion.

Receiver installation

Receiver mounting follows the same basic requirements as described for aircraft installation in Chapter 15 except that vertical positioning is desirable so that the reed comb is aligned vertically fore and aft. This is the position in which the reeds are least likely to be affected by mechanical vibration from a motor (particularly in aircraft). The same consideration applies to relays in the case of a relay receiver. Vertical alignment will be automatic if the relays are incorporated in the receiver casing as both the reed bank and the relays are normally mounted in the same plane.

Servo installation

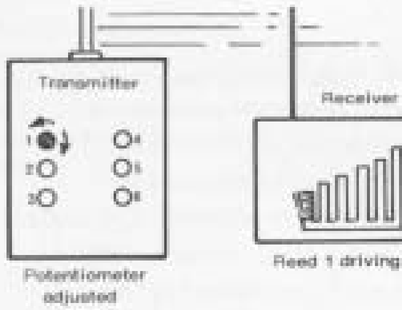
Servos are normally mounted in a group, close together—the only exception being the aileron servo in the case of aircraft which is best mounted in the centre section of the wing to simplify the linkage connections. Resilient mounting is called for, provided either by rubber grommets at the mounting points, or by using fairly stiff foam rubber as an isolation mount. In the latter case bonding has proved very effective for securing both the rubber to the main structure and the servo to the rubber base.

Push-pull motions from the servo output arms are taken by conventional linkage to the appropriate controls (see Chapters 15 and 18). Separate trim controls present rather a different proposition for here the servo output movement is used to modify the normal movement of another servo output, rather than being taken to the control concerned.

Elevator trim applied to an aircraft control installation is a typical example. Both the elevator servo and elevator trim servo have their output motions connected to a floating lever (generally called a trim bar), with the pushrod transferring motion to the elevator horn fitted at an intermediate position. For elevator operation the trim bar pivots about the elevator trim connection point. Operation of the elevator trim servo shifts this pivot point forward or backwards, with the trim bar effectively pivoting about the elevator servo connecting point. This has the effect of shifting the neutral position as far as actual positioning of the elevator control itself is concerned. Proportions of the trim bar are designed to provide the extent of movement required in each case, e.g. normally equivalent to an elevator movement of about 10 degrees up and down, but restricting trim movement to about 2½ degrees up and down about the true neutral.

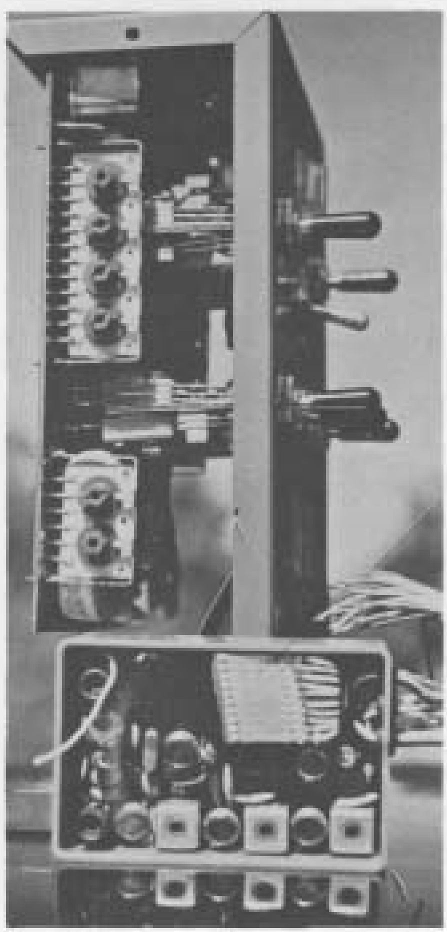
Horizontal positioning of the trim bar is necessary if the elevator and elevator trim servos are mounted side by side. In this case the ends of the trim bar can slide in grooves in the fuselage sides for location (*figure 9.14*).

If the trim servo is mounted in line with the elevator servo, then vertical linkage of the type shown in *figure 9.15* can be used. In both cases the dimensions shown are typical, with alternative positions provided for the elevator push rod for 'cut and try' adjustment of the actual movement.



9.16 Each reed is 'tuned' in turn by adjustment of the corresponding transmitter tone control potentiometer.

Typical multi-channel transmitter (back removed), showing keys. One key for each channel. Matching 10-reed superhet receiver at bottom of picture.



Multi-channel operation

Multi-channel transmitters are normally crystal controlled and their adjustment for maximum RF output is the same as for single-channel transmitters, with one exception. Adjustment of RF output is always made with a 'full' signal applied (i.e. tone-keyed on, not just carrier-switched on), but with a transmitter providing simultaneous facilities one tone should be keyed on from *each* of the simultaneous groups.

Additional tuning controls provided on a multi-channel transmitter are potentiometers for adjusting the specific tone frequencies generated. This is necessary to ensure the best possible match to the specific resonant frequencies of the individual reeds in the receiver reed bank. Such tuning cannot be present, as it can differ from reed bank to reed bank of the same design.

Before the tones can be tuned to the reeds, the receiver must first be tuned to the transmitter. This is basically the same as for single-channel receivers, except that it is only necessary to observe (or listen for) a reed to respond to signal rather than connect up a servo. If no reed responds to any of the tone keys over the complete range of receiver tuning adjustment, then the receiver should be set to its mean tuning position and one of the transmitter tone controls adjusted to make a reed respond. Having 'picked up' a reed, the receiver tuning can then be adjusted to mid position between the extremes where the reed stops vibrating.

The transmitter may, however, be provided with two separate tuning controls—one for adjusting the RF oscillator output, and the other for adjusting the final output. To assist in RF tuning an indicator light is usually incorporated in the circuit as a visual guide. Alternatively a meter may be used, plugging into the circuit, and adjustment made to realise specific working-current figures. The oscillator trimmer normally requires adjustment for minimum current, shown by the indicator light going out, or minimum meter reading, and then being advanced a specified amount. The amplifier trimmer is then adjusted for maximum output (indicator light showing peak brightness, or maximum meter reading).

Once the receiver is tuned to its optimum point each transmitter tone is keyed in turn, holding the signal on and adjusting the appropriate tone control (usually a potentiometer) for maximum reed 'drive', i.e. the strongest vibration of the reed. The transmitter tone key should then be manipulated on and off a number of times to see if the same amount of drive is obtained with intermittent keying. If not, readjust the tone control slightly, as necessary.

Each tone is adjusted in turn in this manner, working alternatively from one tone in one group to a tone in the other group. When this second tone has been adjusted, key both tones simultaneously. Some readjustment of the tone(s) may be necessary to achieve maximum simultaneous drive.

Poor reed drive may be the fault of the relay bank itself rather than poor tone tuning. If this is suspected, and the most likely cause, such

Multi-channel raised aircraft performance potentialities to new levels. It also established the basic pattern for servos, servo installations and control linkages. Although completely replaced by proportional for aircraft controls, many of the techniques described in this chapter still apply.

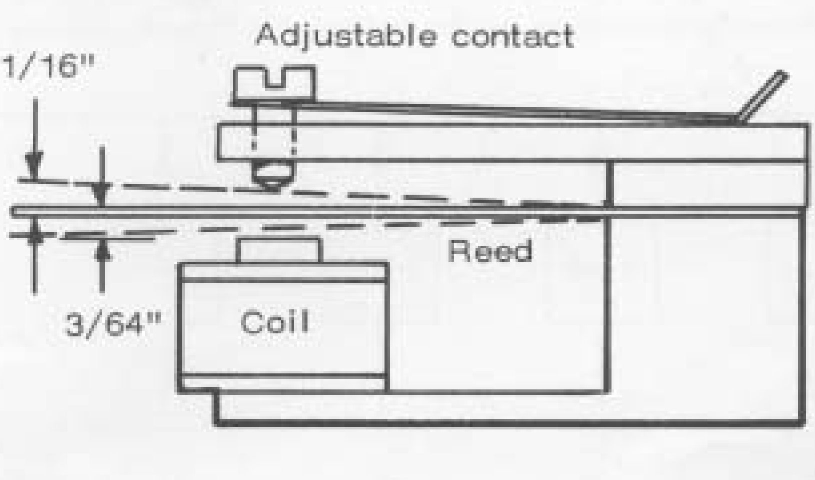
as weak batteries in the receiver or transmitter is first eliminated, adjustment of the reed contacts may be necessary.

Optimum settings are usually as shown in *figure 9.17*. There should be a clearance of about 3/64 in. between the reed and the pole piece of the coil, no more. Too great a clearance will result in loss of drive. Too small a clearance will increase the tendency for the reed to vibrate in sympathy when an adjacent reed is energised, that is it will increase the bandwidth of the frequency response. The setting of this clearance must therefore be a compromise between drive and false response.

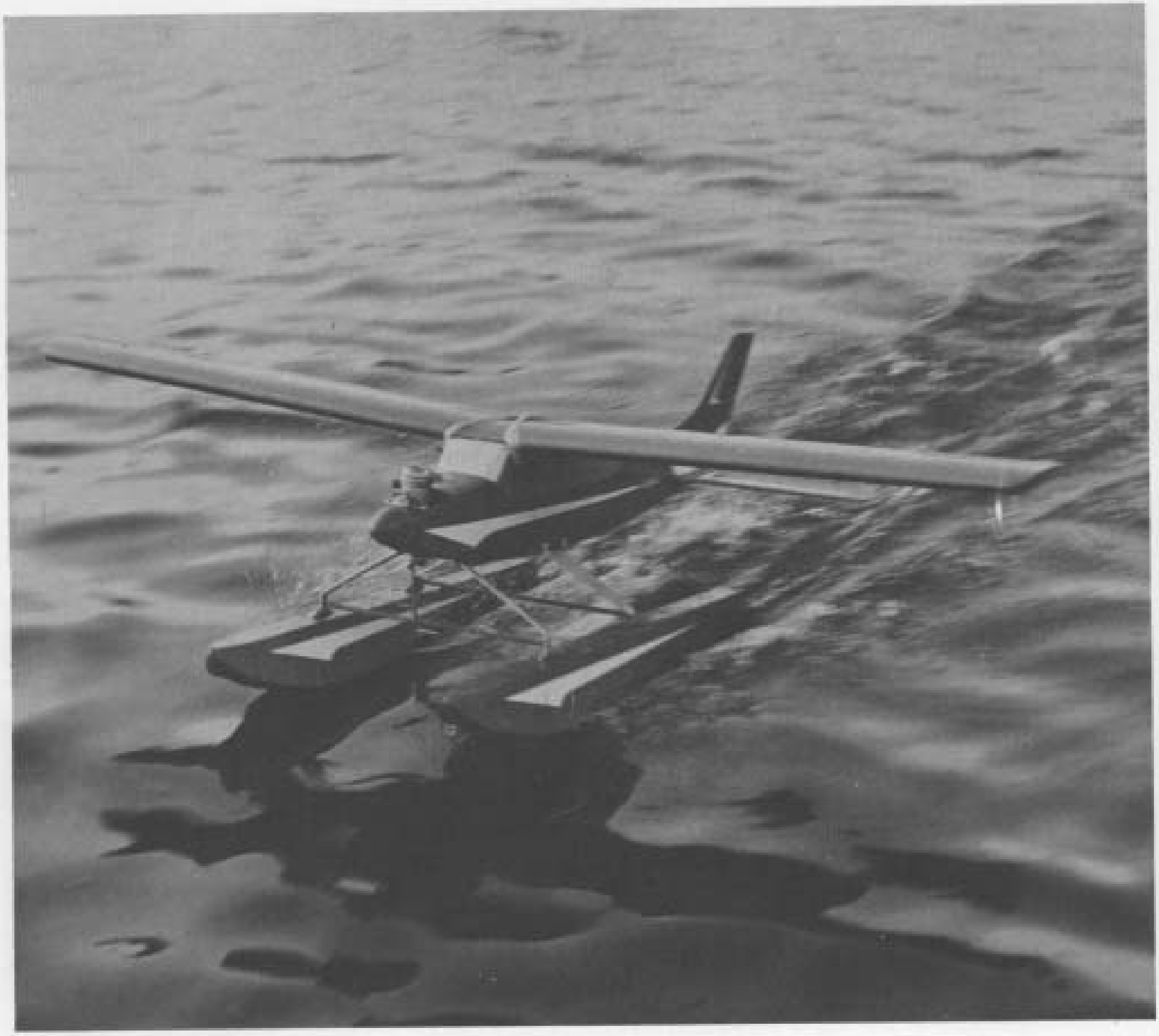
For strong drive the tip movement of each reed should be of the order of 1/16 in. upwards from its unenergised position. Strictly speaking, the longer the reed the greater the tip movement for optimum drive. Thus 1/16 in. tip movement can be taken as a desirable figure for the shortest reed, increasing to 5/64 in. on the longest reed. The tip movement can be set by the adjustable contact (although some reed banks have fixed rather than adjustable contacts, when any adjustment must be made by bending). Adjustment of this contact governs the duty cycle of the reed as a switching element.

Range check

As a final check, tuning should be repeated, if necessary, at range. With initial adjustment, particularly, there may be a possibility of driving both reeds on the same control at the same time, causing damage to the contacts. This can be avoided by disconnecting the servos and simply listening to the reed tones and observing which particular relay is operated in the bank. Plug-and-socket connections between receiver output leads and servo wiring make disconnection and re-connection easy. There would normally be no need to disconnect servos for a final range check which, in any case, is preferably (but not essentially) carried out with the engine running and operation must be judged by the response of the control movements. This technique may also be necessary in the case of boats where accurate tuning can only be carried out with the boat in the water.



9.17 Reed adjustment measurements.



Proportional—the answer to complete functional control of model aircraft! Radio Modeller photo.

10 PROPORTIONAL

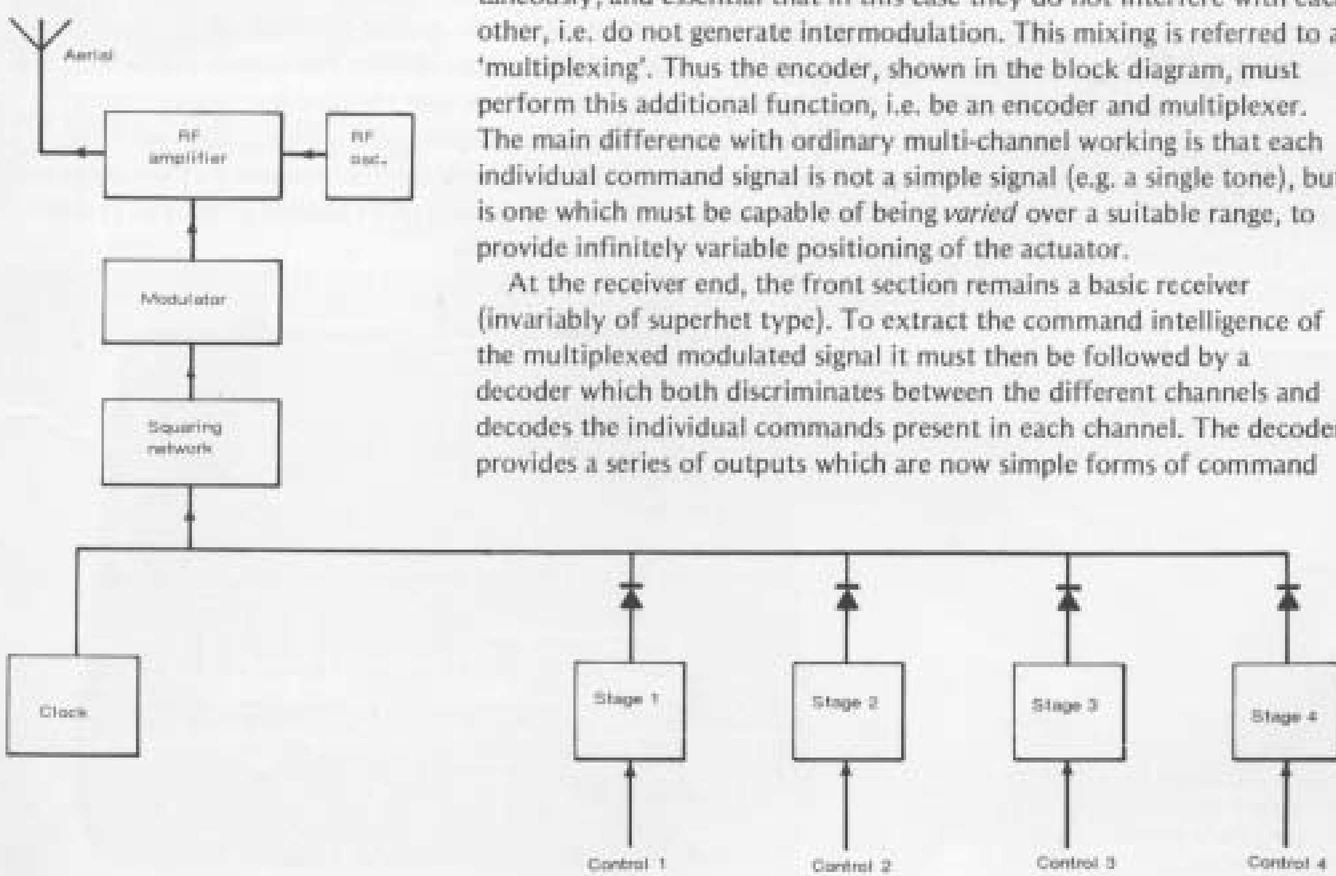
Proportional, popularly known as 'propo', is the modern form of multi-channel radio control. Commands are initiated by variable signals generated by the transmitter, decoded by a matching receiver and translated in terms of proportional output movements by a proportional servo. Feedback is invariably incorporated to ensure exact servo positioning, and any control position signalled is held without further movement until the transmitter control stick is again moved. In this latter respect true proportional systems differ from pulse proportional systems (see Chapter 8). The electronics involved is considerably more complicated; so much so, in fact, that proportional transmitters, receivers and servos are normally considered as 'black boxes', i.e. units which are accepted and used without worrying about *how* they work.

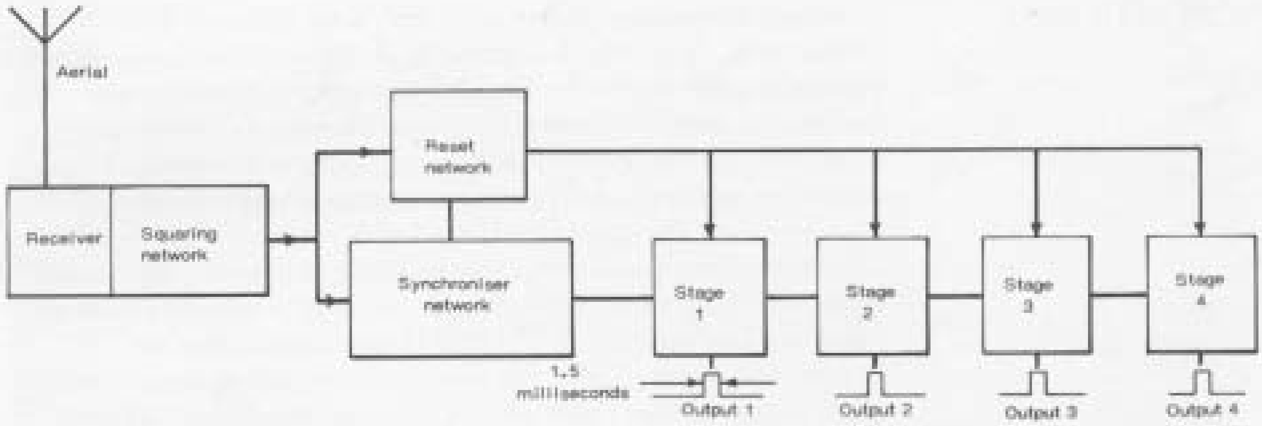
Proportional systems fall into two main categories: analog or digital (see Chapter 1). Analog systems preceded digital operation, but have now been (almost) completely replaced by the latter type. This is largely because the number of channels available for analog control is generally limited because of complexity, intermodulation, and the sheer bulk of the receiver system, plus the fact that stability is generally inferior to that of a digital system. The basis of both analog and digital working is the same however.

At the transmitter end, separate command signals intitiated by control-stick movement are encoded and used to modulate the RF output of an otherwise conventional transmitter (*figure 10.1*). It is desirable that these separate command signals can be sent simultaneously; and essential that in this case they do not interfere with each other, i.e. do not generate intermodulation. This mixing is referred to as 'multiplexing'. Thus the encoder, shown in the block diagram, must perform this additional function, i.e. be an encoder and multiplexer. The main difference with ordinary multi-channel working is that each individual command signal is not a simple signal (e.g. a single tone), but is one which must be capable of being *varied* over a suitable range, to provide infinitely variable positioning of the actuator.

At the receiver end, the front section remains a basic receiver (invariably of superhet type). To extract the command intelligence of the multiplexed modulated signal it must then be followed by a decoder which both discriminates between the different channels and decodes the individual commands present in each channel. The decoder provides a series of outputs which are now simple forms of command

10.1 Block diagram of digital transmitter.





10.2 Block diagram of a digital proportional receiver and decoder.

signals, fed to driver circuits powering the servos. Each servo operates on a closed loop circuit, incorporating feedback, feedback being an essential feature of proportional control.

Earlier forms of proportional systems used audio tones as the individual command signals. Variable intelligence can then be provided by allocating to each individual tone a bandwidth over which it can be varied, with suitable spacing of these bandwidths to avoid inter-modulation. The encoder thus generates tne appropriate (variable) tone signals, which are mixed for simultaneous modulation of the transmitter carrier (frequency multiplex). Movement of a control stick produces a change in frequency (within the allocated bandwidth for that frequency) in the selected audio channel.

At the receiver end, the receiver separates the individual tones, allocating each to its specific output circuit. The output can be rendered in terms of a varying voltage over the tone bandwidth (*figure 10.2*). It will be seen from this diagram how such a voltage variation, which is directly proportional to the specific frequency of the tone signal at any point in the tone band, can be applied directly as proportional command to an analog servo.

Typical control stick configuration with universally pivoted joystick operating the movements of two potentiometers.

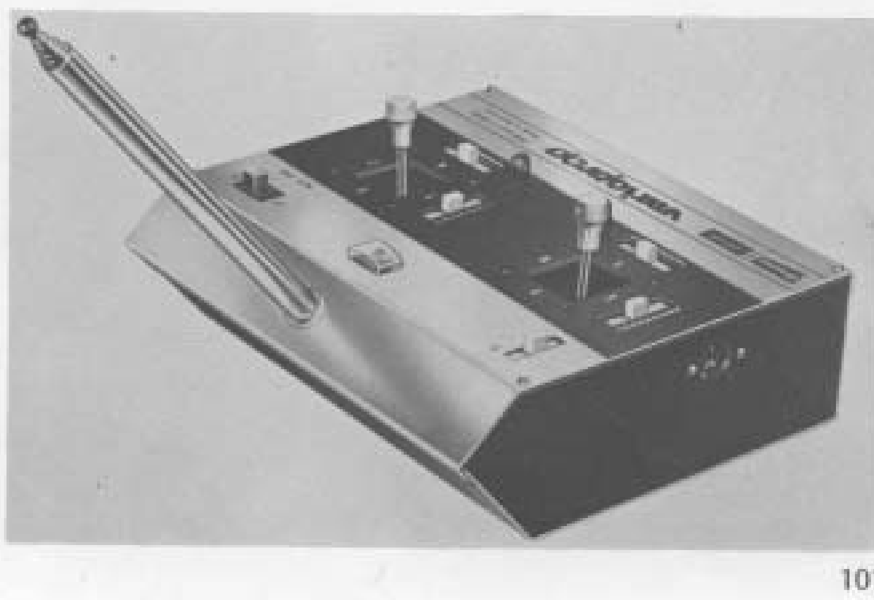
In practice such a system has a number of severe limitations. The usable bandwidth available is of the order of 4 to 6 kHz, whilst the tone change (or bandwidth) associated with each individual tone is about 50 Hz. This would appear to provide sufficient separation to enable a large number of tone signals to be multiplexed. Unfortunately when different frequencies are mixed together various cross-modulation frequencies are generated, particularly at 'sum' and 'difference' frequencies. This severely limits the number of separate tone signals that can be mixed: in practice to three, or at the most, four. Even then it is difficult to avoid some degree of inter-modulation.

Other factors which limit the usefulness of audio tones for proportional signalling are the relatively high power demand on the transmitter, and the difficulty of establishing the high stability necessary in the tone generator circuits. Since varying intelligence is signalled by a small change in note (frequency), and drift in the stability of the circuit will initiate a false signal, and thus a positioning error at the servo.

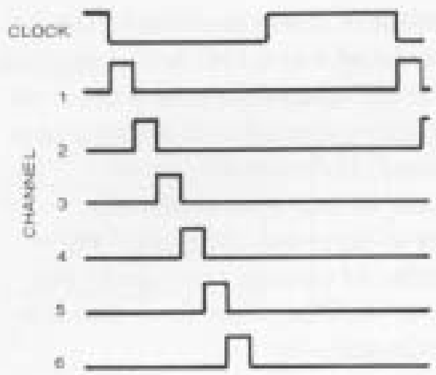
The more drastic problem of inter-modulation can be overcome by commutating or allocating separate time intervals to each tone, rather than transmitting them simultaneously. This is known as time multiplex. Each tone has a certain 'on' time, and remains 'off' for the time interval(s) other tones are allocated for modulating the RF signal. If the repetition rate is high enough—say of the order of 40 Hz—the 'lost' (i.e. signal off) period will have no effect. The receiver decoder merely has to 'hold' the appropriate signal over the commutation time to provide normal analog output.

The use of a pulsed tone signal for each channel, rather than a variable frequency signal, provides a better mode of working, associated with digital decoding. Each command channel is allocated a specific fixed frequency tone, and the encoder renders this signal in the form of pulses of modulation where the pulse length is directly proportional to the amount of movement on the transmitter control stick. Such signals are invariably time multiplexed for multiple channel working.

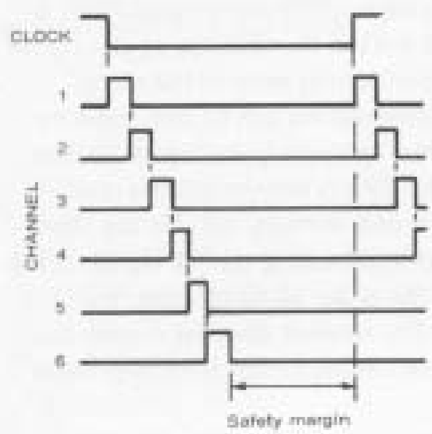
Plug-together module type units are favoured by this German manufacturer (Grundig).



Grundig transmitter configuration is typical of Continental European following.



10.3



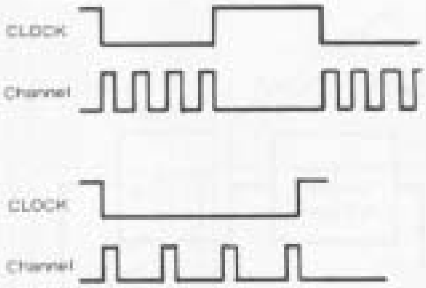
10.4

The repetition rate of the system if controlled by a master 'clock' circuit, normally working at a rate of 20 to 40 milliseconds. In other words, the 'clock' generates pulses with equal intervals of 'on' and 'off', as shown diagramatically in *figure 10.3*. Each signal information channel now comprises a separate tone signal which is variable in pulse width, and which is to be sent in sequence (time multiplexed). By selecting a suitable maximum pulse period, any number of separate tone pulses can be fitted into the 'gap' in the clock pulses without over-lapping.

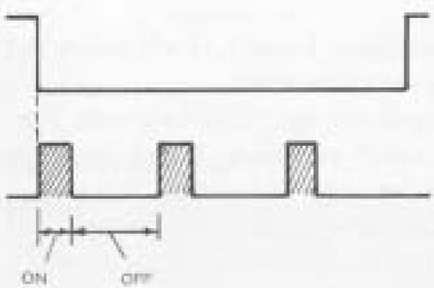
In practice the first, or channel 1, pulse is triggered by the trailing edge of the clock pulse. The trailing edge of the channel 1 pulse can then be used to trigger the channel 2 pulse, and so on. Thus effectively the multiplexed modulating signal is defined by a series of narrow pulses, each generated by the trailing edge of the preceding pulse (*figure 10.4*). It is also necessary to be able to distinguish the start of a sequence of multiplexed signals. This facility is automatically provided by the long gap provided by the clock pulse intervening between each repetition. All the command intelligence is then contained in these narrow pulses which may have a nominal period of some 1.5 milli-seconds, but can be varied by about plus or minus 0.5 milliseconds (i.e. have variable pulse width of this time order). The time interval *between* sequences allows the decoder to reset.

The main requirement is that the width of the command pulse must be clearly identifiable, and there must be adequate separation between individual pulses. The latter requirement largely governs the minimum pulse time acceptable.

A number of electronic problems are involved, such as optimum shaping of the pulses for positive and consistent decoding at the receiver end, and also to avoid any possibility of sideband or spurious signal generation, or overrunning one pulse into another. However, since each succeeding pulse is triggered by the trailing edge of the pulse



10.5



10.6 'On' and 'off' pulse times.

immediately before it in time multiplexing, it is the *position* of each pulse relative to the preceeding pulse which is really conveying the signal intelligence. Widening a preceeding pulse will delay the appearance of the following pulse, and vice versa (*figure 10.5*). It is thus only necessary that the receiver decoder operate on either the leading edge or trailing edge of the pulses. Pulse-shaping is thus based on this requirement, depending on which edge of the pulse is used. The time interval between two leading edges (or trailing edges) of succeeding pulses is then a measure of the *width* of the first pulse.

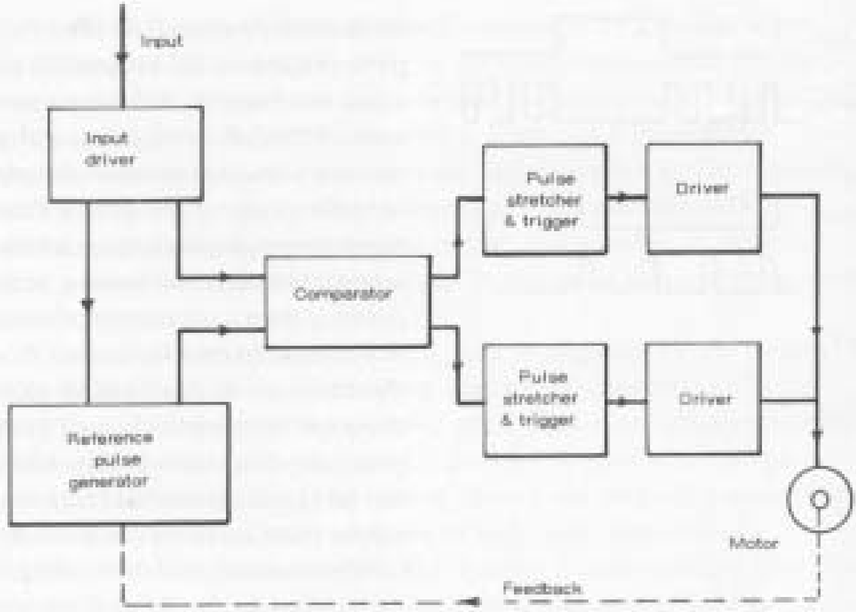
The system may be further modified by introducing variable synchronisation. With a fixed clock time, and thus fixed repetition rate, there can be a relatively long interval with no pulses present, if all the pulses are short ones (*figure 10.6*). It is advantageous if such an interval can be closed up so that there is always only a minimum 'off' time. This can be done by using one portion of the clock cycle to generate synchronisation, and over-riding the remaining part of each cycle by a signal triggered by the trailing edge of the last pulse. Thus, regardless of the spacing of the pulses, the 'off' time is reduced to a safe minimum. In other words, the repetition rate is increased to close up the duty cycle with close spaced (narrow) pulses, and decreased to accomodate wide spaced pulses. This can result in better servo resolution.

Interpretation of the proportional signals at the receiver end first necessitates the decoder identifying the start of a sequence, then directing the individual signals into their respective channels with on-off times governed by the respective pulse intervals between pulses (pulse lengths). It is, in effect, a *counter* allied to gate circuits, with inbuilt synchronisation to reset at the end of each sequence. The latter is initiated by the 'synchronisation pause' derived in the transmitter signal.

Signal output to the servo connected to each separate service thus takes the form of pulses, repeated at the clock, or frame, rate of the transmitter, with a pulse width defining the required position of the servo. The servo circuit is necessarily complicated for it has to generate its own reference pulse, controlled by position via feedback, compare its own reference pulse with the signalled pulse, and trigger drive in a direction to achieve null balance. A block diagram of a typical digital servo circuit is shown in *figure 10.7*.

The reference pulse generator is virtually identical to that used on the transmitter, except that the pulse width is controlled by the output position of the servo via a feedback unit connected to (or driven by) the output movement. This reference pulse is fed to a comparator circuit. The incoming pulse (command signal) is also fed to the comparator, which will have an output if there is any difference in pulse width (*figure 10.8*). This output is in the form of an error signal, which can be negative or positive, depending on which way the servo has to drive to alter the reference pulse to match. In the presence of an error signal the servo will drive in the corresponding direction to reduce the error signal to zero, when it will stop. Both input and reference pulse widths will then be identical, meaning that the servo has taken up a

10.7 **Block diagram of digital servo circuit.**

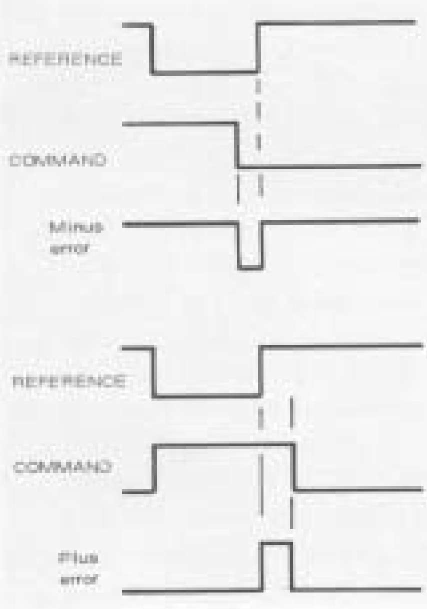


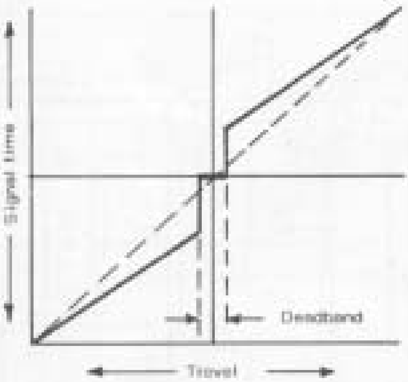
position truly demanded by the input signal. Equally, it will follow any change of the input pulse width in a similar manner.

The repetition rate of the input signal will inevitably be greater than the response rate of the servo itself, which may have a transit time from extreme to extreme of movement of the order of 1 second. It is thus necessary to take the error plus signal and 'stretch' it into a longer pulse, suitable for turning on the driver circuit, which is basically a trigger circuit allied to current amplifiers. The servo also drives with equal power at any position (unlike an analog servo where drive power is variable depending on the amount of resistance effective in the circuit at any position).

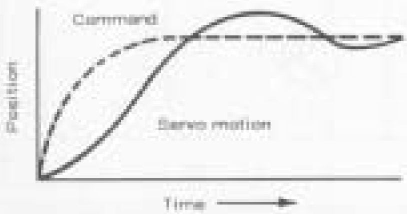
With a completely linear response the servo motor would have a tendency to oscillate about any null position at the repetition rate of the signal. This can be eliminated by providing a small deadband of about plus or minus 1 per cent on movement (*figure 10.9*). The width of the deadband is controlled by the trigger and amplifier circuit. Damping is also desirable to minimise overshoot so that the servo moves to its commanded position in the minimum of time (*figure 10.10*).

10.8





10.9



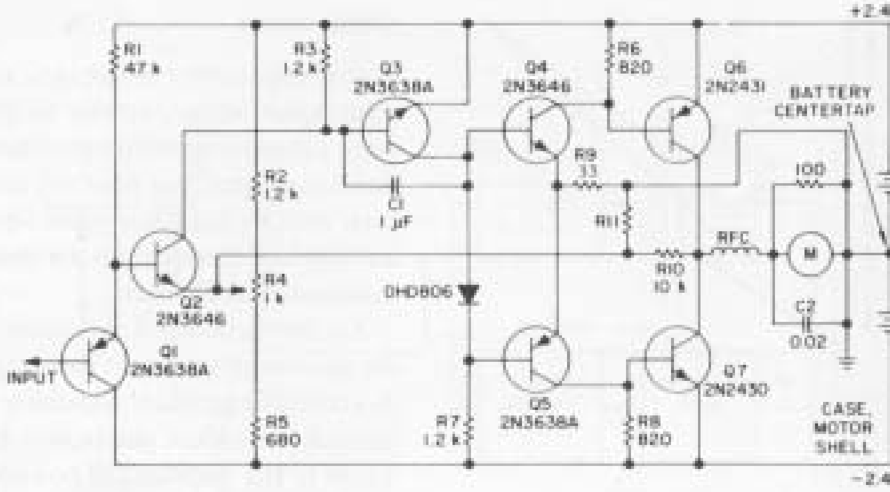
10.10

Analog servos

Analog servos differ in that they are re-controlled by an infinitely variable input signal voltage, usually ranging between plus or minus 0.25 to 0.5 volts. Linearity of movement depends primarily on the linearity of the command signal, but does not compare with that of a digital servo. Even with a good linear input signal, the linearity of the servo response will still be dependent on the linearity of the differential amplifier used to drive the servo motor.

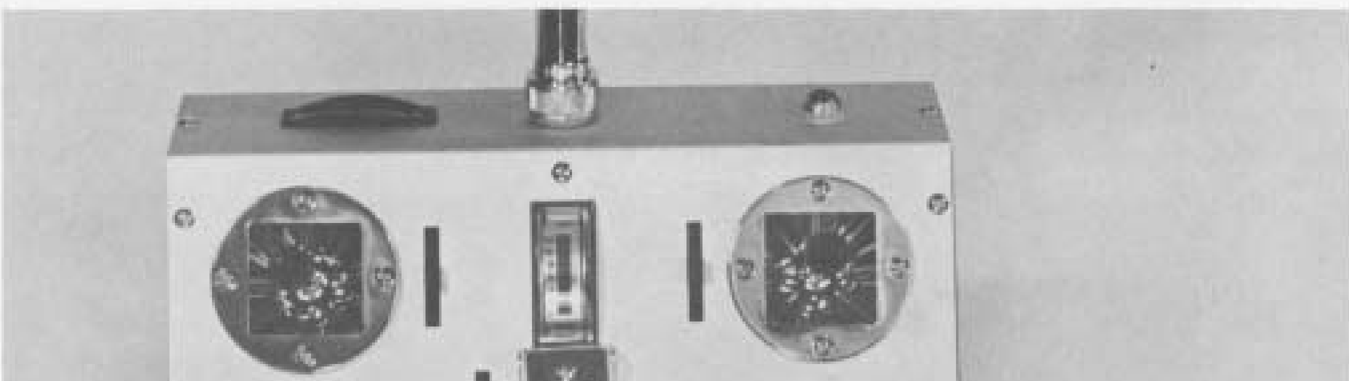
Another problem is overshoot, which is almost unavoidable and in the absence of sufficient damping can cause the servo to oscillate about its command position. Relatively heavy 'electronic braking' is normally necessary to reduce positioning to a single overshoot and immediate return to the commanded position. The circuitry required for an analog servo, however, is considerably simpler than that of a digital servo (compare *figures 10.11* and *10.12*).

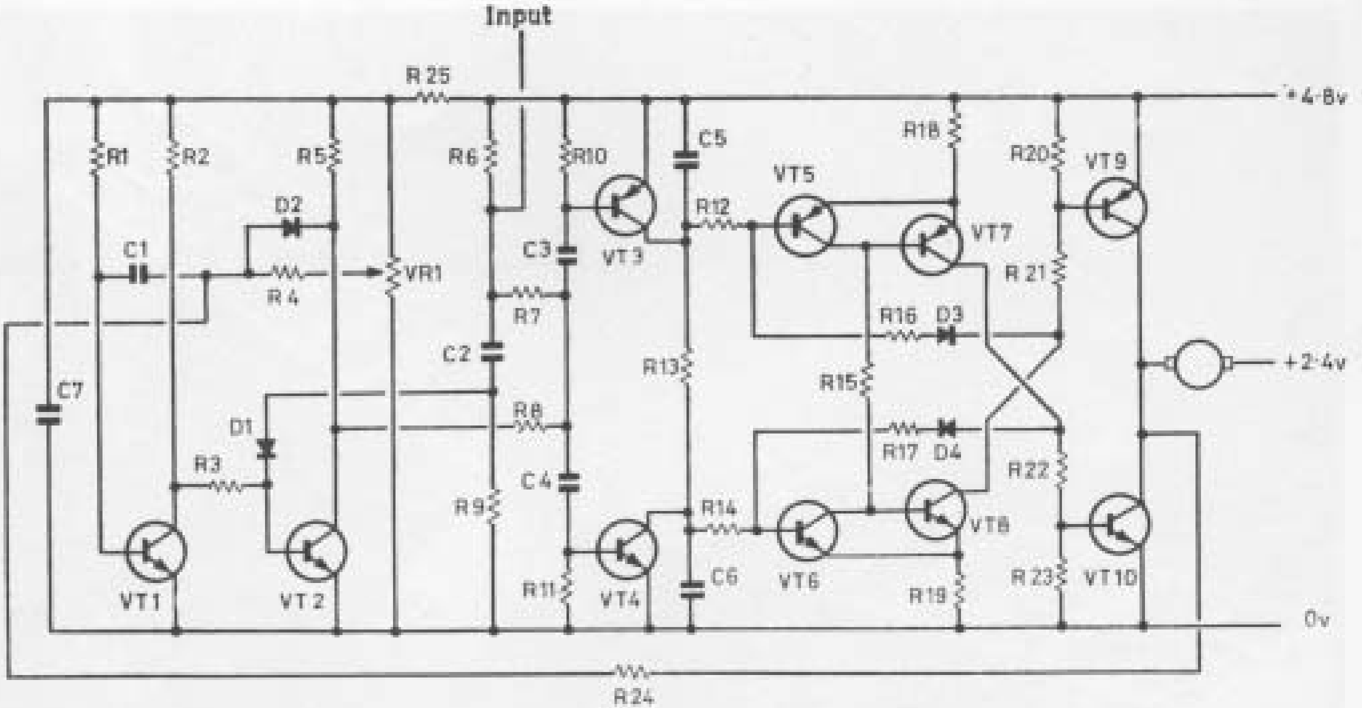
Radio Modeller photo.



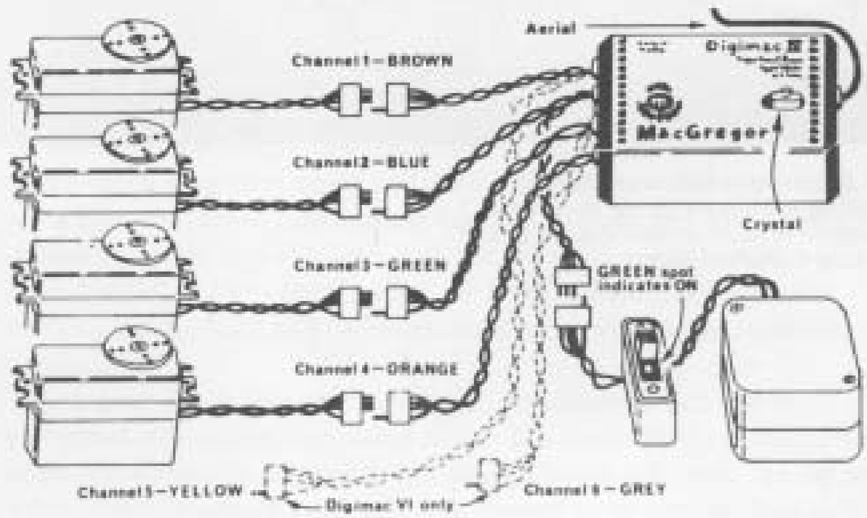
10.11 Typical analog servo circuit.

British, American and Japanese designers follow generally this type of shape and layout for proportional transmitters. Receiver (bottom left) housed in aluminium case. Servos (right) in rectangular 'box' shape.

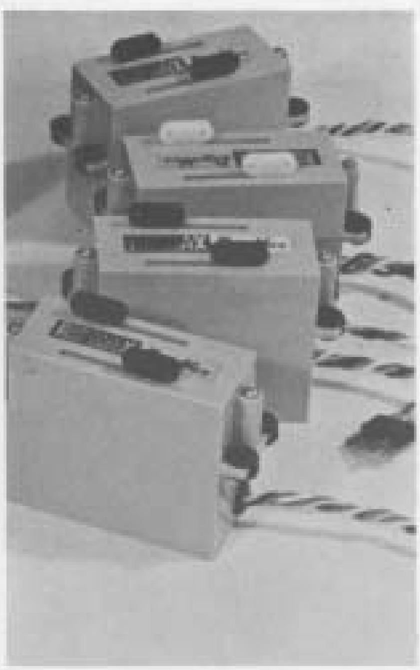




10.12 Typical digital servo circuit.



10.13 (Above) Typical colour coding of British digital equipment (prewired system with polarised plugs and sockets).

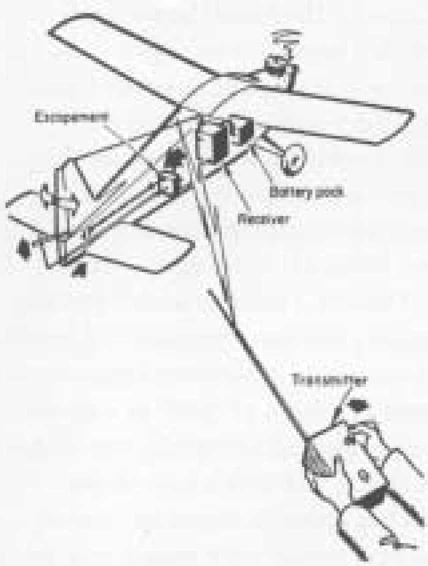


(Above) Typical linear-output proportional servos.

(Right) Type of servos designed for use with German equipment.

A glider model plus single-channel 'rudder only' is by far the cheapest method of starting radio control flying. Photo Radio Modeller.

11 SINGLE-CHANNEL AIRCRAFT CONTROLS



11.1 The single-channel radio link simply provides 'on-off' signalling for operating a rudder movement in right-neutral-left-neutral sequence.

Signalling is done by pressing the 'keying' button on the transmitter—marked 'Tone' in this example. A microswitch keying button is essential for good control.

Where only *one* control is available, a model aeroplane can be controlled in flight by applying this to control of direction, i.e. *rudder control*. This will be a practical method of control only if the model itself has a reserve of inherent stability. That is, the model design is similar to that adopted for free-flying models, with a margin of built-in or automatic stability which enables the model to recover its initial flight path after being disturbed by a gust, or some other influence.

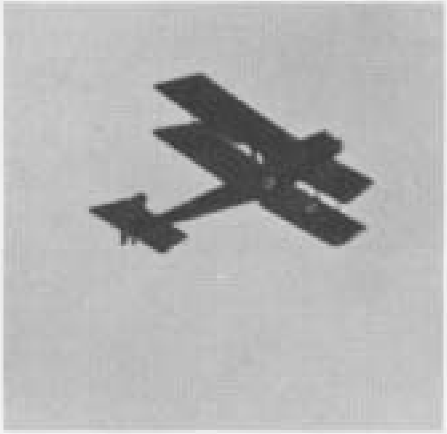
This also influences the *type* of control possible for rudder. It must be capable of automatic self-centring or return to neutral rudder position, to allow the model to recover a normal flight path after it has been influenced by rudder movement. This demands the use of a self-neutralising (S/N) actuator. Normal choice would be an S/N escapement for the smaller models, and an S/N single-channel motorised actuator for larger models.

Rudder-only control has far more scope than would appear at first sight—and also a number of limitations, although these can be countered to some extent. Dealing with scope first, 'bang-bang' rudder movement will obviously give a choice of selecting 'right' or 'left' turn. Response to rudder movement is powerful and rapid on a free-flying model, and so the use of a *selective* actuator rather than a simple S/N type is to be preferred, as this reduces the chances of 'pilot error'. Considerable practice is then needed in order to judge how much rudder can be held on at a time, e.g. the 'timing' of the 'on' signals given by pressing the transmitter button.

If a rudder position is signalled and held on, the model will commence a steep turn which will almost immediately develop into a spiral dive, the rate of turn and the rapidity into which it will develop depending on the size of rudder and amount of movement, the design of the model, and to a lesser extent the free-flight trim of the model. The two latter effects will be very much smaller than actual response to rudder.

The spiral dive is one, quite dramatic, manoeuvre which can be performed with rudder-only control—but it is only safe if the model has sufficient altitude to start with, and enough height left when the rudder is returned to neutral for the model to recover to its normal flight path. To perform a smooth turn it is necessary to 'blip' the required rudder control on and off, the timing of the 'on' signals controlling the rate of turn. In other words the model is made to complete a turn through a series of partial turns (initiated by signal on) and recoveries (signal off). At the same time the model will tend to roll into the turn and then roll in the opposite direction. This 'rocking' motion may or may not be apparent at a distance, it depends on the aerodynamic characteristics of the model and the 'timing' of the control signals.

A secondary effect will also be noticed in rudder-only turns. As the model starts to turn the nose will tend to drop; and as it recovers the nose will tend to rise. A steep turn, therefore, will result in the model nosing down and picking up speed. When the control is taken off to allow the model to recover into a straight flight path the excess speed will cause it to nose up into a zoom, or even a stall.



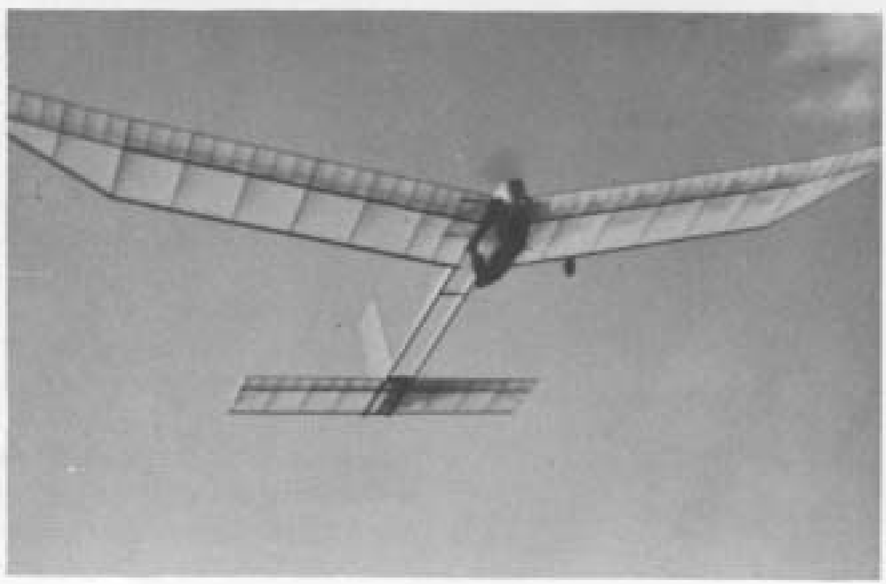
Single-channel models spend most of their time flying on their own, so they must be automatically stable in flight. This is a check for a suitable design. Scale type like this can be tricky to fly.

This can be controlled to some extent by the rate of turn signalled—or even by making a partial turn in the opposite direction to get the nose down again after recovery from a fairly tight turn. Zooming after a turn can also be reduced by trimming the model in a slightly under-elevated condition, compared with a normal 'free flight' trim.

This under-elevated trim is also helpful in improving the penetration of the model against a headwind. Free flight models are normally trimmed to climb under power and will have little forward penetration, relative to the ground, when heading into wind. Radio controlled models need to have a more under-elevated trim so that their forward speed is increased and the rate of climb reduced—more nearly to horizontal flight than climbing flight. There is a limit to which this can be carried out, however. Too much under-elevation can make the model drop its nose rapidly and lose height excessively in even moderate turns.

Rudder control itself can also be used as a form of 'trim' or elevator control. If alternate rudder positions are signalled on rapidly the model will fly an S-path instead of a straight course, starting a turn in one direction, recovering, starting a turn in the opposite direction, and so on. The loss of height inherent in making a rudder-turn means that the nose of the model will be forced down, so that the model increases speed and loses height in flying the S-path. A skilled pilot can use this technique to effect a change of trim during flight, e.g. to change a climb into a shallow dive to improve penetration when heading upwind. A practical limitation which can arise in this case, using an escapement, is that the large number of individual signals employed may unwind the escapement motor before the end of the flight, when further control is lost.

Further manoeuvres are possible using the basic control responses described; and if necessary adjusting the trim of the model to suit. In all cases the response achieved will also be related to the aerodynamic characteristics of the model. The control possibilities with rudder-only can be summarised as follows:



A steam-engine powered radio controlled model in flight! Practical only with very lightweight construction and ultralightweight radio installation. This is an outstanding example of what can be achieved by skilled modellers wanting to try something different.

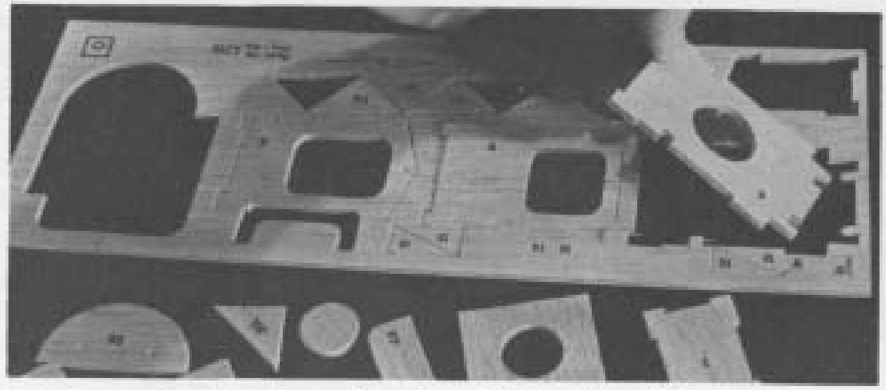
Level turn. Blip the same rudder signal on and off at a rate sufficient to keep the model turning, but with insuffICent dwell with the 'on' signal to cause the nose of the model to drop. The *rate* of turn will then be controlled by the rate at which the signal is blipped on and off.
Climbing turn. As for a level turn, but with even less 'on' signal and a slower rate of blipping. It may be necessary to reduce the degree of under-elevation on the model trim to achieve climbing turns.
Diving turns. As for level turns, but increasing the dwell for the 'on' signal. It may be necessary to apply opposite rudder to counter a zoom when the model recovers to its normal straight path.
Gliding turns. As above, but this time the rudder effect will be less marked because of the absence of slipstream and slower flying speed. The dwell time for signal 'on' will have to be increased to compensate.
Spiral dive. Starting with sufficient altitude in hand, hold on a rudder position. Note that this produces a spiral dive and *not* a true spin. Use alternate rudder signals for 'elevator effect' to counteract the zoom on recovery.
Loop. Make two or three turns of a spiral dive, then allow rudder to neutralise so that the model recovers into straight flight heading upwind. The excess speed built up in the spiral dive can be sufficient to carry the model right over to complete a loop. It may be necessary to reduce the initial under-elevated trim to a minimum to achieve this.
Stall turn. As for loop, but with reduced turns in the spiral dive (or more under-elevated trim) so that the model zooms up into a stall on recovery. At the top of the stall, apply a touch of rudder.
Roll. Build up speed with two or three turns of a spiral dive and recover to straight flight in a crosswind direction. Blip on left rudder, then hold on right rudder. The actual form of roll resulting will depend on the aerodynamic characteristics of the model and its trim. Some models, particularly slower flying types, cannot be made to roll at all.

Other variations are possible, particularly those based on the zoom following a spiral dive, depending on the aerodynamic characteristics and trim of the model. For example, it may be possible to roll the model off the top of a loop. The spiral dive is also the manoeuvre which can be used to lose excess height quickly, e.g. to prevent the model flying out of sight, or out of range. Here it must be remembered that the model will also lose ground downwind. Sufficient height in hand should be available on recovery to fly the model back, using alternately blipped rudder to lose further height as necessary and increase penetration upwind.

Rudder plus motor speed

Using a compound actuator it is relatively simple to add motor-speed control on a powered model aircraft, although this necessitates the inclusion of a second (secondary) actuator of the progressive type. Again the actuators can be escapements or motorised actuators. For ease of control selection the compound actuator should be of the type which accepts 'quick-blip' signalling for the secondary service. The


A back-mounted transmitter, slung on a strap. Possible with single-channel where only a single keying control is required which can be on an extension lead. Modern transmitters are small and light enough to be carried in the hand.

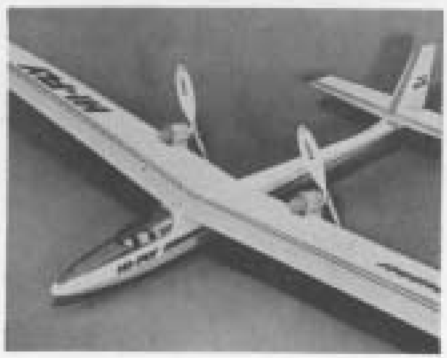


One attraction of single-channel is that there are a large number of inexpensive aircraft kits with pre-cut parts which make excellent subjects for rudder-only control.

secondary actuator can be of the 2-position or 4-position type, depending on the throttle response of the engine used. Thus some engines fitted with throttle controls are really responsive only to 'slow' and 'fast' positions of the throttle arm, with intermediate positions having little effect. In this case a 2-position actuator is suitable. If the engine is responsive to progressive throttle movement, then a 4-position actuator will give a choice of three engine speeds (see Chapter 6).

The addition of throttle control does not extend the range of manoeuvres possible so much as make certain manoeuvres more easy to perform. Certainly it provides a more direct method of height control: reducing engine speed will put the model into a 'powered glide'. It is generally recommended where the size and type of model is such that it can readily accommodate a second actuator; and suitable engines are available with throttle control. Throttle control is usually least effective—and often not available as a standard conversion—with a number of the smaller sizes of engines. As a general rule, too, glow motors are more responsive to throttle control, and more reliable in this respect, than diesel engines.

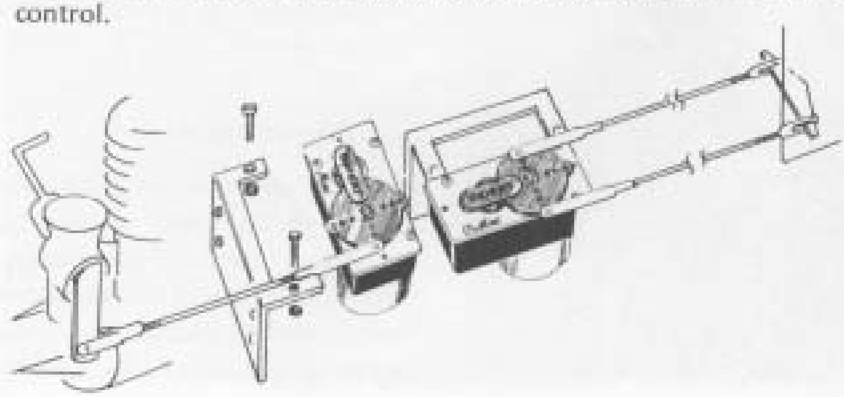
Rudder control with the addition of motor-speed control is still generally classified as 'rudder-only' control.



Electric power for aircraft is the latest development in radio control—silent and quiet in flight. Most of the development work with this type of R/C model has come from Germany. Model shown is powered by twin electric motors and 'pusher' propellers.

Rudder plus elevator control

Elevator control is no alternative to rudder control and so can only be considered as a secondary service *with* rudder as the main control. The *value* of elevator control, on the other hand, is fairly obvious. It can be used to correct the 'dive' and 'zoom' tendencies initiated by a turn and recovery from a turn, respectively, as well as being a 'trim' or altitude control.

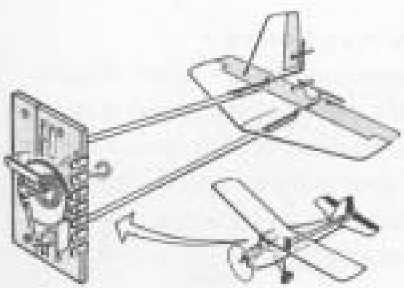


11.2 Rudder control using a compound single-channel and a secondary actuator. Unusual actuator feature of this hook-up is the 'double-sided' rudder linkage.

Because of the rapid and critical response of aircraft control movements it is not possible to utilise a 4-position self-centring main actuator which could provide for *selective* operation of both rudder and elevators controls. Instead it is best to regard the elevator control as a secondary service which can be selected simply, and quickly. The most practical method is the adoption of 'kick elevator'.

This 'kick' movement is provided for at the 'third position' of certain escapements (see *figure 11.3)*. When this position is selected and held, a trip action produces a rotary movement on a separate crank which can be linked to the elevators to provide 'up' or 'down' movement. Rudder is not affected by holding this signal and the escapement wheel position corresponds to (near) neutral rudder position. Equally, rudder cannot be signalled whilst the elevator movement is being held. On release of signal the escapement returns to neutral and the elevator is centralised by spring action.

'Kick elevator' movement can be used to provide up or down trim—or even full up or down elevator movement, if required; but not both up *and* down elevator movement.



11.3 Special type of escapement with extra mechanical movement for 'kick elevator' action.

The fact that the elevator will have a momentary 'kick' movement for every rotation of the escapement wheel will have no affect on the normal flight path. The advantage of this system is that the elevator movement is obtained from the rudder actuator, i.e. only one escapement is needed. A similar sort of movement can be provided for on a motorised actuator.

An alternative system is to work a secondary actuator from the 'third position' on the rudder actuator. This can be a 2-position or 4-position progressive type. A 2P actuator would provide changeover for the selection of elevator trim. For example:

(1) elevator normally neutral, trim position 'up' or 'down'.

(2) elevator normally 'up', trim position 'down' (or the other way round).

A 4P actuator would appear to provide a wider control service, i.e. the possibility of having either 'up' or 'down' elevator position, with the intermediate position giving neutral elevator. The system is less practical, however, since a particular elevator position can only be selected in sequence and if the pilot 'loses' the sequence the result could be disastrous.

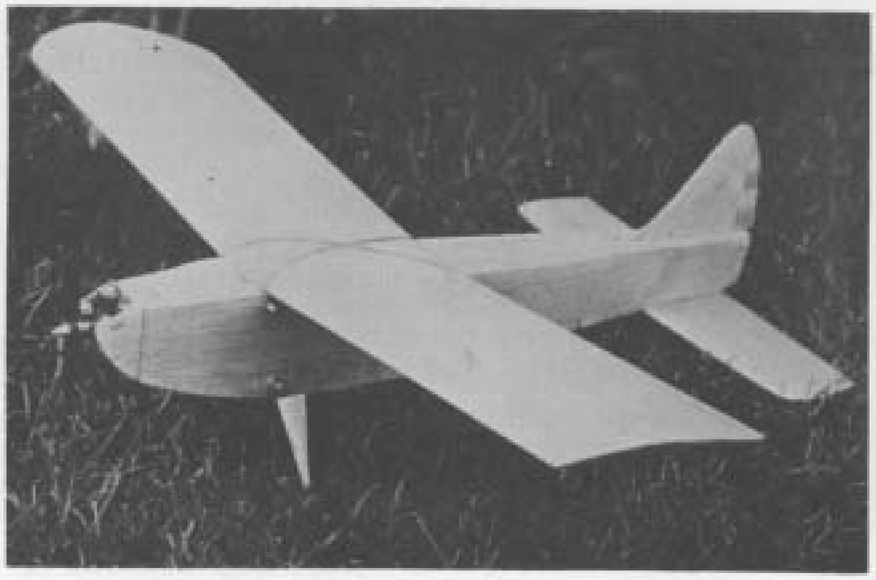
A further possibility is the use of two S/N actuators in cascade. The method of cascading is dependent on the type of actuators used, the main actuator having to provide four selective control positions. The second actuator which is used to drive the elevator linkage then has two selective positions, mechanically and/or electrically linked as necessary. Electrical linkage can be obtained from wiper circuits on the switching circuits of the two units.

The limitation with cascaded actuators is that although the signalling can be made selective, selective signalling of the elevator service is cumbersome. Normal arrangement for signalling is:

press and hold = right rudder

press-release-press and hold = left rudder

Because of the small weight of a single-channel receiver and actuator, and small battery requirements, models as small as 12 inches wingspan can be flown successfully on 'rudder-only' control. Only suitable for calm weather conditions, though.



press-release-press-release-press and hold = up elevator
press-release-press-release-press-release-press and hold = down elevator

This is, however, workable for aircraft, provided the model is not too fast and, or, elevator control critical in response. A fifth service can be provided by 'quick-blip' switching, i.e. adding motor speed control as well. This is about as far as one can attempt to go for a practical single-channel control system applied to aircraft.

Aileron control

Certain types of model aircraft lend themselves to *aileron control* instead of rudder. The response is similar—both aileron and rudder movement have the effect of inducing roll and turn—but the response to aileron movement is far milder. The *advantage* of aileron control for turns, rather than rudder, is that the turn is far less vicious, with reduced nose-dropping tendency. On the other hand this can be more than cancelled out on most types of models by the lack of a true directional control (rudder).

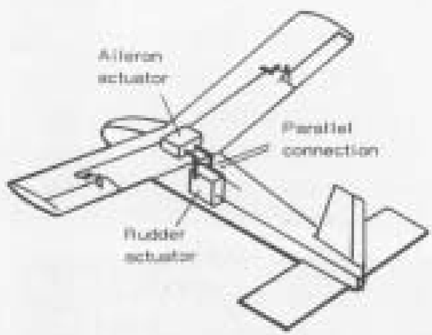
Single-channel model aircraft kits are commonly designed to be powered by .049 to .075 size glow motors. These are inexpensive models, compared with their larger counterparts for proportional radio.

The application of aileron control as an *alternative* to rudder must therefore be approached with caution. It can work well on certain designs (e.g. gliders) and on models where rudder control tends to be too 'vicious' because of the small degree of automatic stability inherent in the design (e.g. low wing models). It would not be a normal choice.

Coupled aileron and rudder

One method of including aileron control whilst still retaining rudder as the main directional control is to couple aileron and rudder movements mechanically, so that both are operated off the same actuator. This can enable the amount of rudder power required for turns to be reduced. However, few manoeuvres require the simultaneous use of ailerons and rudder, and the fact that the two always move together in the same mode can be a disadvantage at times.

In practice, mechanical coupling of the movements can also present elevator stop position problems. In fact a better scheme is to use separate motorised S/N actuators for the rudder and ailerons, electrically connected in parallel to operate simultaneously.



11.4 Coupled-aileron-rudder, using separate actuators connected in parallel electrically to respond simultaneously to a signal.

Other systems

Various other schemes have been tried for extending the range of services provided by simple single-channel systems, but none that rely on-sequence switching can be used for other than secondary or non-critical controls on aircraft. A self-neutralising rudder action (or equivalent directional control) is the basic, and essential, control requirement.

Early attempts to combine rudder action with elevator employed a freely rotating vane which could be stopped in 'equivalent' rudder and elevator positions (see photo above). Stop positions were controlled by

Rudder, elevator and throttle control is possible from single channel, using three separate actuators in cascade. Maintaining full control in flight is difficult, though, because rudder or elevator, can only be signalled in sequence. Throttle control should always be from a 'quick-blip' signal.

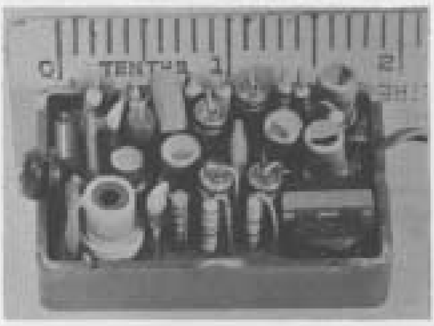
Early attempt to overcome the limitations of rudder-only control by using a rotating vane instead of a rudder, stopped in equivalent 'rudder' and 'elevator' positions in sequence. Again it was the fact that control required had to be signalled through a sequence which led to its lack of success.

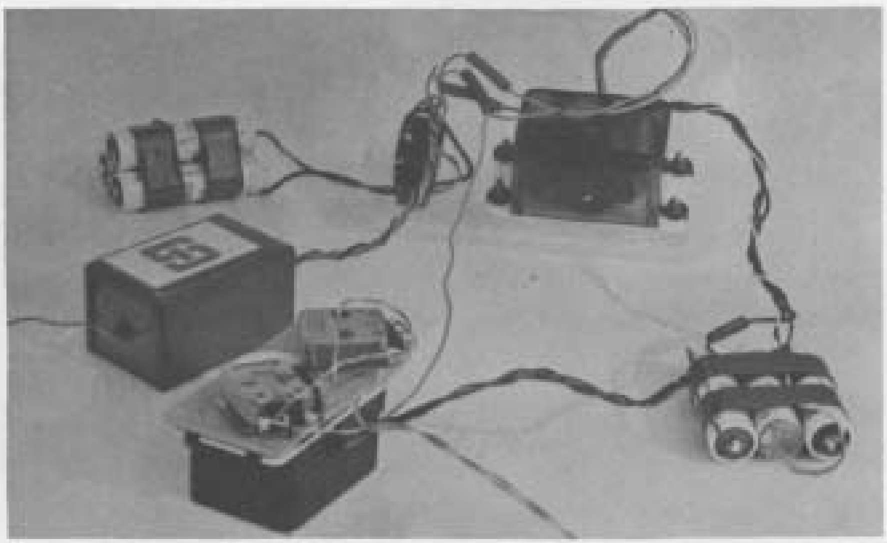
escapement movements—an ingenious, but not particularly successful attempt at a simple mechanical solution to coupling rudder and elevator response.

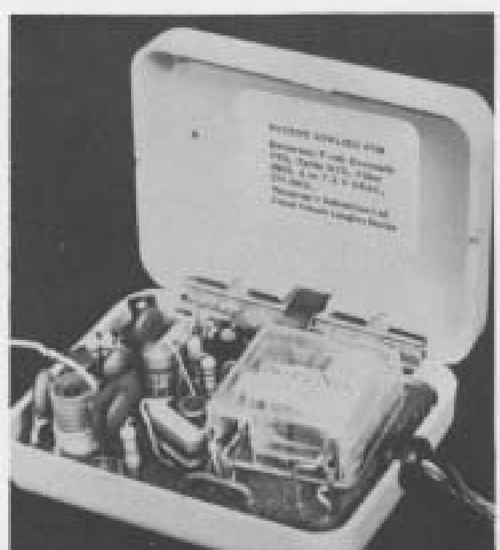
Some thirty years of single-channel working have, in fact, yielded the fact that for *practical* operation as aircraft controls, rudder as a main control, with motor speed control as a secondary service remains the first choice. Performance limitations exposed by this combination are best tackled in terms of model design and model trim, rather than elaboration on the control services available.

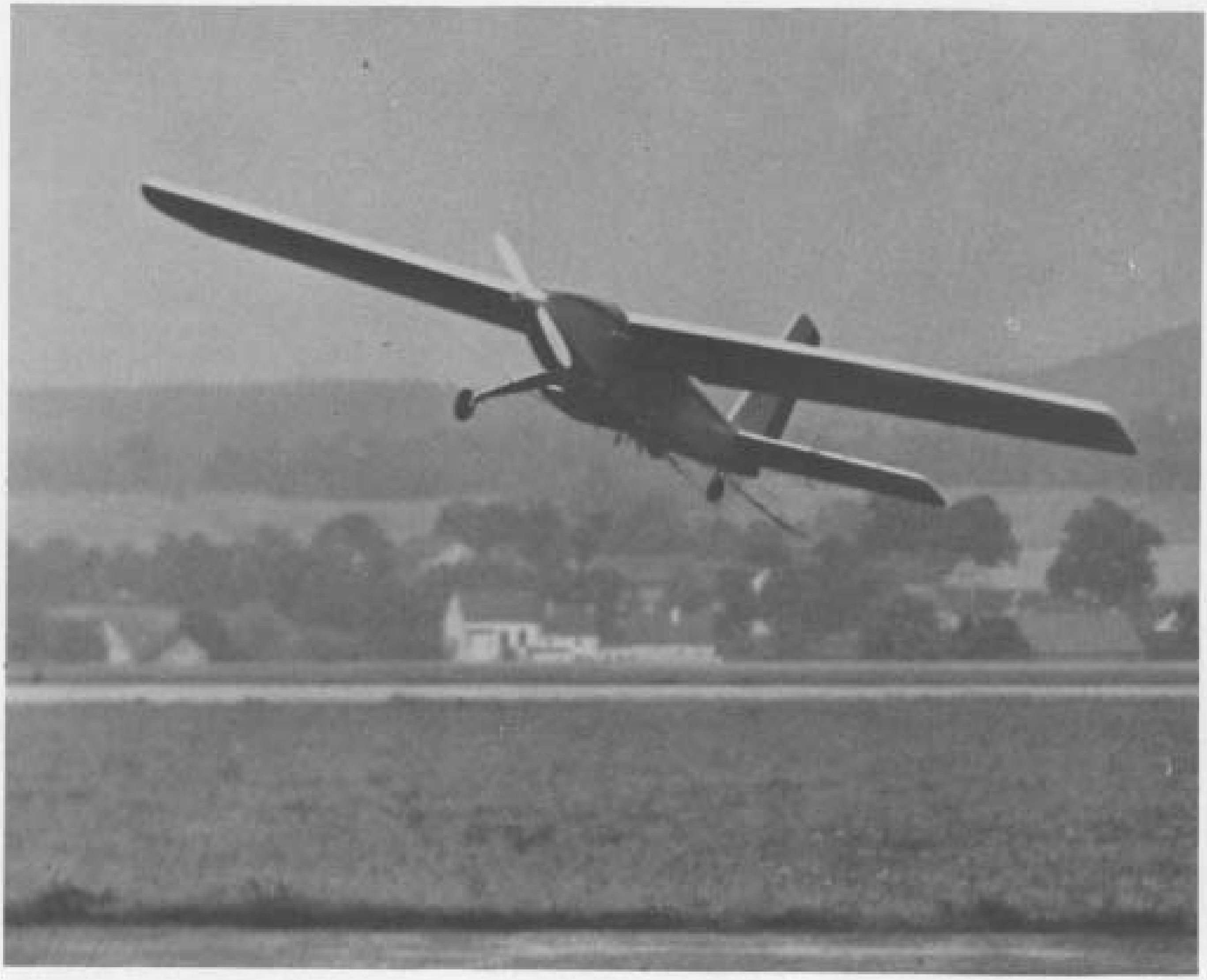
Where extension of control services is desirable, then single-channel pulse proportional systems are worth considering. Basically, however, as far as aircraft are concerned, only 'multi' or proportional systems will give all the coverage needed for complete control. Nevertheless single-channel coverage for aircraft controls continues to command wide support, particularly in Britain and Japan, largely because of its considerably lower cost.

Examples of single-channel radio equipment.



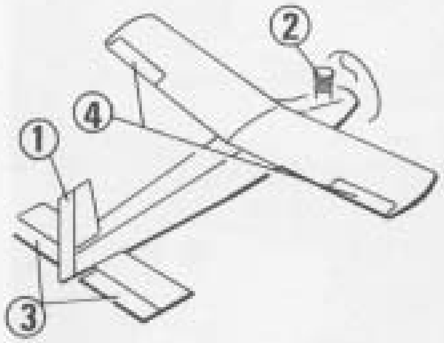






Since 'bang-bang' control movements cannot provide continuous control, 'multi' aircraft designs usually favoured a high wing layout. Low wing models proved much trickier to fly—but more aerobatic.

12 MULTI - CHANNEL AIRCRAFT CONTROLS



12.1 The order of importance of functional controls.

1 rudder 2 engine speed
3 elevators 4 ailerons

Multiple (tone) channel systems are described by the number of separate signalling channels available. Two channels are required for selective operation of one multi servo, which can be either a 'bang-bang' self-centring type, or have a progressive action. 'Bang-bang' S/N servos are used for main control functions, and progressive servos for trim functions.

Multi-channel systems have little advantage over single-channel systems for aircraft until at least six channels are available. This extends the coverage available to rudder and engine speed (also readily available with single channel), plus positive and separate selection of elevator control. This can be regarded as a minimum requirement to justify the greater expense of a multi-channel system for aircraft—a 6-channel transmitter-receiver combination with three multi servos.

Control coverage is still not complete, however. Another two channels are necessary to add aileron control; and a further two channels are desirable to add elevator trim. This then represents complete or 'full house' coverage, where the pilot can have full command over the aircraft in flight.

The allocation of channels, in their order of importance, is thus:

Rudder operated by a S/N servo
Throttle operated by a progressive servo
Elevators operated by a S/N servo 6-channels
Ailerons operated by a S/N servo 8-channels
Elevator trim operated by a progressive servo 10-channels

The maximum number of channels available from reed equipment is twelve. These additional channels can be used to operate ancillary services or an additional trim control. Much depends on whether the controls are to be 'all functional', or are to add some 'display' feature. Thus flaps, or aileron or rudder trim, or undercarriage retraction, are functional controls which could be added by the spare two channels on a 12-channel system. Bomb-release, or perhaps triggering a camera carried aboard, are 'display' controls which could be worked from these spare channels. No such services selected should be included at the

Multi-engine aircraft became practical with the availability of directly-signalled multiple controls.

Typical of an advanced aerobatic design for 'multi' controls—rudder, elevator, elevator trim, throttle and strip ailerons. High wing layout is retained.

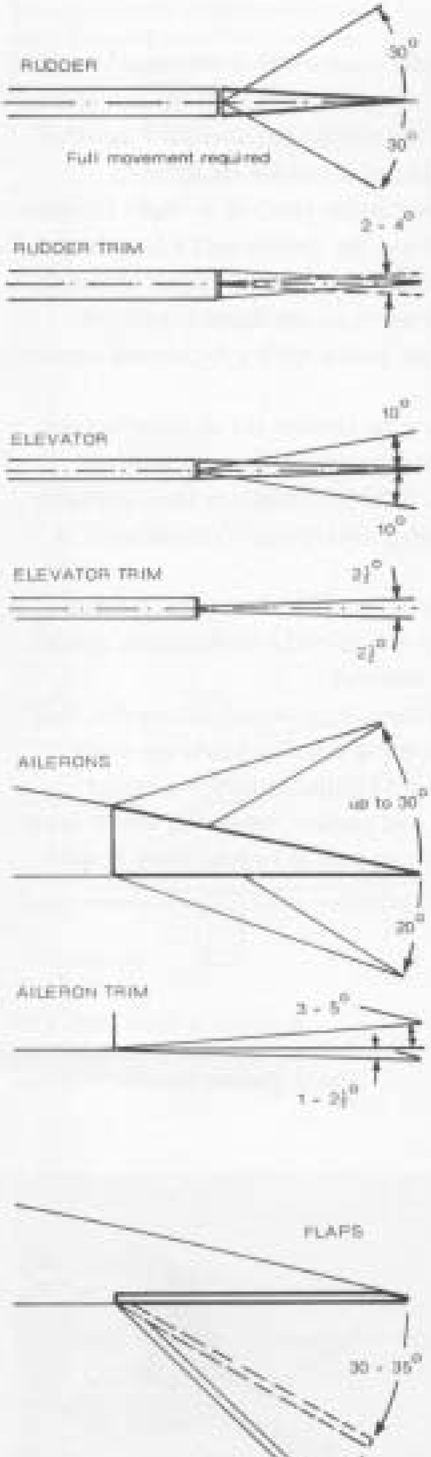
expense of the main functional controls listed above. If they are, this will be to the detriment of full functional control coverage.

Additional control services can also be obtained by coupling. Thus the operation of wheel brakes can be mechanically coupled to elevator movement, (up elevator also applying the brakes is the typical choice.) It is quite unnecessary to use radio control channels for brake operation. Similarly, nosewheel (or tailwheel) steering can be mechanically linked to rudder movement.

A coupled control system which has come into use for slope soaring gliders is coupled ailerons and flap, known popularly as 'flaperon' control or 'flaperons'.

Further extension of controls is possible by electrical coupling and 'limit switching'. This takes advantage of the fact that certain control positions, or combinations of controls, are only used to a limited extent.

For example, slow throttle would normally be associated with a particular requirement such as a need to lose height, or approach for a landing. The limit of movement of the throttle linkage could thus be used to operate a switch, energising a separate S/N servo lowering flaps. The fact that *every* time the limit of 'slow' throttle is signalled the flaps will lower, is immaterial. This extreme throttle movement can be avoided in normal flight (the throttle movement is progressive, not 'bang-bang'). When flaps are required, holding the throttle-signal key in the 'slow' position will ensure that the limit of movement is reached and the flaps are operated. They will continue operated until the throttle is inched forward again, when the flap servo will be de-energised and centre itself.



12.2 Control movements required. The same recommendations apply to proportional controls, taking the figures as maximum travel.

A particular combination of two controls can also be utilised for switching an additional actuator, or service. A number of aerobatic models, for example, are difficult to spin. This is usually because the amount of elevator movement suitable for normal flight control requirements is too limited to enable the model to be stalled into a true spin. To overcome this limitation an addition to the switcher board on the elevator servo can provide for additional up elevator movement under certain conditions by interlinked switching. The control combination to produce a stall would be slow throttle and up elevator. Each of these two positions can close a switch at the limits of the respective movements, these switches being connected in series in the elevator extension switcher circuit. Thus when the two control positions occur simultaneously the extension circuit is completed, allowing the elevator servo to provide extra up movement. In exactly the same way, the two series switches could be used to complete the circuit of a separate servo providing some other control function with a particular combination of two controls signalled.

Mention of the need for limiting elevator movement for normal flight control emphasises a basic limitation of 'bang-bang' flight controls. They have to be held either 'full on' or neutral and so as to provide varying degrees of control have to be 'blipped' in a similar manner to single-channel rudder control. Their controlling power, governed by their area and movement, have also to be balanced to give a reasonably smooth response—not too vicious, and not too weak. To some extent this is governed by the design of the model, and particularly its flying speed, but the following are general proportions and movements:

Rudder Area about 2-3 per cent of the wing area; movement 30 degrees right and left.

Elevators Area about 4-5 per cent of the wing area; movement 10 degrees up and down.

Ailerons Area 4-6 per cent of the wing area: movement depends on the control response required. To achieve rolls movement required is usually 30 degrees up and 20 degrees down with conventional inset ailerons; or 20 degrees up and down with strip ailerons. Less movement is needed for steady turns.

Elevator trim Movement required is quite small, not more than 2½ degrees up and down.

Rudder trim Movement required is rather less than that for elevator trim, typically 1-2 degrees right and left.

Aileron trim 3-5 degrees up movement; 1-2½ degrees down movement.

Flaps Area about 10-15 per cent of wing area: movement 30-35 degrees down (not more than 45 degrees).

Decoupling controls

It is a characteristic of 'full house' multi controls that the rudder control is rarely required to be used in flight, other than for directional control during take off and landing. It is still an *indispensible* control for these two critical parts of the flight, so it cannot be ignored. However it is practical to *decouple* the rudder control in flight by limit switching from another control, breaking the rudder servo circuit and making another circuit, which then enables the rudder signal channels to be used to operate another control servo under these conditions. This would enable aileron control to be added with a 6-channel system, for example.

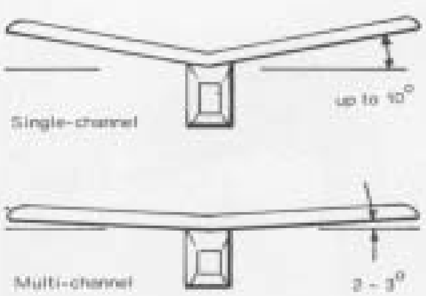
Again a throttle-limit position would be chosen for decoupling one control (e.g. aileron) and switching over to the other (e.g. rudder) actuator. Full throttle would be best. Aileron control is then available at anything less than full throttle-setting, and rudder control only at full throttle.

Rudder control is then available for take-off (full throttle). Once airborne the throttle is eased back just sufficiently to decouple rudder, switching over to aileron for the turn control.

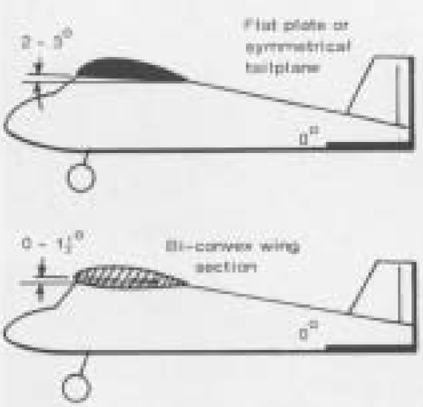
Decoupling obviously has its limitations. It is no substitute for 'full house' coverage, only a means of extending possible coverage with limited channels available from the radio equipment. It is a better working system than *coupled* aileron and rudder, however, which is an alternative method of including aileron as well as rudder control with limited radio coverage.

Widely favoured layout by European designed for 'multi' aircraft working with 6-, 8- or 10-channels.

The same model mounted on floats. A more exacting type to fly, and far better on proportional controls.



12.3 Difference in dihedral requirements between single-channel and multi-channel aircraft design.



12.4 Single-channel aircraft (top) need positive wing rigging incidence. Multi-channel aircraft (below) need small to zero wing incidence for maximum response to controls.

Model design

Rudder-engine speed-elevator-aileron control together make a model aircraft 'pilotable' all the time in flight, particularly if elevator trim control is also available. Not only does this mean that the model is more manoeuvrable, particularly as regards aerobatic performance, but there is less necessity for the model design itself to possess inherent stability. In fact, built-in stability is detrimental to aerobatic performance and can even make the model more difficult to 'pilot' all the time.

The design of multi-channel aircraft can thus differ from that of single-channel aircraft. The most notable feature is usually a considerable reduction in dihedral, one of the most powerful stabilising factors in a free flight or single channel design, but the one which decreases manoeuvrability.

Because the flight control movements are still 'bang-bang', and response can only be smoothed and varied by 'blipping' the control signal, some margin of inherent stability is still required in the design. Most of the early multi aircraft retained the high wing layout because of its better inherent stability, although suitable low-wing layouts were later developed and generally favoured for aerobatic performance.

In general, however, the low wing model remains a trickier proposition to design, and pilot, with multi-channel controls. Similar limitations apply to scale models, which also generally have a low reserve of inherent stability (and in some cases little stability at all).

Limitations on model design imposed by the operating nature of 'bang-bang' controls—or on the ability of the pilot to maintain control over a marginally stable model in flight—have now almost entirely disappeared with the replacement of 'bang-bang' controls with proportional controls, capable of providing *complete* coverage of control requirements.

True proportional control has virtually replaced all other systems of radio control, with models reaching the ultimate in performance. This is an example of a modern aerobatic design.
Photo Radio Modeller.

13 PROPORTIONAL AIRCRAFT CONTROLS

Proportional controls provide infinitely variable positioning of control surfaces (or movements), the degree of movement corresponding to the amount of movement (i.e. in exact proportion to the movement) of the control stick(s) on the transmitter. Again two types of servo movements are available: *self-centring* for the operation of main flying controls, and *progressive* for throttle movement. In the former case the control stick is spring biased to return to its central position. Releasing the stick thus automatically results in the control self-centring. Sticks controlling progressive movements are braked, so that they remain in the position to which they have been moved. In other words exactly the same type of servo can be used for either type of movement (a standard proportional servo). It is the mechanical action of the transmitter control stick (whether spring self-centred or braked), which determines whether the servo action is self-centring or progressive.

Proportional controls offer a further bonus in that a separate *trim* facility can also be provided through the same controlling channels. Thus whilst one signalling channel is used to control each servo, each separate signalling channel can provide both proportional and trim movements on that single servo. A trim facility is not necessary with a progressive servo and so this additional function would not normally be provided on the transmitter channel allocated to operate a progressive servo (e.g. throttle control).

Proportional controls are best described by the number of *functions* they can perform, rather than the number of signalling channels (as is

Proportional has also made true-scale models a practical proposition for flying under radio control.

Proportional transmitters are invariably associated with 'joystick' type control movements—upward movement controlling one service and sideways movement a second service. Both controls can be operated simultaneously. Each movement is also associated with a separate trim control.

done with multi-channel equipment). Thus single function or I-function proportional offers proportional working of a single proportional servo; a 2-function system independent, and simultaneous, working of two proportional servos; a 3-function system independent, and simultaneous, working of three proportional servos; and so on. Proportional systems can also be described as 'single-proportional', 'dual proportional', and so on, referring to the number of separate proportional services (servos) provided.

In certain designs of transmitter-receiver combinations an additional single-channel control may be included, capable of separately controlling a single-channel actuator. This is normally designated by '+I'. Thus 'I+I' designates a system offering 1 proportional plus 1 single-channel service; '2+I', two proportional functions plus 1 single-channel service, and so on.

This has the advantage of simplifying the electronics and reducing the cost of the equipment whilst providing an extra function which can be used for a non-critical control service. Rudder, elevator, ailerons and throttle, for example, cover the complete control requirements of a model aircraft. This is a four-function system, which would require the use of 4-function proportional radio. However, the same coverage can be offered by '3+I', employing the three proportional functions for the main flight controls (rudder, elevators and ailerons), and allocating the '+I' function to operate throttle on a sequence basis, as with single-channel working. The disadvantage of this system is that only 'change-over' of throttle position is available, not progressive throttle movement.

Another modern type of model is the pylon racer—racing two or more at a time at low altitude around a special course.

1-function

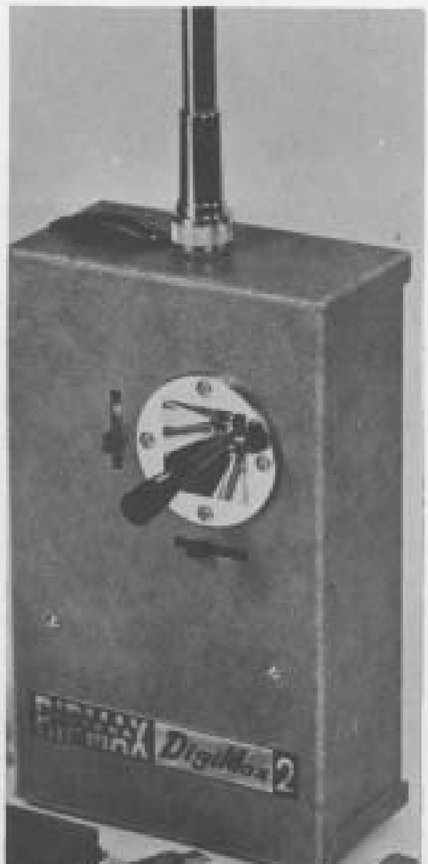
1-function proportional provides the same control coverage as simple single-channel—i.e. rudder-only-control, with the advantage that the amount of rudder movement can be selected at will. The trim facility can also be used to trim out the model for straight flight.

The type of servo used must be self-centring, and the model must possess sufficient inherent stability to recover its normal flight path when rudder control is released, so the system would appear to offer little more than simple single-channel rudder-only control, except for the facility of varying the amount of control by stick movement rather than 'blipping' the signal. And this is only obtained at the expense of considerably more costly radio equipment.

In practice the difference is considerable. The degree of control offered by proportional rudder movement is vastly superior to 'bang-bang' rudder movement. A model is simpler and easier to fly and certain manoeuvres, particularly S-turns to simulate a shallow dive, are readily accomplished.

'1+1' equipment also makes it possible to add throttle control on a powered model; or elevator trim control on a glider. The latter can be a one-position trim ('up' or 'down'), or three-position on the lines described in Chapter 12. A limitation with most '1+1' systems, however, is that when the '+1' signal is being held the main (proportional) function may be locked out (i.e. stay in the position it was when the '+1' control button is pressed), or alternatively return to neutral.

Typical 2-function transmitter with single control stick. Note the separate trim controls for each function.



2-function

Two-function proportional offers control over rudder with a choice of proportional control of either elevator or throttle in the case of powered model aircraft. There are arguments in favour of either choice. Rudder plus throttle is probably the easiest and safest combination for general use. Rudder plus elevator can give more scope for aerobatics, although placing more responsibility on the pilot since the model will be flown at full throttle all the time. Ailerons may be considered as an alternative to rudder in some cases, and also the possibility of using coupled ailerons and rudder (see Chapter 12).

A '2+1' system virtually allocates the two proportional channels for rudder and elevators, with the '+1' function controlling motor speed on a changeover basis.

A 2-function system provides adequate control for gliders, allocated to rudder (or ailerons) and elevator. If a '+1' function is also available, this can be allocated to operate spoilers or flaps.

3-function

The 3-function outfit provides adequate coverage for powered aircraft via rudder, elevators and throttle—this being the preferred choice. There is also the possibility of applying decoupling to the rudder servo to add aileron control. Thus the rudder servo circuit is switched in only at full throttle position, and used for take off. Once airborne the throttle can be backed off slightly, opening the rudder servo circuit switch to decouple this service and switching in the aileron servo.

A '3+l' outfit offers complete control coverage, the three proportional channels being allocated to rudder, elevators and ailerons, and the '+l' function to throttle changeover.

4-function

This offers complete functional control coverage for aircraft, with proportional rudder, elevator and ailerons (and trim on each), plus fully variable throttle positioning. Additional secondary services can be derived, as necessary, by mechanical coupling (as described in Chapter 13), or 'limit switching'.

5-function and 6-function

Proportional equipment is also produced offering more than the four functions necessary for complete functional control of powered aircraft. These additional functions are not necessarily proportional, however. They are of value for independent selection and operation of ancillary services or controls which may be required. For example:

Undercarriage retraction and extension to reduce the drag of the model in flight and thus improve its speed performance or aerobatic capabilities.

Flap operation to reduce speed during approach and landing, and making precision landings easier. Flaps can also be used in flight to assist certain manoeuvres.

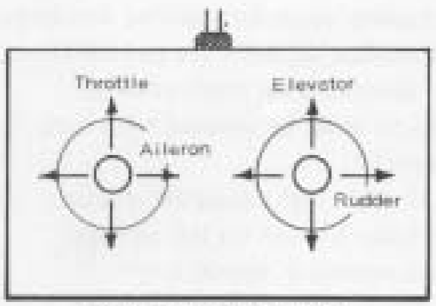
Special duties such as camera operation for taking in-flight photographs; parachute release or bomb dropping or other 'display' items, etc.

4- and 5-function outfits are the most popular for powered aircraft. 2- and 3-function proportional is basically restricted to gliders and model boats.

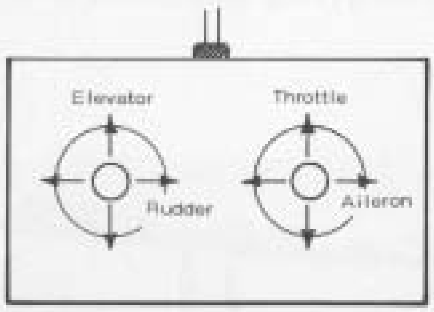
Similar possibilities arise from 'switching' secondary service actuators into movement at 'limit' positions of another actuator (or combination of two actuator positions), as already described for multi-channel controls (Chapter 13). Coupling positions must be selected with care, however, to avoid unacceptable response(s).

Whatever the projected coverage, all main flight controls–rudder, ailerons, elevators and throttle–must have first call on the services available (i.e. taking up four functional controls). Remaining functions available can then be allocated in order of merit, putting performance first. Direct command is always better than indirect or 'coupled' command.

No substitute for 'proportional' if you want to fly models like these in safety!



MODE 1 ('Throttle Left')



MODE 2 ('Throttle Right')

13.1 Transmitter modes.

Different type of joystick controls favoured by leading German proportional manufacturers (Grundig).

Transmitter modes

It has already been mentioned that the transmitter controls are invariably in the form of pivoted sticks. Stick motions are arranged to provide natural control movements. Thus a 1-function transmitter, which would only be used for rudder (or aileron) control on an aircraft would have a side-to-side movement, spring centred.

A 2-function transmitter may have one or two sticks. A single stick would have universal movement, sideways for rudder and up and down for the second control. If the second control is throttle, then the corresponding movement would be braked (not spring-centred). if required for elevator control, it would be spring-centred on both movements.

The same principle applies if two sticks are used. The rudder control stick would have a side-to-side movement, spring centred. The second stick would have an up-and-down movement, braked or spring centred, as appropriate.

3-function transmitters normally have one dual-axis stick, spring centred (controlling rudder and elevators); and a second stick with an up-and-down movement braked, for throttle control. This would need to be modified for gliders (or power models adopting elevator instead of throttle control), so that the second single-movement stick had a side-to-side action, spring centred. Allocation is then largely arbitrary. Some pilots prefer rudder and elevators on one stick; others ailerons and elevator on the one stick. The former is more logical for gliders, and the latter for power models.

4-function transmitters normally have two dual-axis sticks, the vertical movement of one being braked for allocation as the throttle control. This can be on the left or right hand stick, depending on personal preference or choice. Again there are alternatives for the allocation of the other control movements, usually referred to as *modes* to provide a standard reference.

Mode I allocated the right hand stick for rudder and elevators; and the left hand stick for ailerons and throttle.

Mode 2 allocates the left hand stick for rudder and elevators and the right hand stick for ailerons and throttle.

These are the usual alternative configurations adopted by manufacturers, and the classification can also apply to any 2-stick arrangement (regardless of the number of functions). Another popular description is 'throttle left' (Mode I) and 'throttle right' (Mode 2).

Certain proprietary equipment may also vary the type of control levers, e.g. using sticks only for main flying control movements and employing a separate lever for throttle control.

Trim controls are normally in the form of 'wheels' located alongside the appropriate movement, readily operated by a thumb or finger. A '+I' function, where included, is normally pushbutton operated.

The only real significance of the allocation of transmitter controls (or transmitter mode) is that piloting becomes instinctive and, once learnt with a particular arrangement or transmitter controls, has to be re-learnt to some extent if a change is made to another mode.

The majority of proportional transmitters follow a layout like this, with twin joysticks. Meter indicates RF output and state of batteries.

Another typical proportional outfit with transmitter, receiver, battery charger and alternative servos.

With proportional control models can be piloted and kept under full control all the time they are in flight. This opens up considerable scope in both design and performance possibilities. Photo Radio Modeller.

14 OPERATING PROPORTIONAL

Proportional radio control equipment is invariably operated 'as is'. The transmitter-receiver combination invariably incorporates a superhet receiver, which is pretuned and aligned. No tuning adjustments are necessary—nor should they be attempted—and thus a range check virtually implies nothing, except to give confidence that the equipment will work at range. If the range proves inadequate, there is virtually nothing that the average owner can do about it, except to eliminate the obvious cause—run-down batteries. Faulty equipment—or suspected faulty equipment—has to be returned to the manufacturer or approved servicing agent for checking and rectification as necessary.

Built-in faults do, however, commonly occur, the cause being binding or jamming mechanical movements which apply a braking action to the servo output movements. These *must* be eliminated, and recommended procedure with a completed installation is to temporarily disconnect the mechanical linkages at the servo end and operate all the servos in turn via the transmitter controls, listening carefully to the noise of each servo. This is then repeated with the control linkages attached, and the servo noise compared. Any appreciable change in servo operating speed, shown by a marked change in noise of operation, indicates excessive friction or load on that particular linkage. The cause should be traced and cleared.

This preliminary check-out should, of course, also be used to confirm that all the controls are working in the required mode, i.e. that rudder stick movement does give rudder control response, and so on. Operation can be checked initially with the motor off, and then again with the engine running. Vibration and 'noise' can cause faulty operation if servos are not properly mounted and metal-to-metal contact is involved in mechanical movements.

The only pre-flight check necessary is to confirm that all the control movements are available with the engine running.

All trim controls are normally set up to correspond to true geometric neutral positions (with the exception of throttle, where the separate 'trim' function is not used). Neutral control positions with the 'trim' control movement also in the central position on the transmitter will give maximum trim movement in either direction for in-flight corrections of trim, as necessary.

It is a characteristic of many proportional outfits, however, that the neutral position of the servo is subject to drift with small changes in battery voltages. The initial voltage of fully charged nickel-cadmium accumulators will be slightly higher than the normal, and substantially constant, load voltage, which can cause the servo to drift slightly off neutral, and return to normal neutral after a minute or so. Neutral drift may then tend to occur again as the battery voltage approaches the point of rapid fall-off in voltage. This can only be avoided by avoiding running the batteries down to this state. Initial servo drift, if present, can be ignored and trim re-adjusted in flight to compensate for the subsequent change to normal neutral; or worked off by leaving the receiver installation switched on for two or three minutes before starting the flight. This will allow sufficient on-load time for the battery voltage to stabilise at its normal value, and give a normal and constant neutral position free from any further drift.

The most likely cause of operational troubles, or faults, developing in a proportional control system are as follows, in order of likelihood:

(1) Pilot error, especially in the case of aircraft where the model has to be controlled in three dimensions. R/C boats and cars are also subject to 'pilot error', although the consequences are not usually so drastic.

(2) Poor installation, such as:

(a) Receiver badly mounted, with insufficient foam rubber isolation.

(b) Mechanical movements which are binding or jamming, the cause of which can be traced and eliminated in a preliminary check as described above.

(c) Servos badly mounted so that they can move and modify mechanical output movements.

(d) Tight or poor wiring, which can produce disconnection(s) under vibration, etc.

(e) Discharged batteries (see Chapter 21).

(f) Electrical 'noise' generated by mechanical movements, which can be cured by bonding or insulation.

(g) Receiver or servo circuit faults. These are comparatively uncommon in proportion to other possible faults, but they can occur, particularly if the equipment is abused.

(h) Outside interference. Even superhet receivers are susceptible to interference by spurious transmissions spanning the spot frequency of the crystal controlled transmitter-receiver link. Spurious signals can show up as involuntary (unsignalled) control movements, popularly known as 'glitches'. The presence of spurious signals cannot be eliminated, but receiver circuits can be designed to suppress or minimise their effects on an 'interference rejection' basis. Some receiver circuits are particularly good in this respect, others less so.

Suspected receiver or servo faults can be checked out on a 'substitution' basis. A servo may fail to centre, or be sluggish in centring,

A really exciting type of model to fly is the pylon racer—fast and designed to perform sharp turns. Not all pylon racers are flown with full control coverage.

Orthodox low wing layout, preferred for aerobatic flying. Modern designs tend to be sleeker.

when all the linkages involved check as satisfactory as regards friction. The fault is thus electronic rather than mechanical. A simple check is to unplug that servo and plug in a servo from another service. If the fault is still present, then it is the receiver circuit which has the fault. If the fault disappears (i.e. the substituted servo works normally), then the fault is in the original servo circuit. Note that the fault may be in the circuit or the unit involved. For example, it may be a fault in the receiver or servo; or in the wiring between receiver or servo and the respective plugs and sockets completing the connection between the two; or in the plugs and sockets themselves.

Note that this method of substitution can be used for both ground and in-flight checks. In the latter case, if the fault occurs in a main control service, a servo from a secondary service can be substituted by changing over plugs. Thus throttle control, for example, could be sacrificed to check out a rudder servo, limiting the engine run by reducing the amount of fuel in the tank and presetting the throttle to a suitable position for safe flying. Alternatively the pilot may prefer to sacrifice aileron control to check out the rudder servo. It is generally advisable to leave the suspected faulty servo unplugged rather than couple this to the 'sacrificed' service in order to maintain some degree of movement of this service. If the fault present is one which is in the nature of a short circuit, drawing high current, the batteries could be rapidly run down.

Faults isolated as occuring in the receiver, or a particular servo, require that the unit be sent back to the manufacturer, or specified service agent. The same applies to servos which are suspected of developing a fault, e.g. continue to operate normally but are developing a rough noise when operating.

The high wing layout still makes a good 'trainer' for learning to fly proportional. Beginners can go straight to proportional models—but the best method of learning to fly is to be taught by an experienced pilot.

Photos: Radio Control

Photos: Radio Control

Semi-scale model using sheet balsa construction. Rudder, split elevons and throttle control. Photo Radio Modeller.

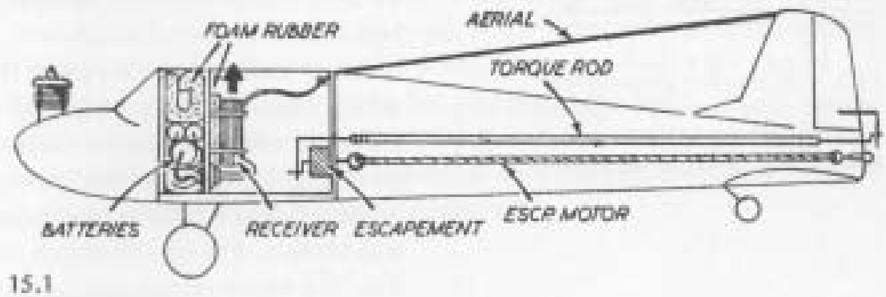
15 AIRCRAFT INSTALLATIONS

A complete installation involves the following items:

Receiver	These items are interconnected
Batteries	electrically by wiring, usually
Main on-off switch	employing plugs and sockets
Actuator(s)	

Mechanical linkages connecting the actuator output movement(s) to the appropriate control(s).
Movable controls e.g. hinged rudder, elevators, aileron, motor throttle arm.

Receiver and batteries are normally fitted into the forward part of the fuselage. The batteries should be mounted *in front* of the receiver, so that in the event of a crash they cannot be projected forwards to



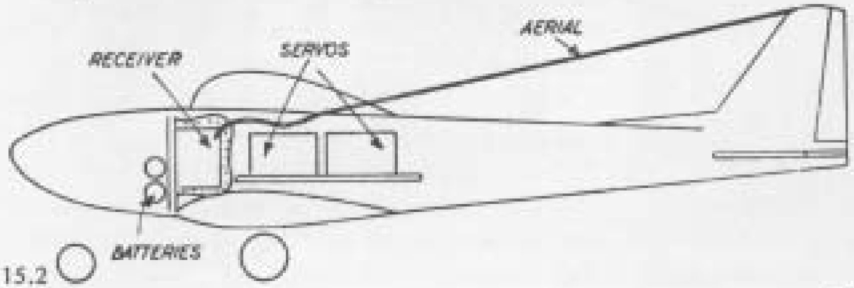
15.1

strike the receiver and damage it. The receiver should thus be mounted behind the front main bulkhead; and the batteries in front of this bulkhead, rigidly supported against displacement in a forward direction. *Figures 15.1 and 15.2* show typical installation positions.

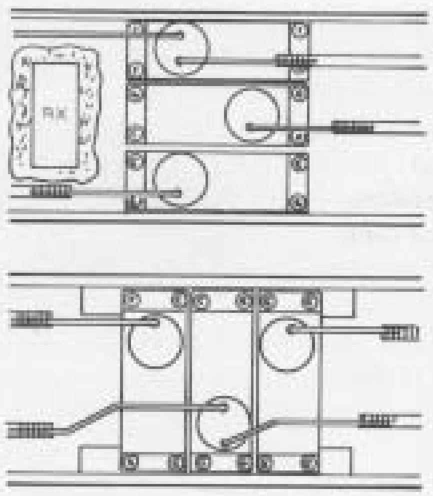
Batteries are rugged and can be fairly rigidly mounted. They should be strapped together with insulating tape or servo tape to form a single 'pack', which can then be wrapped in foam rubber and slid into a matching size compartment, so formed that they cannot move or drop out. Any movement could strain, and possibly break off, wires connecting the batteries to the rest of the circuit.

In the case of nickel-cadmium batteries, battery installation can be 'permanent', wiring to a socket mounted in the fuselage side for plugging in a charger. If it is preferred to remove the batteries for recharging, or dry cells are used which must be replaced frequently, access must be available to the battery compartment for battery removal and replacement.

The receiver is normally fitted with a rectangular metal case. This can be wrapped round with foam rubber held in place with rubber bands. To improve 'isolation mounting', the compartment into which it fits



15.2



15.3 With modern proportional control, three servos are installed in an aircraft fuselage. Mounting can be side-by-side, or across, as shown.

Typical installation with servos mounted on tray. Note foam packing around receiver; also control linkages.

can also be lined with foam rubber. The fit should be tight enough to prevent movement of the receiver, or dislodgement in the event of a crash, but not so tight that the foam rubber is unduly squashed and its vibration isolation properties impaired. Whether the receiver is mounted vertically or horizontally is largely immaterial, except in the case of reed type receivers (see Chapter 9).

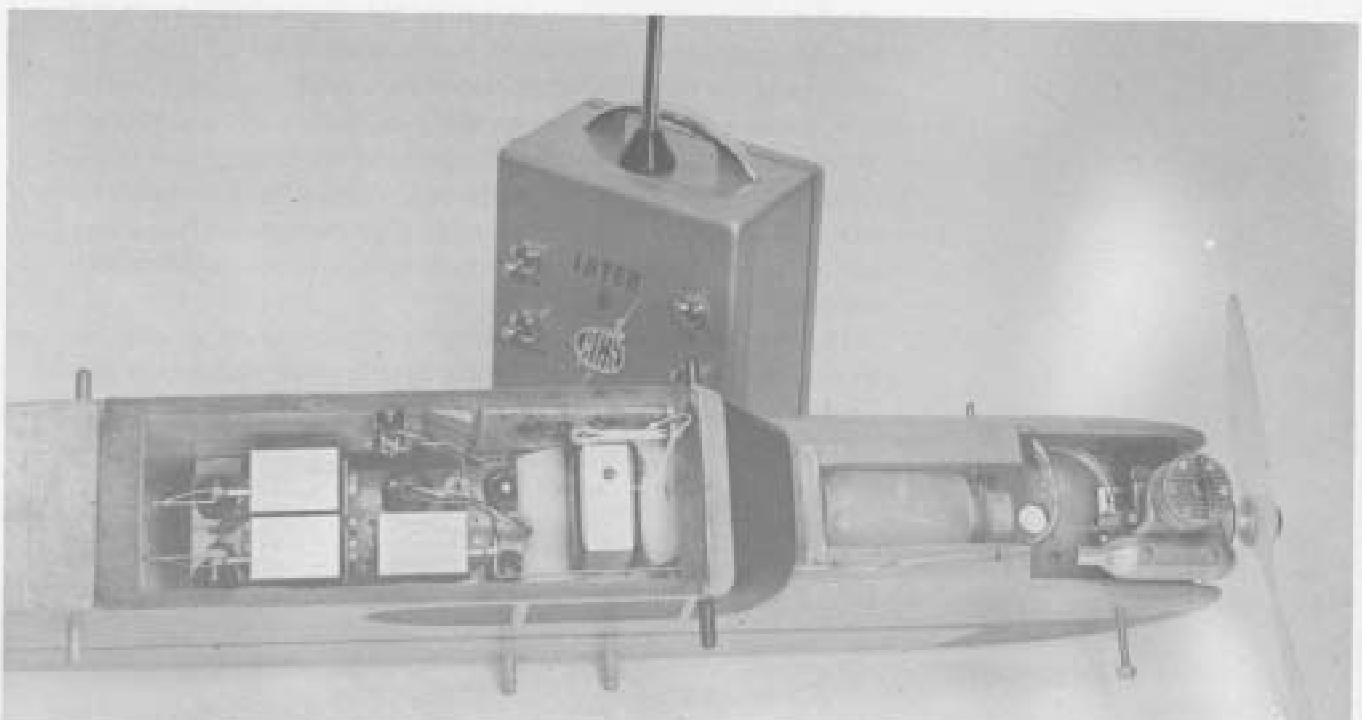
Actuators are mounted behind the receiver, the manner of mounting differing whether escapements or motorised actuators are involved. Detailed requirements are described under separate headings, following.

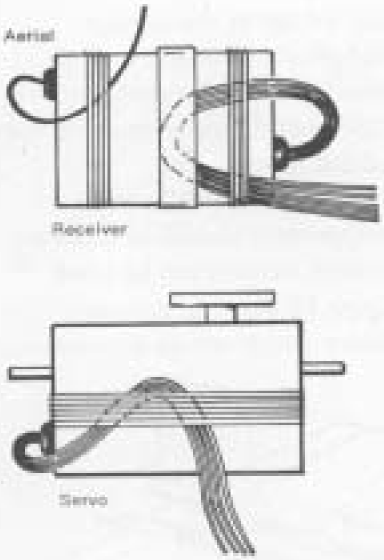
The main on-off switch can be mounted on the side, top or bottom of the fuselage. The main requirements are that it should be easily accessible (but not in a position where it can be accidentally knocked on or off); and also located in an area shielded from the exhaust of the engine on a powered model.

Some modellers prefer to fit the on-off switch inside the fuselage where it is completely protected from dirt, oil and moisture, with the movement operated by an extension arm—such as a length of wire emerging through a rubber grommet in the fuselage side.

Most modern proprietary radio control units are prewired to plugs and sockets. The on-off switch is preconnected to a wiring harness and thus the whole system can be connected up simply by plugging together. This is to be preferred to integral wiring as it enables individual units in the system to be unplugged and removed, if necessary, without having to unsolder wiring connections.

All wiring runs should be left with plenty of slack, but cabled together and then *secured* at suitable points (e.g. at intervals to the fuselage side, leaving a generous amount of slack at the ends of wiring runs.) Taut wiring can cause connections to fail under vibration.



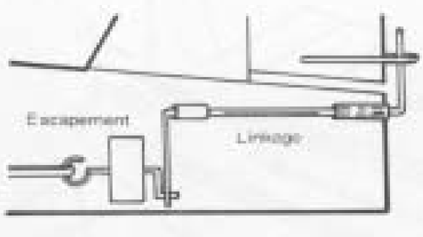


15.4 Lashing wiring to receiver or servo case is strongly recommended, leaving a loop of slack.

Unsupported runs, or excessive end slack, can also cause premature failure of connections due to movement eventually causing a wire to become brittle and break. For that reason wiring emerging from individual units, including the on-off switch, is best supported by binding to the unit, leaving a nominal amount of slack as shown in *figure 15.4*. Some modellers also prefer to bind plugs and sockets together as well, e.g. with cotton, to prevent any possibility of accidental separation and disconnection of the circuit. This should not be generally necessary with tight-fitting miniature plugs and sockets.

The aerial wire normally emerges from the receiver case at a different point to the main wiring. Again it is advantageous to bind the aerial wire to the case, leaving a loop of slack. It should then be taken through the fuselage side, or top, in a direction at right angles to, or at least away from, all current carrying wires; and thence usually back to the top of the fin. A knot at this point, through which a pin can be passed to secure the wire to the fin, completes the aerial installation, leaving any remaining slack wire to trail. An alternative arrangement sometimes adopted is to take the aerial wire through the bottom of the fuselage and then glue along the bottom.

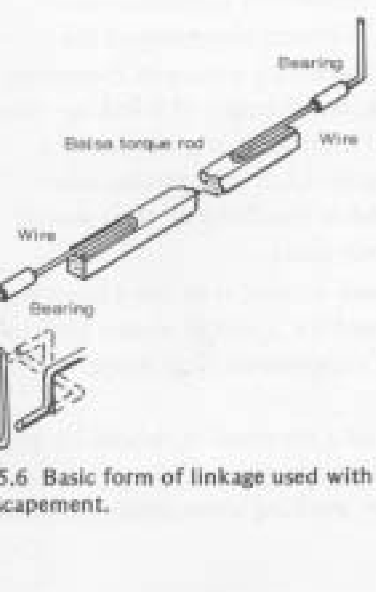
Escapements



15.5 Example of rear-end mounting of an escapement.

Escapements are normally mounted on a vertical bulkhead or sub-bulkhead in the centre section of the fuselage. This provides a reasonable length for the rubber motor driving the escapement. The longer the rubber motor length the more turns it can take, and thus the greater number of escapement actions which can be stored by a single winding. Forward positioning of the escapement is also preferred since although this needs a long linkage to connect to the rudder movement, the other end of the rubber motor is in a position where it is readily accessible for winding. Also the weight of the escapement is kept well forward, helping balance the model.

With a lightweight escapement, and a larger model, mounting the escapement well aft to simplify the rudder linkage may be attractive. Such a system is shown in *figure 15.5*.



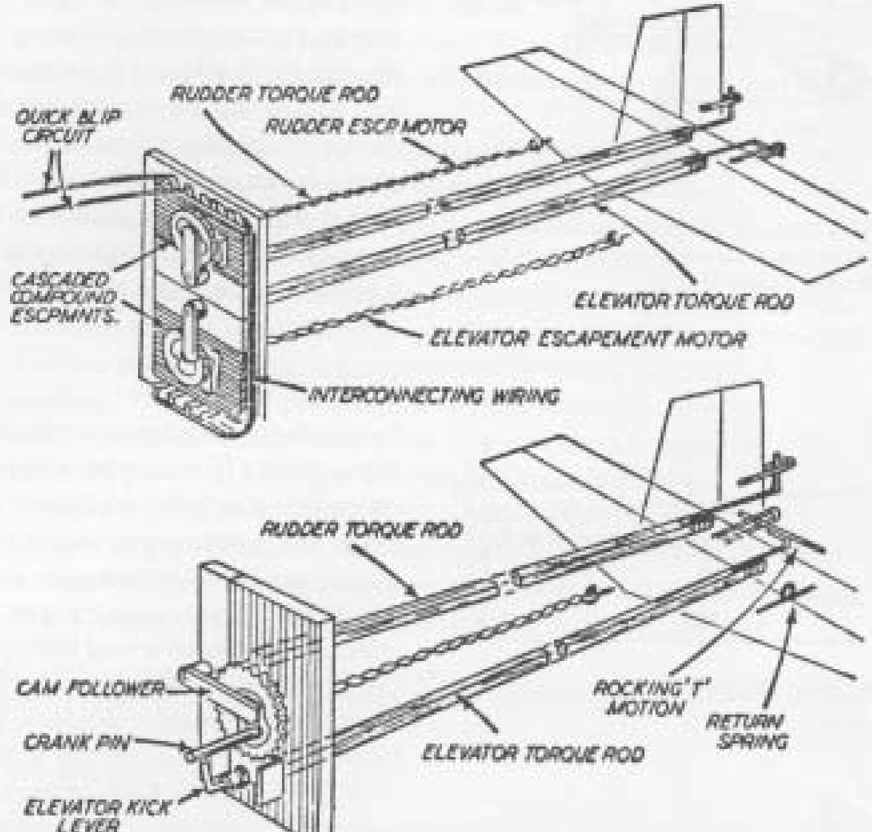
15.6 Basic form of linkage used with escapement.

Escapement output movement is derived from the cranked end of the escapement spindle, sideways motion of the crank being transformed into rudder movement by the type of mechanical linkage coupling shown in *figure 15.6*. Metal wire is used only for the ends of such linkage. Wire end fittings are bound to a rigid section torque rod of light material, usually balsa strip about 3/16 in. or ¼ in. square, as shown. The weight of such linkage is carried adequately by two simple tube bearings, one at each end. The system is light and rigid, both axially and torsionally. Alternatively proprietary linkages can be used instead of a balsa torque rod, fitted with matching ends, or shaped wire ends. Metal torque rods should be avoided for long runs, however, because of their weight and the possibility that they might bow.

An escapement for driving an elevator movement can be mounted in a similar manner, e.g. immediately below the rudder escapement, with its own escapement motor and torque rod linkage to the elevator movement. Note, however, that a 'kick elevator' movement may be derived from a single compound escapement of suitable type (see Chapter 6). In this case only a single escapement motor is required, but two torque rods with their respective end linkages.

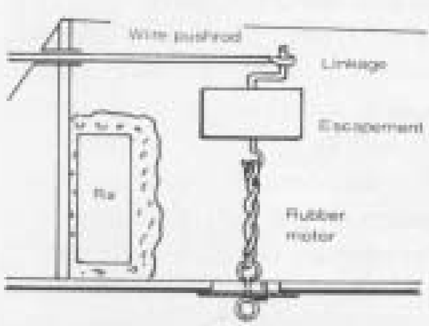
The use of an escapement for driving a throttle control present a rather different problem. Logically the escapement should be mounted horizontally (crank axis vertical) so that crank motion can be taken directly forward as a push-pull action (*figure 15.8*). This, however, seriously restricts the length of rubber motor which can be accommodated within the fuselage, and thus the number of throttle control motions possible from a single winding. Vertical mounting of the escapement is thus usual, obtaining the necessary push-pull movement from a bellcrank or similar type linkage. An example of a linkage system which can be used to produce push-pull motions in a plane at right angles to the crank axis are shown in *figure 15.9*. It is particularly important that where bellcranks are used in this fashion, they should be rigidly mounted, but very free on their pivot.

15.7 Two examples of special escapements with 'kick elevator' action and linkage to rudder and elevator.

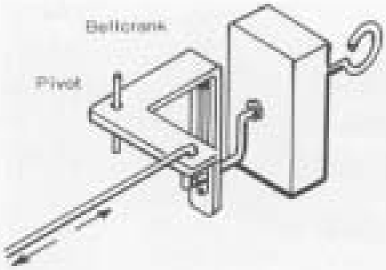


An alternative solution for motor speed control is to use a clockwork escapement which dispenses with the need for a rubber motor to drive the escapement. This particular type of escapement is no longer manufactured in any quantity, however.

Escapements are generally mounted on a plywood bulkhead (or ply panel cemented to a balsa bulkhead), bolted in place. The nuts should be locked with adhesive to prevent them working loose under vibration.



15.8 Vertical mounting of secondary escapement for throttle control limits length of rubber motor and number of turns which can be applied.



15.9 Output movement derived from pivoted bellcrank.

1/16 in. plywood is thick enough for small models, but 3/32 in. ply would be preferred for larger models. The bulkhead should also be braced to the fuselage sides with ¼ in. square balsa strips on each edge, both to prevent the bulkhead breaking loose in a crash and to resist the pull of the wound rubber motor. The rubber motor comprises a single loop (two strands) of either 3/16 in. or ¼ in. flat rubber strip, depending on the type and size of the motor.

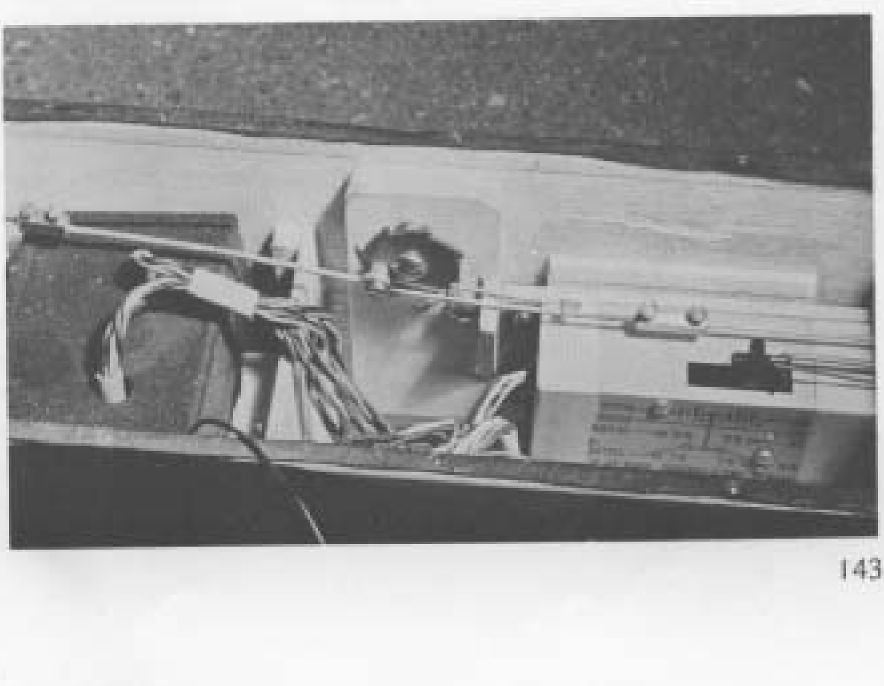
The number of turns such a motor can be expected to accommodate is:
3/16 in. rubber—60 turns per inch of motor length
¼ in. rubber—50 turns per inch of motor length

Thus a 12 in. long loop of ¼ in. rubber would take 600 turns. At least 80 per cent of these can be regarded as 'usable' for powering the escapement, giving in this case 600 rotational movements of the escapement.

Two strand motors will actually take a greater number of turns than those given above without breaking. However increasing the number of turns beyond a given point will greatly increase the stored torque and can lead to inconsistent operation of the escapement by causing the movement to bind or stick. For the same reason an escapement designed to take a 3/16 in. motor should not be used with a ¼ in. motor in an attempt to get more control operating force out of it.

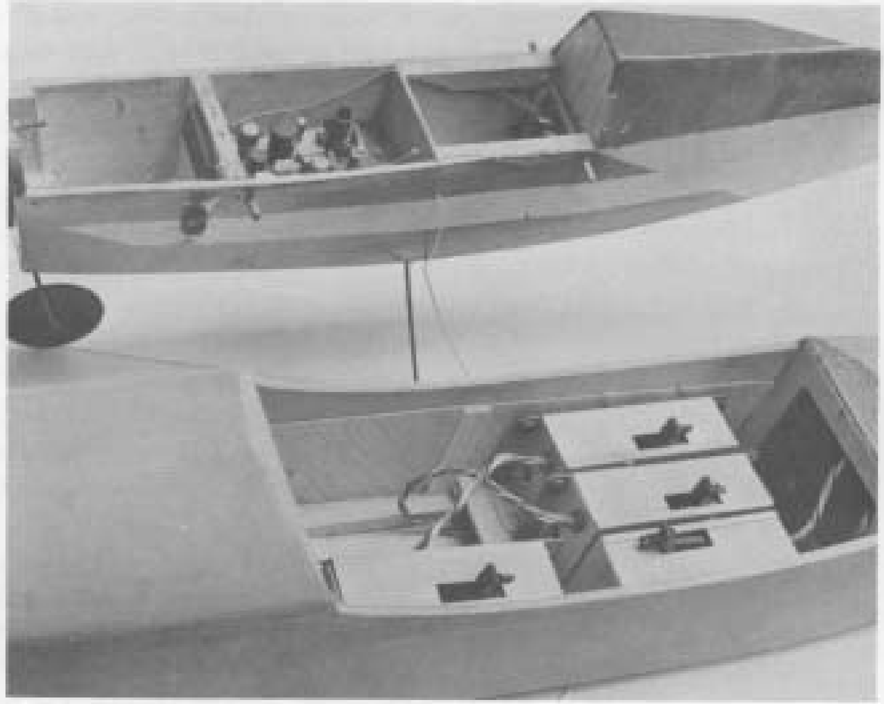
Motorised actuators

Motorised actuators are generally much easier to mount since they are usually in the shape of 'boxes' with mounting lugs on the base, or face. Linkage hook-up is also simplified since the mechanical output is in the form of a disc or arm with rotary or semi rotary movement and it is relatively simple to align this movement with the plane of motion involved. Simple rigid linkage can then be used to transmit the push-pull action.



Servo installation and special linkage for 'coupled' control.

Side-by-side installation of servos is practical with most modern slim servos. Single-channel and multi installations compared.



The mounting and coupling up of single-channel motorised actuators, multi servos and proportional servos all follow the same principle, and generally employ similar linkages. Because of their relatively high weight (a motorised actuator can weigh more than a receiver), servos are invariably positioned at or near the centre of gravity of the aircraft, i.e. in the fuselage mid-section. Where several servos are involved, this means that they should be grouped together. At the same time they must be positioned to provide straight runs for the mechanical linkages they drive, in order to avoid binding and, or, 'lost' movement.

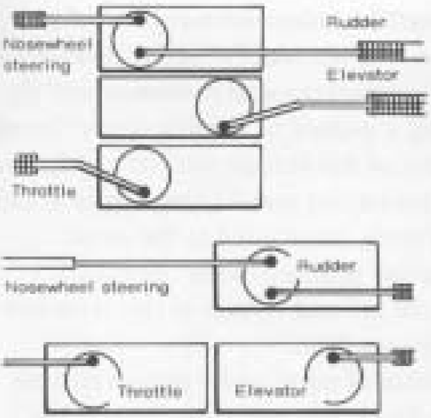
This consideration produces logical grouping for servos:

(1) with 'fore and aft' grouping, servos should be on the side nearest the control they operate. Thus elevator and rudder servos can be mounted side by side at the rear, and the throttle servo in front in a group.

(2) Push rods operating separate controls should be as widely separated as possible to avoid possible 'collision'. This can affect the optimum position of the rudder servo in a group where this also drives nosewheel steering.

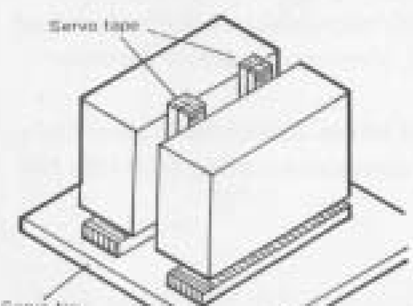
Typical examples of grouping are shown in *figure 15.10*. The aileron servo is not shown since this is almost invariably mounted in the centre section of the wing.

Once satisfactory grouping has been worked out, actual *positioning* depends on balance requirements. The weight of up to three servos (or four in the case of multi installations) can have a considerable effect on the final centre of gravity position. If the model is completely assembled, including batteries and receiver, the servos can be laid on top of the fuselage, or wing, and adjusted fore and aft to balance the model at the design point. If it is impossible to balance the model in this way, then it may be necessary to remove the receiver and try



15.10 Typical servo allocation and linkage arrangement.

15.11 Use of self-adhesive servo tape for mounting servos. Note tape fitted between servos for vibration isolation.



positioning the servos as far forward as possible, with the receiver behind. The positioning of the servos (and receiver, if finally located behind the servos), is then the final one for permanent installation. It is far better to use equipment weight, which has to be carried by the model anyway, to achieve the design balance point than have to add deadweight ballast to achieve the same end.

Servos may be mounted directly by bolting or screwing with self-tapping screws (not wood screws) to hardwood rails secured to, or across the fuselage sides, resilient mounting being provided by rubber grommets. This is lighter than mounting the servos on a plywood tray, which was favoured for multi-channel servos. However, tray mounting is still favoured (particularly as servo sizes have got smaller, and so the size of tray can be reduced). The ply tray can be glued to the fuselage floor, or bolted to ply doublers on the floor using grommets as isolation mounts. Equally the individual servos can be bolted to the tray through grommets, or bonded to the tray with a strip of foam rubber between the servo and tray.

This latter technique is now simplified by the availability of *servo tape*, which is sponge plastic strip material with a contact adhesive on both sides. With close grouping of servos, sponge rubber or servo tape should also be used between the individual servos to prevent them touching each other and also to make the group mounting more rigid. Bonding of individual servos to the sides of the fuselage is a further alternative, using the largest area face as the bonding surface and foam rubber or servo tape for isolation mounting. This is most successful with servos which are rectangular in shape and relatively narrow.

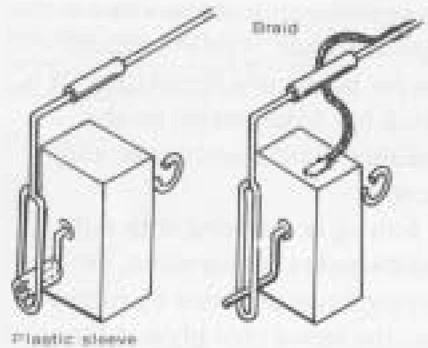
For straightforward bonding of metal (servo case) to foam rubber and rubber to wood etc., contact adhesive is quite suitable. If a servo has to be removed, bonded joints can be cut with a thin, sharp knife, or dissolved away by 'floating' ether over the joint line. Foam rubber, or servo tape, which has been freed by cutting away should not be re-used by coating with contact adhesive as its original uniform thickness will have been destroyed and its vibration isolation properties impaired.

Servos are normally mounted with the output disc or arm on top. There is no reason why, if necessary, a servo should not be mounted with the output disc or arm on the side, and the plane of the linkage adjusted accordingly. In this case the linkage connecting to the servo output *must* be fitted with a keeper.

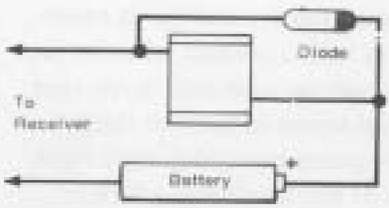
Suppression

The crank arm of the escapement rubbing in the wire yoke transferring the motion to the torque rod is capable of generating an electrical signal or 'noise' which can interfere with the receiver working, particularly as the receiver and escapement are usually close together in a single-channel installation.

One method of eliminating this possible source of interference is to make the yoke slightly wider and slip a length of plastic sleeving over the wire. The crank arm then rubs only against the plastic.

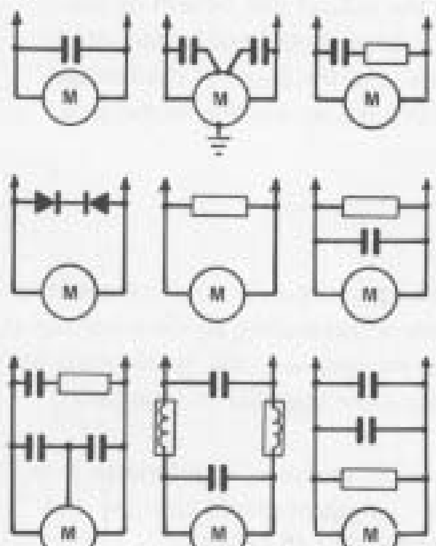


15.12 Two methods of eliminating 'noise' on escapement linkages.



15.13 Method of suppressing a coil with a diode.

15.14 Nine different methods of suppressing an electric motor, using capacitors, diodes, resistors and radio frequency chokes.



Noise may, however, also be generated by the rubbing action of the metal wire in its front bearing, and so a rather more effective method of suppression is to electrically bond the separate metal movements of the escapement. This is done by soldering a 'pigtail' of flexible copper braid between the body of the escapement and the linkage end fitting (*figure 15.12*). This will ensure that all the contacting metal components in the complete front end linkage are effectively maintained at the same electrical potential, and cannot therefore produce 'noise'. Similar bonding should not be necessary at the tail end linkage as this is remote from any magnetic field, and from the receiver.

The actuator coil can also be a source of noise under certain circumstances, although this is not ususal with escapement coils. A probable cure, when this does occur, is to connect a diode across the coil, as shown in *figure 15.13*. It is important to connect the diode the right way round, i.e. the + end or red end to the positive battery side of the coil.

Suppression of motorised actuators

Simple electric motors, such as used to power motorised actuators, are inherent spark-generators at the commutator and thus a source of electric noise which can cause interference with the receiver. It is essential that motors be suppressed; and even then motorised actuators should not be mounted close to receivers, unless this is unavoidable. Some receivers are more sensitive to 'noise' than others, even to the extent of being unsuitable for working with suppressed motorised actuators.

The simplest method of suppressing a motor is usually to connect a capacitor across the motor terminals (or better still directly across the brushes) to act as a spark quench. A capacitor value of .01 to .05 microfarads is generally suitable. Rather better results may be achieved by using two capacitors, one connected to each brush, with the other end in each case earthed to the casing of the motor.

Instead of a single capacitor, a resistor can also be connected directly across the motor to provide suppression. This needs to be of sufficiently high value, relative to the motor coil resistance, to avoid 'starving' the motor of current .47 ohms is a typical value.

In severe cases of motor interference it may be necessary to go to a more elaborate form of suppression, starting with a single capacitor across the brushes, and adding a 70-100 microhenry choke in each lead. A second capacitor can then be added, if necessary, across the other side of the chokes.

Proprietary motorised actuators and servos are normally adequately suppressed, the necessary compressor components being built into the unit.

Retractable undercarriage unit; really a special type of actuator.

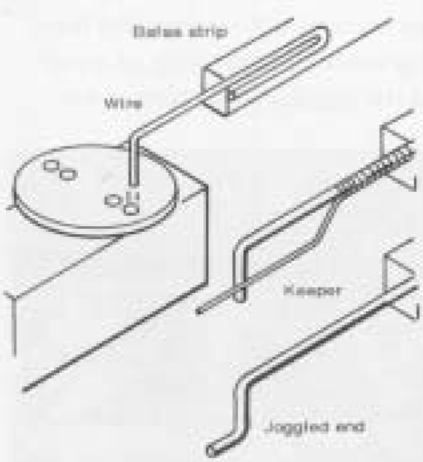
Rudder and elevator linkages

Servos may have a rotating wheel, rotating arm, or sliding arm output motion (see photos). The former two are known as rotary (output) servos, and the latter a push-pull or linear (output) servo. In all cases the linkage to rudder or elevator movement is the same—a rigid rod with suitable end fittings for pivotal mounting to the servo output motion at one end and the rudder or elevator horn at the other.

The rod, generally known as a push-rod, is commonly made of ¼ in., $\frac{3}{8}$ in. or square section balsa strip, depending on the length required. Light balsa of a larger section is to be preffered to a smaller section in hard balsa since it will be stiffer for the same weight. Proprietary push-rods are also available in both metal and plastic, with matching end fittings which usually screw on.

Balsa rods require wire end fittings, bound and cemented in place. For the front (servo end) fitting a simple right angle bend is adequate, with the run of wire resting on the top of the wheel or arm in the case of rotary servos. Piano wire of 16 swg, or bicycle spokes of the same diameter, is the usual material for making the end fittings.

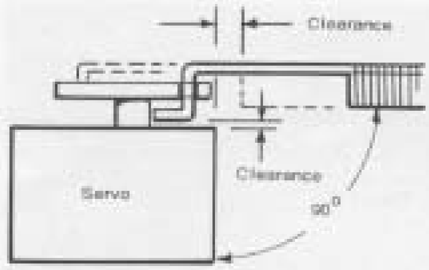
15.15 Wire end fittings for rigid pushrods.



To avoid any possibility of the wire fitting being displaced and dropping out of the pivot hole in the servo drive some form of lock is necessary. There are two simple ways of doing this. The wire can have a double bend of 'joggle' which automatically locks in it place when inserted; or a keeper bent from thinner wire can be bound and soldered to the wire (*figure 15.15*). The latter avoids the practical difficulty of making close right angled bends in stiff wire, and also makes the push rod easier to detach from the servo if necessary.

A variety of proprietary keepers are available, moulded in plastic, designed to clip in place over wire end fittings. These are often used in preference to home-made keepers, and are easy to fit and remove.

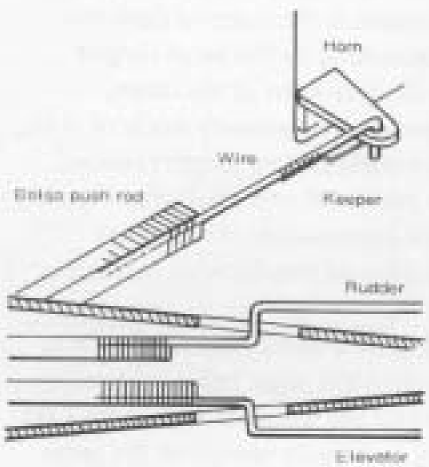
Another example of servo installation showing mixture of rotary output and push-pull servos.



15.16 Alignment and clearances required on linkage at servo end.

The three most important requirements for the front (servo) end fitting are shown in *figure 15.16*. Clearance between the wire and hole in which it is fitted is minimal to eliminate backlash (holes are usually a nominal 1/16 in. diameter, which closely matches 16 swg wire size). To avoid binding the top bend must be exactly 90 degrees, so that the wire moves parallel to the output travel. There must also be adequate clearance between the bottom of the wire joggle, or wire end and the face of the servo. Finally, the wire must be long enough so that in the extreme forward position there is clearance between the end of the push-rod and the servo case. Excessive friction will increase the load on the servo motor, and the current it draws. Motions which can jam up will stall the servo motor, with far more drastic consequences.

The rear (control surface) end fitting is also of wire and similar considerations apply as regards bending the end and providing a lock for it to be retained in the rudder or elevator horn (*figure-15.17*).



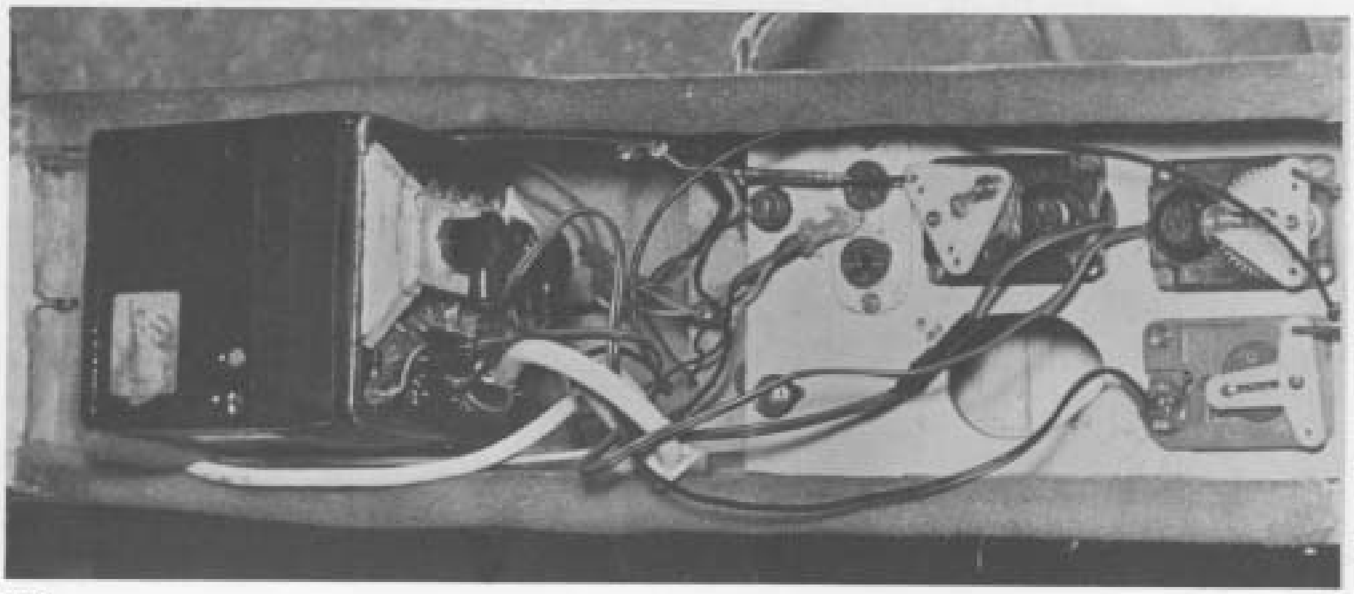
15.17 Typical rear-end fitting.

Wire length will normally have to be longer than that at the front end for the push-rod has to be contained within the fuselage with the wire emerging from a slot in the fuselage side. Thus a kink will have to be bent in the run of the wire to maintain internal clearance for the push-rod and line the end of the wire up with the control horn. This can be an acute- or right-angled kink.

A right angled bend is better in practice for this provides more scope for adjustment of the overall length of the linkage by further bending. Adjustment of linkage length may be necessary both for initial rigging, and also to adjust for any changes in the set-up.

Alternative hole positions are usually provided on both the servo output and the control horn. Alternative positions can be selected at either, or both, end(s) to adjust the amount of push-rod travel. Thus selecting an outer hole on the servo movement will increase the fore-and-aft travel of the push rod, and vice versa: and selecting an outer hole in the control horn will decrease the angular deflection of the

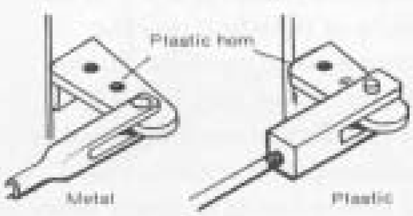
Servos mounted on a ply tray, with plug and socket wiring connections.



Modern proportional servos are invariably pre-wired to a multi-pin plug to connect directly into the receiver wiring harness.

control surface for the same push-rod movement, and vice versa. All clearances for the wire end fittings and the push rod should be based on the combination giving the greatest travel, i.e. the outermost hole positions at each end.

Proprietary end fittings are commonly based on a clevis or forked end, drilled and tapped to screw onto a wire push-rod (*figure 15.18*). The clevis incorporates its own pin and is mounted by springing open. A keeper may also be provided (or the clevis can be bound with thread once in position).

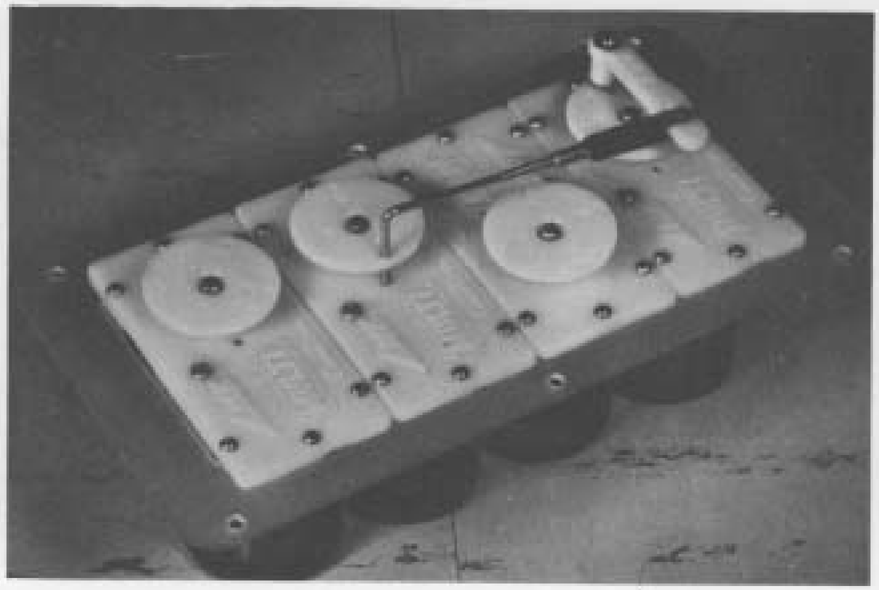


15.18 Horns with typical clevis-type end fittings.

The fact that a clevis is screwed onto the push-rod permits adjustment of the effective length of the complete assembly, by screwing one (or both) clevis end fittings in or out. Metal clevises are usually provided with a nut for locking the adjustment position, but this is not necessary with a nylon clevis. In practice adjustment is only required at one end, and so a fixed clevis can be employed at the servo end of the push-rod and an adjustable clevis at the control end.

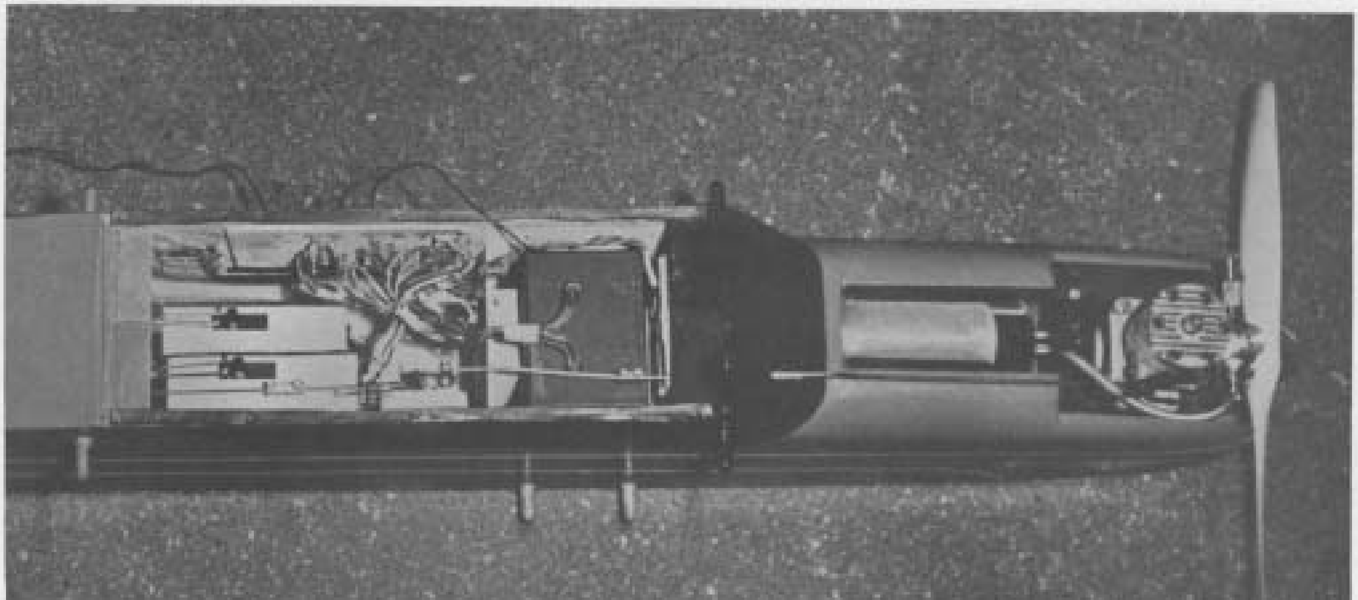
Example of servo grouping, with the two servos on the left coupled to a floating lever for differential or 'trim' movement (not necessary with modern proportional equipment, as 'trim' is available directly as a separate control response).

Four servos mounted side by side in a cut out in a Paxolin panel.



Whilst clevises would appear to provide a better 'engineering' solution than bent wire end fittings they do have certain disadvantages. They cannot, for example, be used on multi or proportionate servos with wheel outputs, unless they are of specially long type to provide the necessary clearance with the periphery of the wheel over the complete fore-and-aft travel. Nor can they be used on single channel actuators with complete rotary movements. A bent wire fitting is preferred, although this does not mean that a clevis cannot be used at the control end. The other, lesser, disadvantage is that clevises only match wire push-rods. A long push-rod in wire can be relatively heavy and also require support along its length by running through simple bearings to prevent bowing. However, clevises can be used with balsa push-rods by binding straight wire end fittings to the balsa rod and tapping these to screw on the clevises.

Typical aircraft installation with 'prewired' servos and plug-together connections.

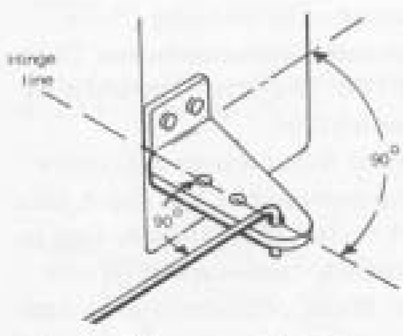


'Noise' and interference

Exactly the same considerations apply as for escapements. Metal-to-metal sliding or rubbing contacts can generate 'noise' and interference. A metal clevis, therefore, should only be used in conjunction with a non-metallic control horn (servo output drives are non-metallic, so the same problem does not arise here). Equally, whilst a plastic clevis (usually nylon) can be used with either a metal or plastic control horn, sometimes a plastic clevis is fitted with a metal pin. In that case it should only be used with a plastic horn.

If a metal horn has to be used (e.g. throttle control arms are normally metal) in conjunction with a metal clevis (or metal clevis pin), the horn can be fitted with a plastic bush to eliminate suppression. Alternatively the linkage can be bonded, as with escapements.

Control horns



15.19 Basic horn geometry and alignment.

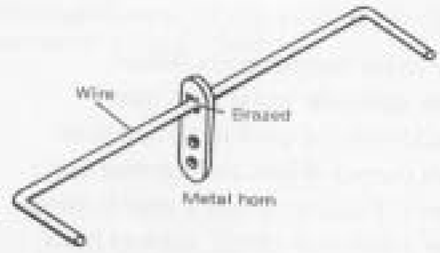
The shape of the standard form of control horn is shown in *figure 15.19*. Detail design differs mainly in the form of the base, through which the horn is bolted or keyed to the control surface. Proprietary horns are usually moulded in nylon, which is the preferred material. Control horns are also produced in metal, and can also be cut from aluminium sheet or ply. Metal horns (particularly aluminium) are generally to be avoided as wear can cause rapid enlargement of the hole carrying the push-rod end fitting, producing a 'loose' movement. Metal horns (preferably in dural) may be necessary, however, where a horn has to be tailor-made to suit a particular application. But, the wide range of proprietary moulded horns available covers most possibilities.

Although a control horn is a very simple device for transferring a push-pull motion into an angular deflection of a control surface, some appreciation of the geometry involved is necessary. For example, for a given push-pull travel about a central (neutral) position, the angular movement will only be the same in both directions if (1) the horn is exactly at right angles to the control surface; (2) the mounting point of the push-rod is in line with the hinge line; (3) the push-pull movement is applied at right angles to the control horn in the neutral position.

A control horn which is raked forwards or backwards, or displaced fore and aft relative to the hinge line, will produce unequal displacements in either direction, or a differential movement. This can be eliminated by making sure that the horn is correctly aligned when fitted. The necessity of cranking the push rod end is also obvious (*figure 15.24*).

15.20 For symmetrical movement, pushrod must be at right angles to horn in neutral position.

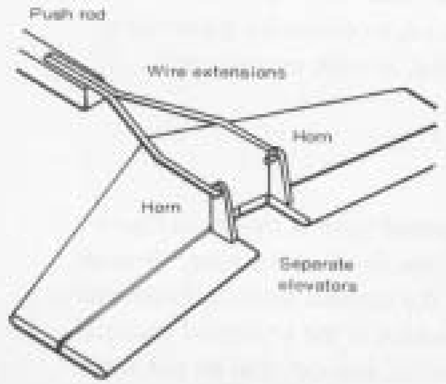
Control surfaces with angled hinge lines present a problem. To avoid the push-rod end correction binding the hole in the horn may have to be made oversize, resulting in slack movement, which is undesirable. For this reason angled hinge lines (swept back or swept forward) are generally to be avoided in design. If they are used, e.g. for aesthetic or aerodynamic reasons, then a special 'universal joint' or ball-and-socket end fitting should be used for connecting to the control horn.



15.21 Horn for split elevators.

Split elevators call for the use of a special type of horn, normally called a split-elevator horn, as shown in *figure 15.21*. The rigid assembly ensures that each elevator has the same movement, but it is important to ensure that half of the elevator is exactly aligned with the other when initially fitting the horn.

A particular problem arises on designs employing split elevators which have sweptback hinge lines. A split-elevator horn cannot be used in this case. Instead each half elevator will have to be fitted with a horn at the inboard extremity, and the end of the elevator push-rod split into parallel lengths, one connecting to each horn (*figure 15.22*).

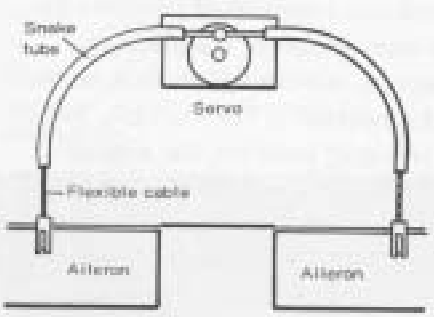


15.22 Arrangement necessary with split elevators and sweptback or angled hinge lines.

Cable movements

A flexible cable running in a rigid outer tube can be used instead of a push-rod to transfer the push-pull movement of the servo to a control horn. The cable is thin stranded steel wire (Bowden cable), to which any suitable type of end fitting can be attached by soldering (*figure 15.23*). The rigid outer tube must be non-metallic to avoid noise. The two tube materials used are nylon and PTFE. The latter is generally to be preferred as having considerably lower friction.

The main advantage of a cable movement is that it does not require any internal clearance (except for the end movements), and also it does not necessarily have to run in a straight line. It is thus primarily used to control services which introduce more tortuous runs—such as throttle control, nosewheel steering, and ailerons. It can, of course, also be used for rudder and elevator movements.



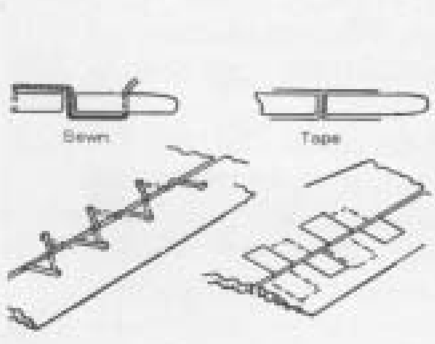
15.23 Bowden cable operation of strip ailerons.

Control surface hinges

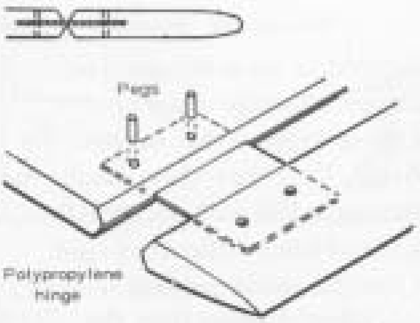
The stitched or tape hinge has been widely used for control surfaces because of its good strength and reliability. In its simplest form the control surface and adjacent fixed surface are butted up flat and then either sewn or taped together as shown in *figure 15.24*. Since the hinge movement effectively pivots about one side of the thickness and the other, the angular displacement has a certain amount of differential, although this is not necessarily significant in practice.

This particular limitation can be overcome by chamfering the abutting edges of the two surfaces to produce a definite, and single line, pivot point for the movement (*figure 15.26*). There is little to choose between sewing (with nylon thread) or hinging with tape (binding tape or cloth tape) on the score of satisfactory hinge action, strength and durability. The main thing is to ensure that no glue gets into the hinge line when assembling the two surfaces as this will stiffen the action and can also weaken the hinge material by making it rigid.

Much neater hinges—again of simple form—can be made using thin, flexible plastic sheet material as an inserted leaf hinge. Polypropylene is the ideal material in this respect, with good strength and flexibility and indefinite resistance to fatique, however many times it is flexed.



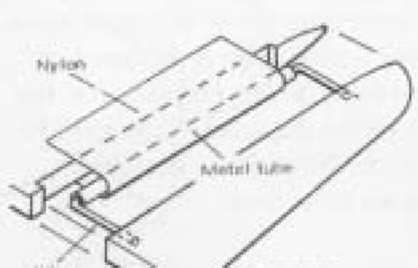
15.24 Sewn and tape hinges.



15.25 Plastic (polypropylene) hinge fitting.

15.26 With centreline hinges the edges of the fixed and movable surfaces should be chamfered off.

15.27 Plastic film used for making a 'top' hinge.



15.28 Wire-and-tube hinge. Metal tube is secured in place with a strip of nylon or tape cemented to the fixed surface.

The hinge material is used in the form of a single strip, or series of shorter strips, inserted into slits, as shown in *figure 15.25*. Since polypropylene is difficult to glue, the hinge strips should be keyed in place with small dowels, as shown. It can also be stuck with contact adhesive, but gluing alone should never be relied upon to secure a strip hinge of this type.

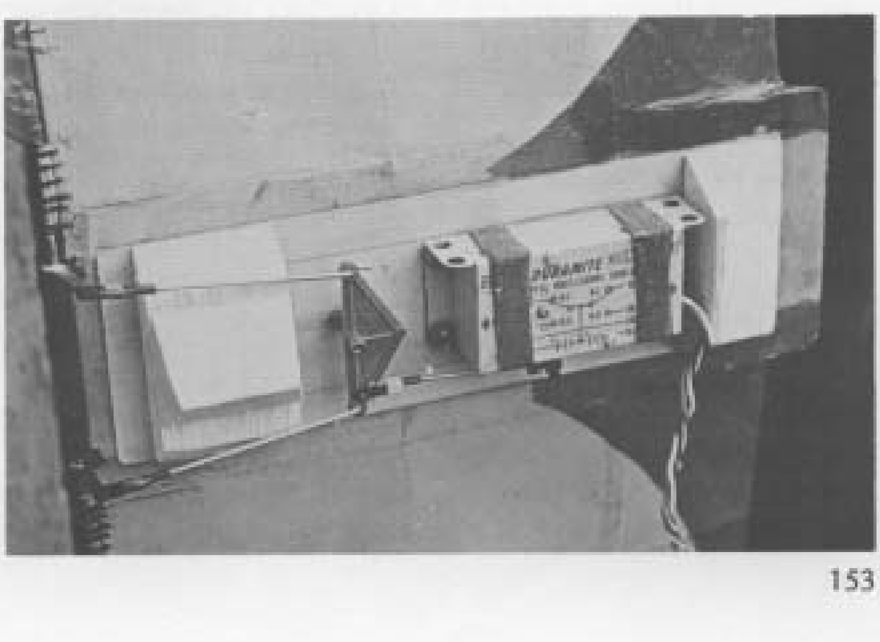
The other important thing is to ensure that the hinge line is 'tight', i.e. there is no physical gap bridged only by the hinge material. This will result in uneven movement, or even allow the control surface to flutter.

Proprietary hinge strip material and individual leaf hinges are produced in polypropylene, nylon and 'Mylar' (polyester).

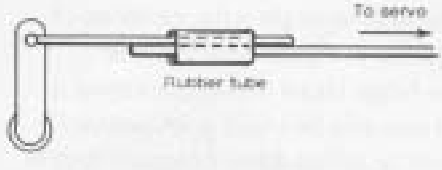
Some of the plastic film materials used for covering model aircraft are also suitable for making simple hinges. These are too thin to be used as inserted leaf hinges, but can be applied for making top or bottom hinges, or in place of tape for conventional tape hinges, as shown in *figure 15.27*. Top hinges are the usual method of mounting ailerons. Elevators can also be top hinged. Rudders are always centre hinged.

Mechanical hinges are, of course, another solution. Home-made hinges of this category are usually of wire-and-tube type, typical examples being shown in *figure 15.28*. These are by no means as widely used as sewn or tape hinges, or inserted leaf hinges, except that they may be preferred for individual applications—particularly where an inset hinge line is required.

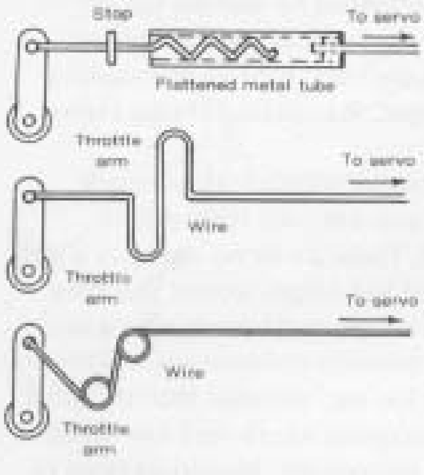
A properly made mechanical hinge has less 'stiffness' than the other types described and thus can be advantageous where only low actuator power is available, e.g. when using an escapement. Numerous types of proprietary mechanical hinges exist, the majority of which are designed for 'inserted' fitting, i.e. gluing and pinning into slots. They are produced in top hinge (or bottom hinge) and centre hinge configurations. Proprietary hinges are invariably moulded in plastic and thus are free from any 'noise' problems which may occur with metal-to-metal mechanical hinges.



Wire-and-tube hinges on ailerons, with aileron servo and linkages.



15.29 Simple self-adjusting throttle pushrod.



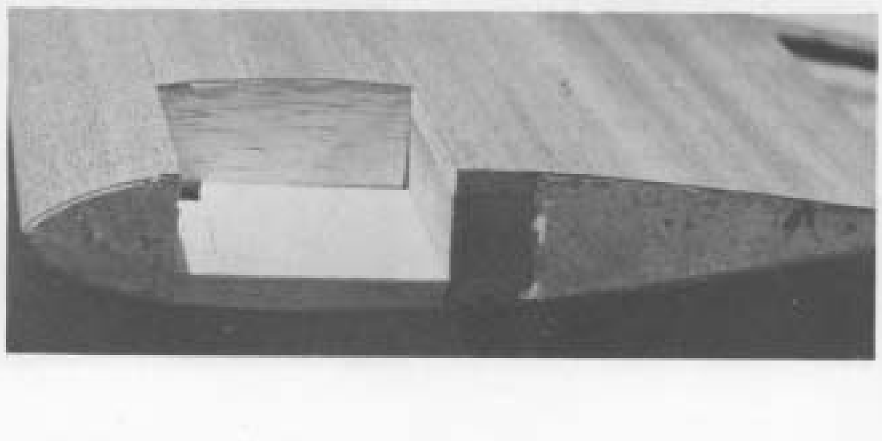
15.30 Three other methods of providing automatic length adjustment on a throttle linkage.

Throttle linkages

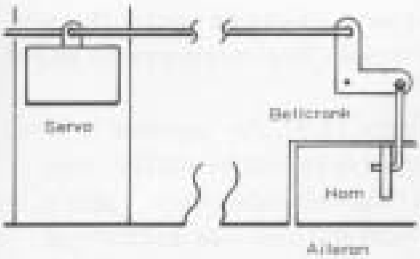
Throttle linkage may be based on a push-rod or cable linkage. Two problems are involved which makes a throttle linkage requirements differ from rudder or elevator linkage set-ups. One is that the path the linkage has to negotiate is not unrestricted. Thus the linkage usually has to pass through a main bulkhead, to emerge in line with the throttle arm of the motor. This can favour the use of cable rather than rigid push-rod action. The other is that the throttle arm movement is necessarily adjustable to achieve suitable 'slow' running from the motor. Adjustment of the throttle stop—which may have to be re-adjusted from time to time—will vary the travel available on the throttle arm. Thus it is virtually impossible to arrive at an exact linear travel required from the linkage.

This difficulty can be overcome by providing 'override' movement in the linkage. The simplest method is to split the push-pull rod, or wire end, into two separate lengths, which overlap. They are then bound together with a tightly fitting piece of synthetic rubber tube (*figure 15.29*). This tube couples the two wires together by friction, but should the wire connecting to the throttle arm be brought to rest (e.g. by the throttle arm reaching its stop) before the servo movement has been completed, the 'driving' wire simply slips through the tube. This is a preferred system for a progressive throttle control since the response of throttle to servo movement is immediate on reversal of signal (and all engines are most responsive to throttle movement over the first part of the movement away from 'slow'). The slip action works at both ends of the movement, if necessary, and this simple type of slip link is also readily adjustable for length.

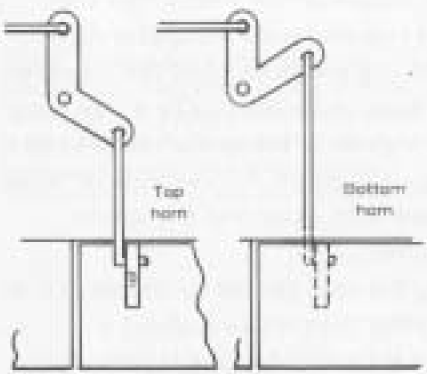
Other solutions to this problem of providing a 'slip' motion or over-ride are shown in *figure 15.30*. In most cases the compensating action is incorporated in the run of the push-pull linkage. It can also be incorporated on the actuator itself, e.g. by using a separate arm for deriving the movement, bolted to the servo output disc or output movement with a self locking nut and a spring washer. This is tightened up sufficiently to be rigid when the movement is driving normally (i.e. the arm moves with the servo output), but to slip should the movement be brought to a stop. Under this condition the arm remains stationary whilst the servo output continues to move to its limit.



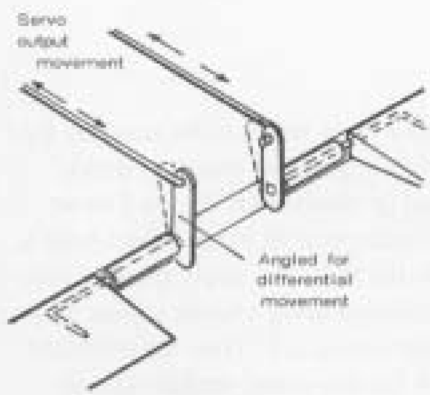
Wings are now commonly made from foam plastic, sheeted with balsa or hardwood veneer. This picture shows cut out in centre for aileron servo.



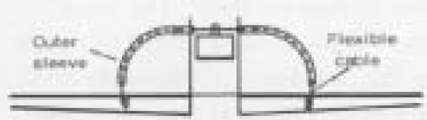
15.31 Basic inset aileron control linkage, with servo mounted in wing centre section.



15.32 Differential aileron movement obtained with offset bellcrank.



15.33 Linkage for operating strip ailerons.



15.34 Alternative method of operating strip ailerons via Bowden cable linkage.

Aileron linkage

The typical arrangement for aileron linkage, with conventional inset ailerons, is shown in *figure 15.31*. The servo is mounted in the wing centre section, transferring the output movement via wire push-rods each side to a bellcrank. Movement is then taken off the other arm of the bellcrank via a short push-rod to the aileron horn. To prevent the long wire push-rods from bowing under 'push' motions they can be supported by small bushings inserted in the wing ribs at appropriate intervals.

The system is quite straightforward except for the fact that ailerons require a *differential* movement, that is substantially more 'up' than 'down' movement. Thus typical maximum movements required may be 30 degrees up and 20 degrees down (see Chapter 17).

The simplest way of providing differential movement is to apply the principle of 'rake' to the movement (see sub-section on Control Horns) This can be done by using a bellcrank which has the arms at an acute or obtuse angle, rather than at 90 degrees. It does not really matter which type is used. This merely affects the way the bellcranks have to be mounted to provide maximum movement on 'up', which in turn is governed by whether the control horn is on the top or bottom of the aileron. *Figure 15.32* should make clear the two combinations possible.

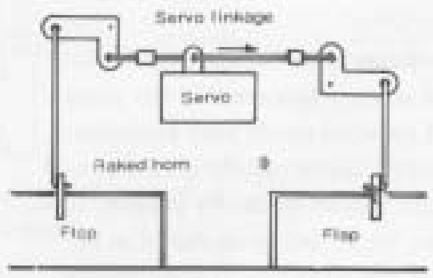
The angle required on the bellcrank arms can be calculated from basic geometry to provide the exact degree of differential required. However, this is only a design 'guesstimate'. Angled bellcranks are available as proprietary items with either 60 degree or 120 degree arms as standard. These will provide all the differential normally required on aileron movements.

Strip ailerons are easier to link up since only a short run is required for the push-rods, and the horns can be in the form of a half of a conventional 'split elevator' horn (see *figure 15.33*). Differential movement in this case is obtained simply by connecting the push rods to the servo wheel either *above* or *below* the normal neutral position, depending on whether the horns are on the top or bottom. If this is not possible, if for example the servo has a linear (push-pull) output movement, then differential movement can be obtained by raking the horns.

Bowden cable controls may be preferred to push rods for the aileron linkage, in which case the pivotal movements are the same and only the 'run' of the linkage is affected, and usually simplified. Cable controls are generally used with strip rather than inset ailerons. They have the advantage over push-rod linkage that the horn can be moved outboard, so that the hinge load is more balanced (see *Figure 15.34*).

Flaps

Flap movement required is considerably greater than that for other control surfaces, e.g. up to 45 degrees. Special servos are available with increased movements for working flaps, although a conventional servo

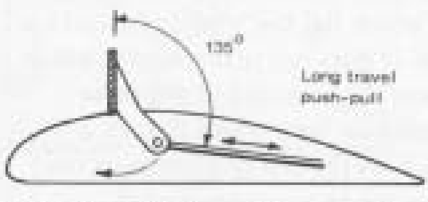


15.35 Typical flap control linkage.

can be just as suitable. A *linear output* servo should be used as this will provide maximum movement with minimum 'lost' motion at the end of the movement.

A typical flap linkage is shown in *figure 15.35*. An 'override' or loose link can be included to ensure that the servo cannot be started when the flap is raised to its closed position. The only other major requirement is that the push-pull movement must not over-ride its centre at extremes of travel. To avoid this it is usually necessary to rake the flap horn forward at an angle of up to 30 degrees.

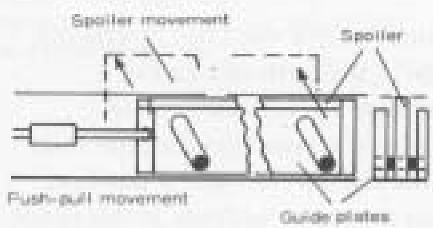
Spoilers



15.36 Angled bellcrank for operating spoiler.

Spoilers are best operated with linear output servos with longer than normal travel. The angular movement required with straightforward push-pull action is of the order of 135 degrees, because of the restricted depth available to accommodate the horn inside the profile of the wing (see *figure 15.36*). Loads will also be high since the spoilers have to be raised against progressively increasing air pressure. An over-ride or 'loose link' is required in the system to ensure tight closure of the spoiler, when retracted, without stalling the servo.

A method of substantially reducing the load carried by the servo is to raise or lower the spoiler vertically, rather than rotate it about a spanwise hinge. In this case the spoiler is located by pins at each end, free to slide in parallel angled guide slots, as shown in *figure 15.37*. Push-pull motion from the servo is then directly linked to one end of the spoiler, the sideways 'pull' or 'push' raising or lowering the spoiler vertically, respectively. The main load in this case is the friction of the pins in the slots.



15.37 Alternative spoiler movement, worked off sideways push-pull servo movement.

Brakes

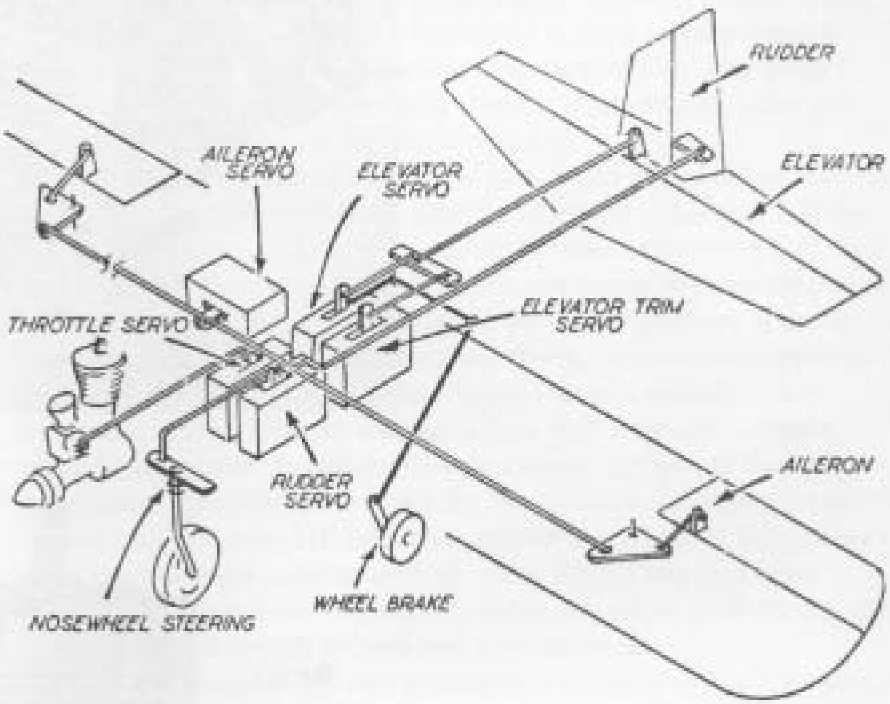
Wheel brakes are invariably coupled to a main servo, to be actuated by a particular 'limit' position of that servo—e.g. down elevator. Brake actuation at the wheel can be electrical or mechanical. In the former case, the brake mechanism (normally incorporated in the wheel hub) is actuated by an electro magnet (also in the hub). To apply these brakes it is only necessary to close a circuit incorporating a battery (usually a separate battery because of the high current drain). Thus the electrical brake circuit is wired to a microswitch (or any other similar type of switching contact) which are normally open, but closed by the mechanical movement corresponding to down elevator.

Mechanical brakes may be of a simple friction type pressing against the tyre of the main wheels, or built into the hub of the wheels. In either case a 'pull' movement is required to operate them. The usual method of obtaining this 'pull' movement is to attach a length of nylon line to the elevator movement, feeding the line down to the undercarriage through a tube or other suitable guides to attach to the brake lever (*figure 15.38*). Brakes are then pulled on every time full down elevator is signalled and release under spring action, allowing the nylon line to go slack so as not to impair opposite movement of the elevator servo.

Both electric hub brakes and mechanical hub brakes are available as proprietary items (as pairs of braked wheels, complete with tyres). Mechanical brakes can also be added to ordinary wheels.

Wheel steering

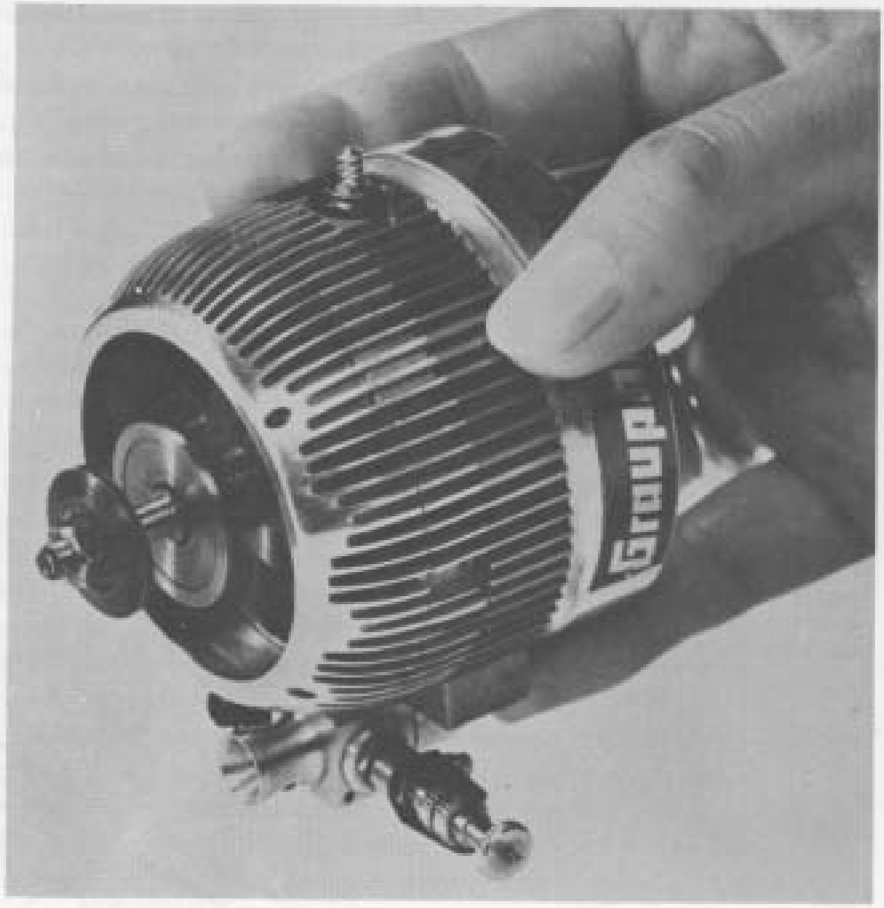
Tailwheel steering can be provided by mechanically coupling the tailwheel to the rudder movement, as shown in *figure 15.38*. This is a simple and direct solution which imposes very little extra load on the rudder servo.

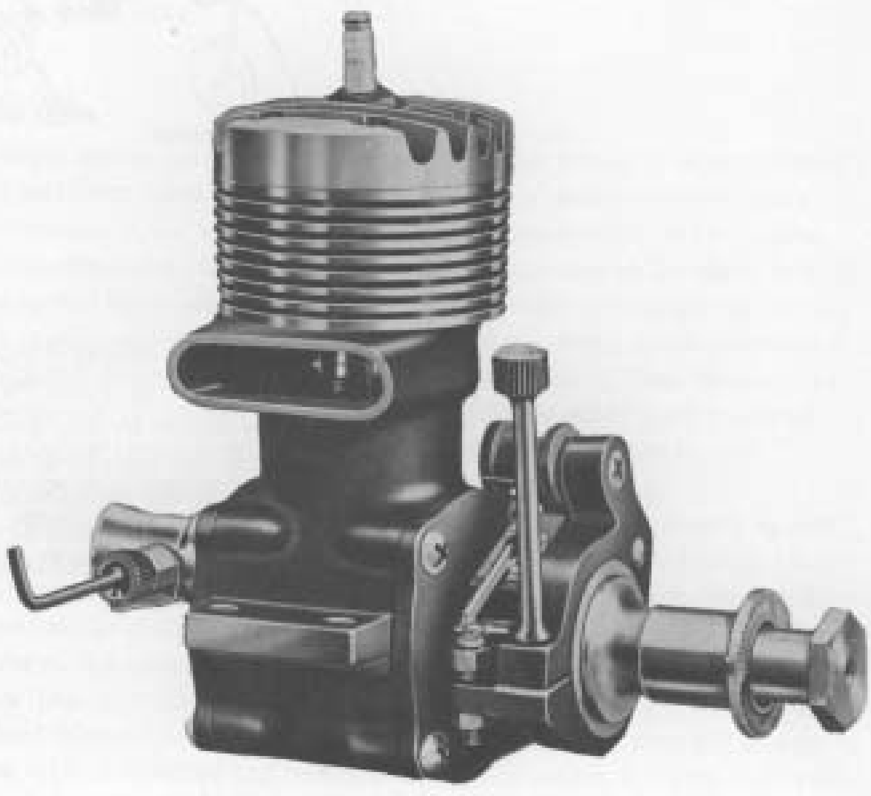


15.38 Typical servo allocation and linkage runs. This is shown for a 'multi' installation. A proportional installation would not require the elevator trim servo, and the elevator servo linkage would run direct to the elevator horn.

Ground steering control is much better with tricycle undercarriages, which is the preferred layout for freelance designs. In this case the nosewheel is steered by mechanical linkage taken to the rudder servo. It is necessary in this case, however, to introduce some form of shock absorbing link in the mechanical coupling to prevent shock loads on the nosewheel being transmitted directly to the servo. These loads can be quite high, even in a normal landing.

Latest development in model power units is the Wankel rotary engine. This should have particular advantages for radio control models because of the smooth running characteristics. Production of model Wankel engines is, however, very limited at present, and they are considerably more costly than conventional diesel or glow motors.





Spark ignition motor, the standard type of model engine up to the mid 1940s now only made in limited numbers for boats. Ease of speed control is a favourable feature for radio models.

16 R/C ENGINES

The small internal combustion engine developed for powering models—generally described as a 'model engine'—has evolved in three distinct forms. Originally the only practical form was the *spark-ignition engine*. In the post-war years this was superceded by the compression ignition engine or so-called *diesel*, and the glow plug engine, more usually known as a *glow motor*. Both these latter types have the advantage of dispensing with the coil, condenser, contact breaker and separate battery needed with a spark-ignition engine, and also proved capable of developing considerably more power output for a given size of engine (mainly because they can run at much higher speeds).

The *diesel* is a completely self-contained power unit in that it only requires a supply of fuel. This is an obvious advantage for model applications. The *glow motor* is similar in that once running it needs only a supply of fuel to keep running. It does, however, employ a plug (a glow plug) which needs to be connected to an external battery to heat up the plug element for starting. Once 'warmed up', the battery can be disconnected, when the plug element is self-heating under the catalytic action of the alcohol-containing fuel.

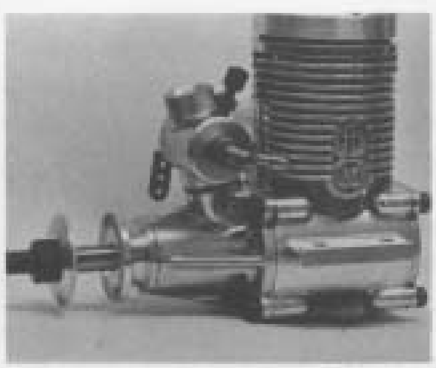
The diesel was until recently the most popular type of 'sports' engine in Britain.

The respective merits of diesels and glow motors need not be discussed in detail. Diesels evolved almost exclusively in Europe; and their size or displacement is invariably quoted in cubic centimetres (cc). The glow motor evolved in the United States, and motor sizes are invariably quoted in cubic inches (cu in). Thus on the simple question of availability, European modellers mainly used diesels, and American modellers glow motors. However, it was soon found that 5 cc was about the maximum practical size for a diesel. Above that it became temperamental and 'brutish' to handle in single-cylinder designs. In fact the 3.5 cc diesel subsequently became the largest diesel size manufacturered on any scale. No such size limitation applied in the case of glow motors, and since the larger radio controlled model aircraft required more power than that provided by a 3.5 cc diesel, the use of glow motors for radio controlled aircraft became widely established.

There are a number of other reasons why the glow motor is generally preferred for R/C work.

(1) Glow motors are generally easier to start and adjust for smooth running since only one control is involved (the mixture control or needle valve). Starting and adjustment is very much a matter of familiarity, however. Modellers used to diesels can find glow motors difficult to start and adjust at first, and vice versa.

(2) Glow motors can be made in very small as well as larger sizes. In the case of very small engines—under 0.5 cc—the diesel tends to become very 'tricky' to start and adjust (as well as to manufacture). Glow motors as small as 0.02 cu in displacement (0.3 cc) can be easy to handle. The production of very small glow motors opened up new scope for the operation of very small aircraft, capable of being adapted to radio control with the advent of lightweight transistorised receivers.

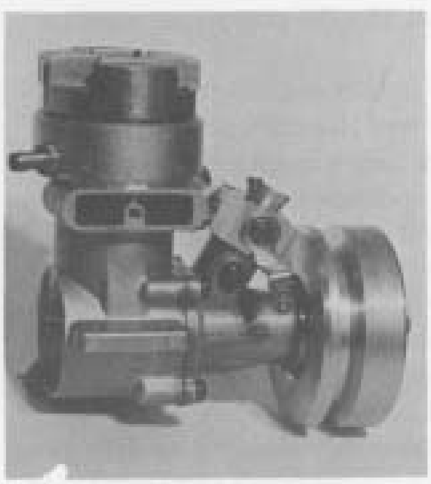


Glow motors are generally preferred for all sizes of radio controlled model aircraft.

(3) Although their operating speeds tend to be higher, glow motors run with less vibration than diesels. This is a considerable advantage for radio control applications, particularly with relay receivers.

Watercooled 'marinised' version of a glow motor, with throttle control.

Watercooled diesel with plain throttle. Diesels are less suitable for throttle control.



Throttle operating arm and 'stop' movement adjusting screw (idling speed control) can be seen in this photo.

One of the most common causes of 'engine vibration' on aircraft, however, is an unbalanced propeller. Moulded nylon propellers are not necessarily balanced, statically and dynamically, and an unbalanced propeller rotating at speeds in excess of 10,000 rpm can generate a lot of vibration—far more than that generated by any unbalance of reciprocating parts in the engine itself. Regardless of the type of engine used, therefore, propellers should always be checked for balance and corrected if necessary by removing material from a 'heavy' blade—before being used on a radio controlled model.

(4) Glow motors are generally more consistent in running characteristics than diesels, particularly when the load on the airscrew varies, as in manoeuvres, producing a change in rpm. In the case of diesels 'balanced' running conditions normally require a reduction in compression setting to maintain smooth running when the motor speeds up, as in a dive.

(5) Glow motors are more readily responsive to speed control by 'throttling' than diesels. Thus it is possible to provide a fully variable response from slow to fast with a glow motor, particularly on larger engine sizes. Diesels are far more difficult to 'speed control', largely because of the effect of a fixed compression setting as mentioned in (6). Certain diesels have been produced, however, with good throttle response. These are usually slower running engines, with a main application to marine model use.

Despite their advantages for R/C aircraft, and the considerable expansion in the numbers of active radio control modellers, very few glow motors are manufactured in Britain. The main sources are the United States and Japan, whose productions are distributed throughout the world and readily available. Almost all the standard size of glow motors (see Table 1) developed around free flight applications have their R/C counterpart with throttle control; and most of the larger sizes .45 cu in and above have been developed primarily as R/C engines.

Diesels remain the standard choice for non-contest-type free flight models in Britain, and so are also used for radio controlled aircraft in a similar category, both with and without throttles. Where more power is required than that available from the largest production size of diesel, a glow motor must be used. This covers virtually all 'performance type' radio controlled aircraft.

Diesels, however, remain strongly favoured for marine model power plants, where their tougher and more rugged construction is an advantage, and throttled performance is not so critical. Only comparatively recently, in Europe, have water-cooled glow motors become readily available in a wide range of sizes.

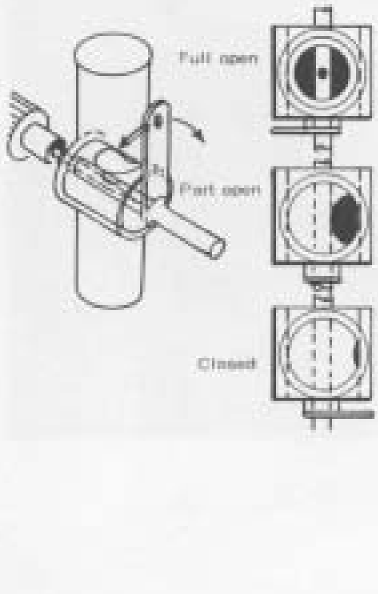
The spark-ignition engine, too, which virtually disappeared as a model aircraft power unit in the 1940s maintains a following for marine models. It offers an extension in size, and thus power, not readily possible with a diesel without going to multi-cylinder layouts, and extreme flexibility of control. It is by far the easiest type to which speed control can be added. Instead of throttling the mixture supplied to the engine, smoothly variable speed control can be produced by

TABLE I
EQUIVALENT SIZES

European and Diesels (cc)	*American and Glow Motors (cu. in.)*
·16	·01
·33	·02
·5	·03
·75	·046
·8	**·049**
1·0	·06
1·5	**·09**
2·0	·122
2·5	·15
3·1	·19
3·5	·21
4·75	**·29**
5·75	**·35**
8·0	**·49**
10·0	**·61**

Figures in **bold** are standard production sizes.

16.1 Throat opening on the venturi intake is controlled by the position of the throttle barrel.



rotating the contact breaker to advance or retard the spark timing, with a fixed mixture setting. Some larger spark-ignition motors, however, may be designed for throttling via a carburettor control, working on a similar principle to that of a larger internal combustion engine.

Spark-ignition engines are still produced, in limited numbers, in both two-stroke and four-stroke versions. Model diesel and glow motors are invariably two-stroke engines.

There is virtually no difference between an aero engine and a marine engine, except for cooling. The basic model has a finned cylinder and is air cooled by the slipsteam of a propeller, i.e. as an aero engine. It can be adapted for, or produced in, a marine version by replacing the finned cylinder or cylinder jacket with a water-cooled jacket. In some cases with glow motors the crankcase is also cooled by a jacket, but this is not now usual. In the absence of the flywheel effect provided by a fairly large diameter propeller, marine engines must necessarily have a solid flywheel mounted on the crankshaft. The drive to the propeller shaft is taken off a suitable coupling at the front of the flywheel (actually the back of the flywheel when installed, since a marine engine is mounted 'facing aft' in a hull).

Adjustment for marine engines is rather different since the engine is normally started with the boat out of the water and thus there is very little load on the screw (the flywheel does not produce any 'braking' load). When the boat is put in the water, the load is increased considerably since the screw is now rotating in a more 'solid' medium. This load will decrease again as the model is released and accelerates up to normal running speed. Variations in load from then on will be less than in the case of aircraft. Initial throttle adjustment with the boat out of the water is purely nominal, with a rich setting, merely to get the engine running continuously. The mixture is then readjusted carefully when the boat is put in the water, allowing for the further 'leaning out' effect of the increase in speed when under way.

Speed control in the case of diesels and glow motors is achieved by varying the mixture. The usual method is to employ a barrel-type carburettor replacing the normal plain tube intake. The barrel unit is a cylindrical 'plug' mounted at the throat of the intake tube, drilled with a large hole so that rotation of the barrel opens or closes the effective opening of the throat (*figure 16.1*).

In other words the position of the barrel controls the amount of air drawn through the throat and flowing past the spray bar through which fuel is fed, metered by the needle valve. For a fixed setting of the needle valve the mixture of air and fuel can vary from very rich (barrel opening almost closed) to maximum lean (barrel fully open and needle valve setting to match).

The latter condition corresponds to normal (unthrottled) running and is easy to adjust—the mixture merely being leaned out (by screwing in the needle valve to an optimum point, giving maximum rpm. The only thing governing rpm will be the load produced by the rotating propeller. This will be a maximum when the model is static but will decrease, and thus the rpm will increase, when the model is airborne

Rear mounted throttle (rear induction)—needle valve side.

(the effect on marine engines is different and will be described later) The initial (static) adjustment of the needle valve must allow for this, i.e. be slightly on the rich side, to allow the mixture to 'lean out' as the rpm goes up in flight.

To slow the engine under any condition (static or in flight), the barrel valve is rotated to richen the mixture. This will induce four-stroking instead of two-stroking, and richening the mixture can continue until the engine is completely four-stroking and on the point of being choked by the excessively rich mixture.

The limiting speed for slow running is thus the richest mixture the engine can take and still continue running consistently, and respond without stalling to opening of the throttle and leaning out the mixture. The limiting lower speed may be as low as 2-3000 rpm, with a maximum speed of the order of 10-15,000 rpm; or the range may be much narrower. The response to intermediate throttle settings may also differ widely. Some engines will have a progressive response to throttle opening; others may only be happy running slow or fast, and generally inconsistent at intermediate throttle settings. This depends on the design of the engine, and in particular the design of the throttle.

Individual barrel throttles vary a lot in detail design. The usual method of slow speed setting is adjustment of a stop controlling the degree of closure of the barrel valve opening. An additional 'bleed' adjustment may also be provided for fine setting of the slow running

Throttle arm on a slightly different type of rear-mounted intake.

Typical 'front rotary' induction throttle. Picture on right shows typical throttle linkage.

mixture. The spraybar may or may not rotate with the barrel. This again can affect the low speed running characteristics. A fixed spray bar is to be preferred as this means that the fuel tubing attached to the end of the spray bar does not have to 'twist' with the throttle movement. Rotating spraybar throttles need fuel tubing which remains fully flexible—and many types of fuel tubing get hard and rigid under the slight chemical action of the fuel flowing through the tube.

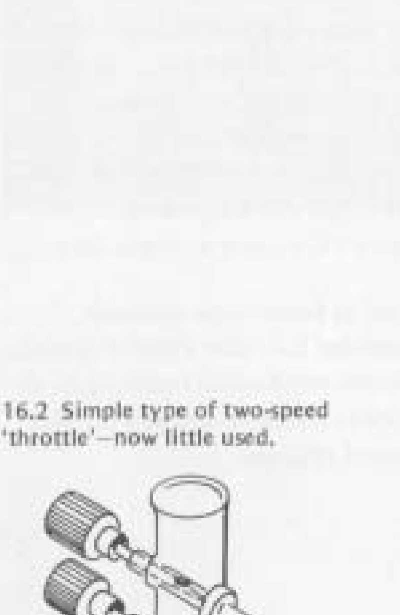
Response to intermediate throttle positions can often be improved, particularly in the case of glow motors, by mechanically coupling an exhaust flap to the throttle movement. As the throttle closes, so this flap also progressively closes and blocks off the exhaust opening. Back pressure is thus applied to assist in slowing the engine and provide a more graduated form of speed control.

With the advisability or even necessity of fitting silencers to model engines to reduce noise output, the coupled throttle and exhaust flap is now less used. Main advances in speed control have been in the detail design of the engine porting, and development of highly effective barrel-type (or similar) carburettors. In the case of engines designed specifically for radio control aircraft, minimum speeds of the order of 2-3,000 rpm can readily be obtained by reducing normal maximum speeds to the order of 10-12,000 rpm, instead of the 15,000 rpm plus which might be realised by comparable 'free flight' engines. This can also result in improved intermediate throttle response. In general, however, this will always be non-linear. The maximum speed change will normally be realised over the first part of the throttle movement away from 'slow' speed.

Throttle controls are actuated by a single movement, usually that of a lever attached directly to the barrel valve (see photos). The hook-up is therefore quite straightforward—merely a push-pull linkage connecting the throttle arm to the motor speed actuator or servo. Certain precautions are necessary, however, to 'match' the movements required (see Chapter 15).

Barrel-type throttles can be applied to any size of engine. They are usually most effective in the larger sizes (e.g. glow motors of .35 cu in capacity and above) particularly as regards intermediate response achieved. They are not particularly suitable for the smallest sizes of glow motors which tend to have very high normal running speeds and are not particularly consistent if made to run at lower speeds on rich mixtures.

16.2 Simple type of two-speed 'throttle'—now little used.



An alternative type of engine speed control, developed in the earlier days of single-channel radio, dispensed with a throttle control as such and instead employed two separate spraybars, mounted one above the other (*figure 16.2*). Each spraybar had its own needle valve.Thus one could be adjusted to normal lean mixture (for maximum speed running), and the other to 'maximum rich' mixture at which the engine would keep running (slow speed running).

To change from high to low speed, or vice versa, it was thus necessary to switch the fuel supply from one spraybar line to the other. One simple method of doing this is shown in *figure 16.3.* Each spraybar

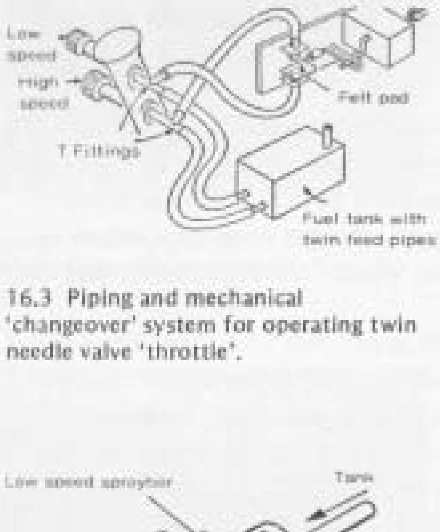
Radial cowlings on scale models offer an opportunity for completely enclosing the engine, giving true scale appearance with a dummy motor fitted in front of cowl.

tube is fitted with a T-piece, to which tubing is connected as shown. The motor speed actuator movement changes the position of a felt pad from the end of one T-piece tube to the other. The closed tube is sealed off, and thus that spraybar can draw fuel from the tank. The other tube is open, introducing an air bleed into that line, which means that no fuel is drawn into that spraybar. The next movement of the actuator changes the felt pad position, opening the spraybar originally drawing fuel and letting the other spray draw fuel. Thus the engine changes over from high speed to low speed running, or vice versa, and so on.

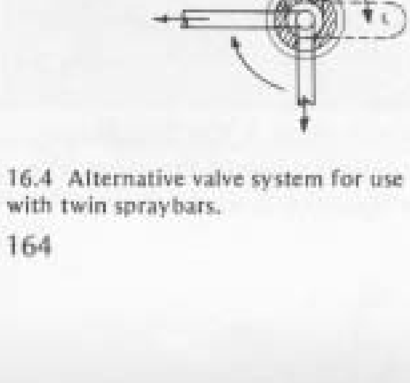
Supply changeover can be controlled in other ways. For example, the T-pieces and their tubes can be omitted and very soft tubing used for the two feed lines from the tank to the spraybars. The actuator movement can then be arranged to alternately squash one tube, then the other, blocking off the supply in the 'squashed' line. This would need the power of a motorised actuator rather than an escapement.

A neater arrangement is shown in *figure 16.4* using a simple flow control valve in the fuel line.

Twin spraybar systems, no longer used as barrel-type throttles, are now widely available for engines intended for radio control models, with the advantage of requiring only simple mechanical coupling to an actuator. Barrel-type throttles are also more efficient and can provide speed control on suitable sizes and types of engines.

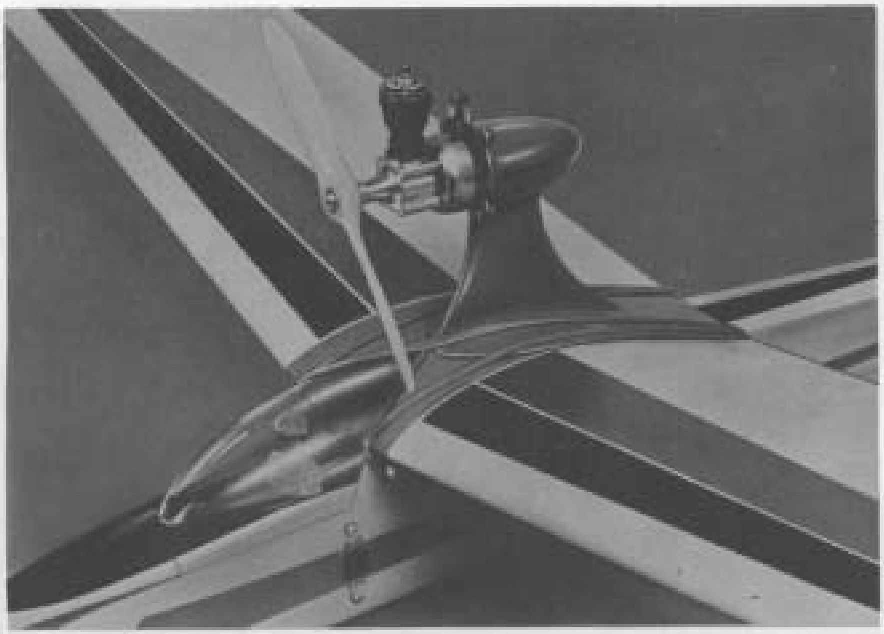


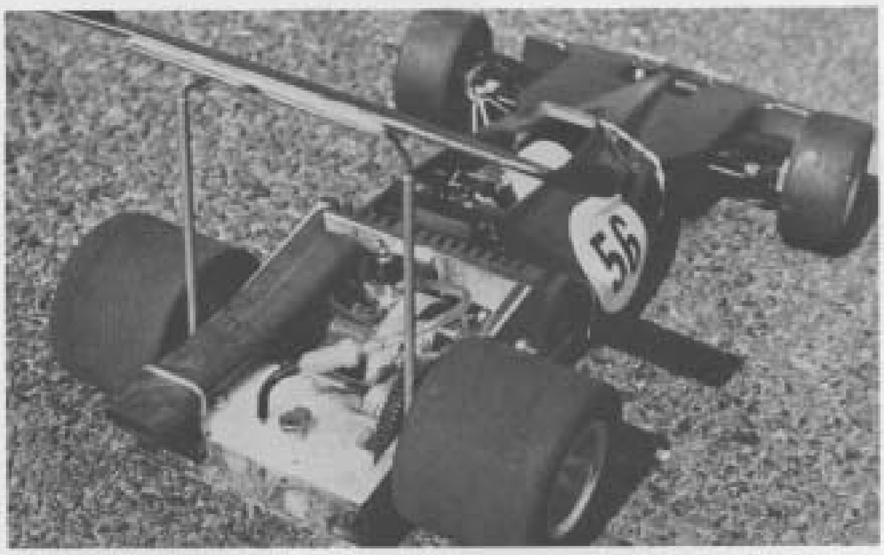
16.3 Piping and mechanical 'changeover' system for operating twin needle valve 'throttle'.



16.4 Alternative valve system for use with twin spraybars.

Examples of engine installations.

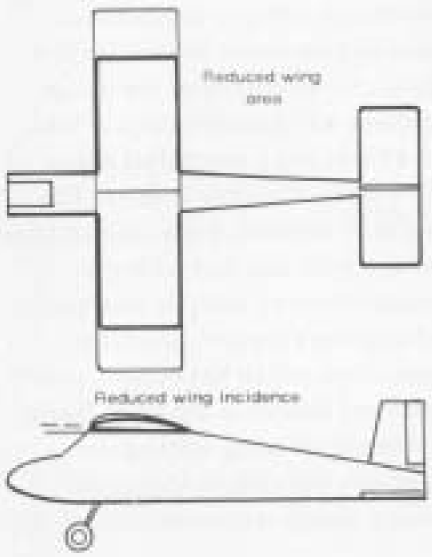




Photos: Radio Control

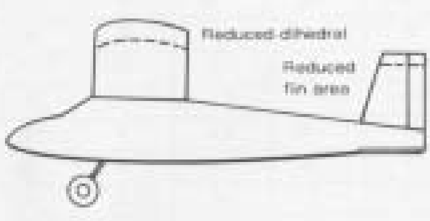
Example of the realism achieved in a modern radio controlled pylon racer. Photo Radio Modeller.

17 R/C AIRCRAFT DESIGN



17.1 Methods of making a model fly faster are to reduce the wing area and/or wing incidence.

17.2 Generous dihedral is necessary on a single-channel aircraft design.



17.3 Reducing the dihedral (to make the model more responsive) must also be accompanied by a reduction in fin area. This makes the design proportions more critical.

In the early days of radio control the models used were straightforward adaptions of 'sports' type free flight power models: high wing or cabin monoplanes. The models had to be large, to carry the weight of valve receivers and their batteries; and to maintain a reasonably low wing loading the span (and thus the wing area) was often increased over normal free flight proportions. Thus the average rudder-only radio control model of the period had a span of 6 ft. or more, weighed some 6-8 lbs, but was reasonably slow flying.

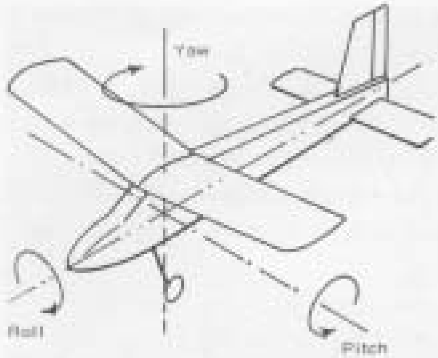
It soon became evident that this type of model had a number of limitations. A relatively slow flying speed is a safety feature, but also limits the suitability of the model to fly in winds. The natural tendency will be for a model to 'lose ground' downwind in any turn or similar manoeuvre, and once this has happened the model must be headed upwind in a straight line to bring back to the point from which is was launched. The tendency for a rudder-only model to climb and reduce speed over the ground with such a flight path has already been explained (Chapter 11). Operation of a rudder-only model which lacks penetration or the ability to fly reasonably fast in an upwind direction, is thus very restricted in windy conditions.

This led to the preference for clipped wings to reduce rather than increase area, and thus increase wing loading very much a compromise solution since it made the model more tricky to fly and keep under control. A better solution is the adoption of an underelevated trim, which naturally makes the model fly faster, and climb less, without having to increase the wing loading. But this can introduce problems of stability, especially when the model is displaced from its normal straight flight path.

The other basic limitation of a conventional free flight design layout is that it is *too* stable to be properly responsive to displacement from its normal straight flight path by control movement(s), particularly as regards *directional* control (rudder control). The basic answer here is to reduce the dihedral of the wings, compared with normal free flight practice, although this places a premium on the rest of the design proportions being right. Reducing the dihedral makes, for example, the choice of vertical tail area more critical, and the response to rudder movement more drastic.

Normally a model without dihedral will be laterally unstable. That is, if disturbed it will tend to slide off to one side and continue side-slipping, without recovery. If no dihedral is present, however, a rudder can be an almost independent directional control, producing turns without inducing any bank. Such turns, however, will produce skidding sideways during entry and sideslipping on recovery. Adding dihedral to the wing produces a powerful banking effect with rudder turns, with a corresponding tendency to drop the nose at the same time as the aircraft is rolled into the bank. Thus a rudder-only model has to compromise between the least amount of dihedral possible so as to minimise rolling into a bank and nosing down; and the amount of dihedral that is *necessary* to maintain sufficient lateral stability.

The other important stability factor is the manner in which the



17.4 The three axes of movement of an aeroplane in flight.

model responds in the *roll* and *pitch* axes when being maae to turn by the rudder. Effectively an aeroplane has three axes about which it can rotate: yaw (or turn), roll, and pitch (*figure 17.4*). Displacement around one axis will inevitably tend to produce some degree of rotation about the other two. Thus rudder movement will give displacement about the yaw axis, inducing corresponding rotations around the roll and pitch axes. Ideally the aerodynamic characteristics of the design should provide for these reaction rotations being favourable, i.e. little or no pitch movement up or down in a turn, and a controlled degree of roll. Unfortunately neither is possible with rudder-only control. The aerodynamic design has therefore to aim at reducing these unfavourable reactions to an acceptable level, when the pilot can deal with the 'unstable' movements induced by a rudder-turn by suitable manipulation of the rudder control, or by adding more control functions.

The form of design layout and proportions which has evolved over the years as the optimum for single-channel aircraft is shown in *figure 17.5*. This is applicable to any size, proportions being worked out relative to the wing semi-span (S) as the key dimension. Values for these other dimensions, and other general design recommendations, are summarised in the table below.

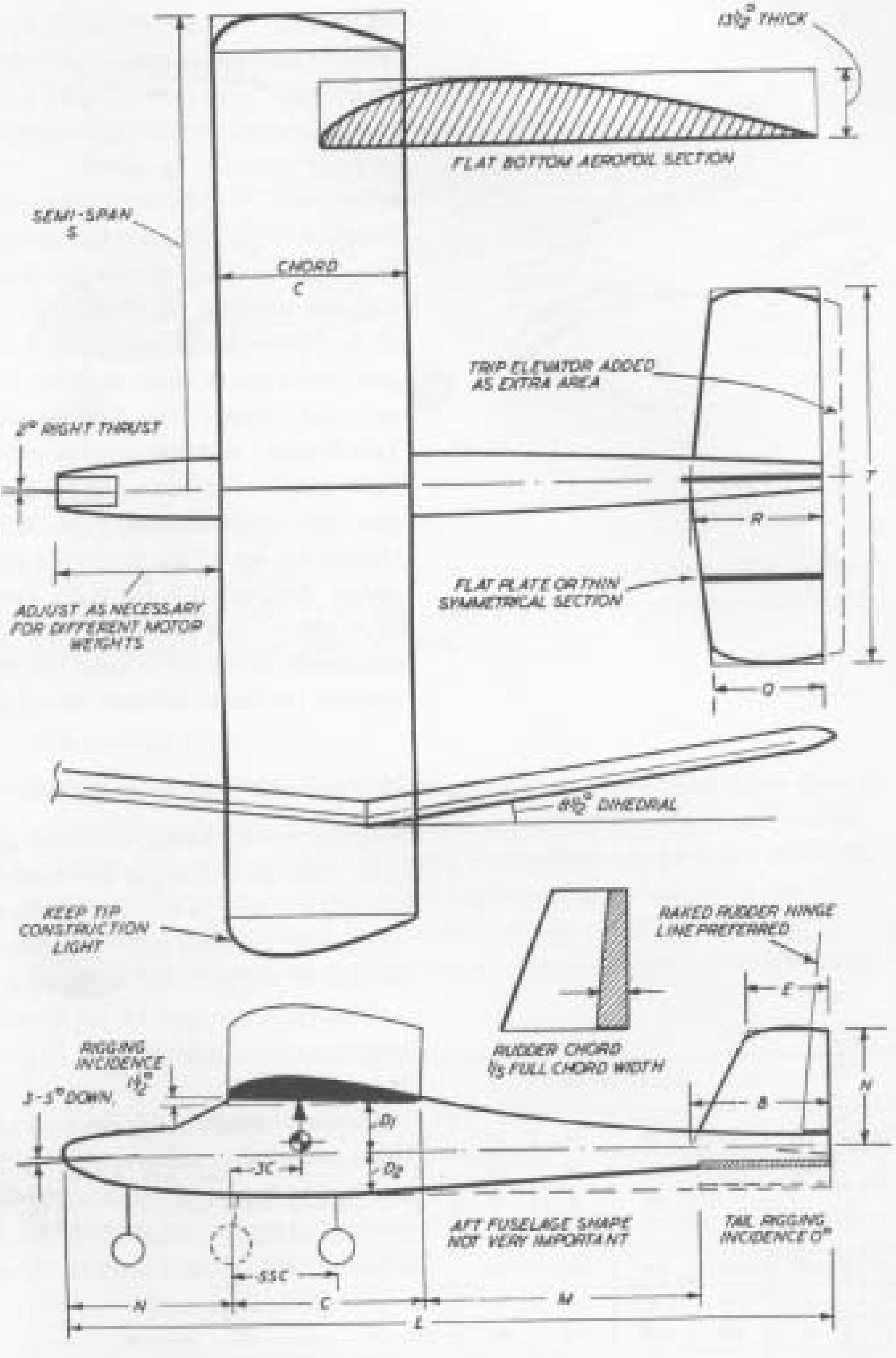
Actual size can range from about 20 in span upwards. A 20 in span model is about the limit for powering with the smallest size of commercially produced glow motor, with enough wing area and power loading to carry modern lightweight radio gear. A 60 in span model is about the logical upper limit for single-channel control. Performance is generally lost rather than gained by making a single-channel model larger than about 48 in span.

Small models have the advantage of being quick and easy to construct, cheaper as regards engine and material cost, easier to transport, and less prone to suffer crash damage than larger models because of their lighter weight. On the other hand, the smaller the model the less

Using the outline shape shown opposite, this table gives dimensions for designing and drawing up a model in various sizes from 20" span up to 60" span.

LAYOUT DIMENSIONS (See Basic Plan)	SPAN (inches)						
	20	28	36	42	48	54	60
Semi-span S	10	14	18	21	24	27	30
C	4	5½	7·2	8·4	9½	10½	11
N	3-3½	4-4½	5½-6	6½-7	8	9	10
M	5	7	9	10½	13½	12	15
L	16	22½	29	34	38	42	46
H	2½	3½	4½	5¼	6	6¾	7½
B	3	4·2	5·4	6·3	7·2	8·1	9
E	1½	2·1	2·7	3·15	3·6	4	4½
D_1	1½	1¾	2	2½	2¾	3	3¼
D_2	1¼	1¼	1½	2	2	2¼	2½
T	8	11½	14½	17	19	22	24
R	2·6	3·65	4·7	5¼	6¼	7	7¾
Q	2·3	3·2	4·2	4·8	5¼	6¼	7
Chord for Parallel Chord Tailplane	2·5	3½	4½	5¼	6	6¾	7½

17.5 This is the design layout established by experience as the most suitable for single-channel aircraft. Proportions shown are applicable to any size.



suitable it is for flying in windy weather because of inherent lack of penetration. Larger models are less critical as regards trim, permit additional control facilities to be incorporated, fly rather better, and are easier to control.

Single-channel model sizes, in fact, break down into seven groups, classified by nominal span size with proportions based on *figure 17.5*: *20 in span* for powering by a .010 glow motor. Radio gear: relayless receiver and lightweight escapement. Control: rudder, plus the addition of 'kick elevator', if this can be driven from the escapement

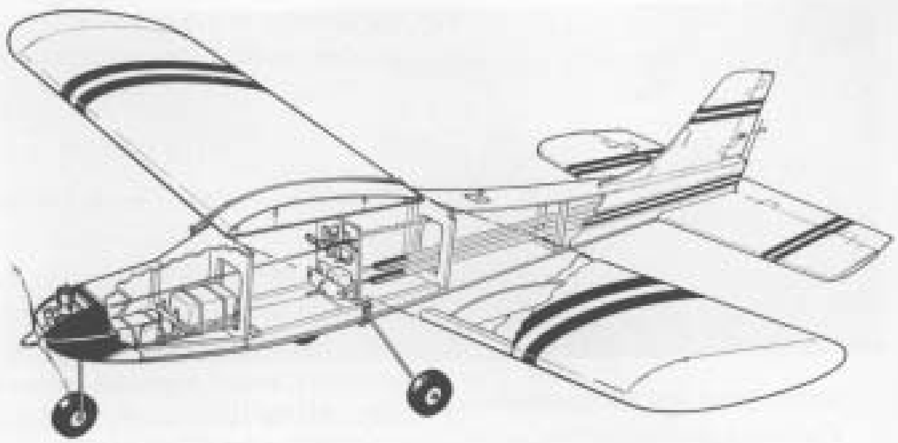
28 in span for powering by a .020 glow motor. Radio gear: relayless receiver and escapement. Control: rudder, plus 'kick elevator'.
36 in span for powering by a .049 glow motor or 0.5 cc diesel. Radio gear: relayless receiver and compound escapement. 'Kick elevator' or elevator trip may be added.
42 in span for powering by a 0.49 glow motor, or a 0.75-1.0 cc diesel. Radio gear: relayless receiver with compound escapement; or a relay receiver and lightweight motorised actuator. 'Kick elevator' or elevator trip may be added.
48 in span for powering by a .09 glow motor or 1.5 cc diesel. Radio gear: relayless or relay receiver. Compound escapement or motorised actuator, respectively. Rudder plus motor speed via secondary actuator. This is also a suitable size for pulse-proportional control.
54 in span for powering by a .15 glow motor or 2.5 cc diesel. Radio gear: any single-channel type. Motorised actuator(s) preferred. Rubber plus motor speed are preferred controls, with scope for elevator to be added. Also suitable for pulse proportional control.
60 in span for powering by a .29 glow engine or 3.5 cc diesel. Other comments as for 54 in span model above, although the size is *less* suitable for pulse proportional controls.

Single-channel model construction

Single-channel models in all the above sizes normally employ sheet balsa fuselage sides, top and bottom, assembled in the form of a rectangular box, with intermediate formers and corner stiffeners, as necessary. Thin plywood 'doublers' may be glued inside the nose section of the sides for additional strength in the case of larger models. Tail surfaces can also be cut directly from balsa sheet, although built-up construction is preferred on larger sizes, both to save weight and improve rigidity.

Conventionally, built-up construction is used for wings, with partial sheet covering (leading edges) in the case of larger models. Several alternative forms of construction can be used, however, but are generally heavier. All sheet wings, using thin top and bottom sheets separated by ribs and a tip-to-tip spar is suitable for span sizes from 20

With single-channel control, scale or near-scale models are virtually limited to high wing layouts with larger-than-scale dihedral to give a model which is automatically stable in flight.



17.6 Many single-channel aircraft up to about 48 inches wingspan feature all-sheet balsa construction. Model shown follows the design proportions of Fig. 17.5.

in up to 54 in, provided the weight is kept down by using light balsa. Wings cut 'in the solid' from expanded polystyrene are also practical for models of about 36 in span upwards.

Other model types

The above descriptions apply to *functional* single-channel radio control models. Various alternative layouts and proportions are possible. For example, low wing or shoulder wing positioning can be used; biplanes; and also, of course, scale models. In attempting, or adapting, such alternative design layouts, it must be borne in mind that certain performance limitations may appear in original designs. Also the basic

This table summarises recommendations for the type(s) of construction suitable for radio-controlled model aircraft from 20" to 60" span.

STRUCTURE	SPAN (inches)						
	20	28	36	42	48	54	60
Fuselage: Sheet box	X	X	X	X	X	X	X
Built-up, tissue covered	S	S	S	S			
Built-up, nylon covered				S	S	S	S
Glass fibre moulding	NS	NS	NS	NS	NS	NS	S
Wings: Built-up, tissue covered	S	S	S	S	S	S	S
Built-up, nylon covered	NS	NS	NS	NS	NS	S	X
All-sheet	X	S	S	S			
All-sheet, tissue covered	S	X	X	S			
Built-up, sheet balsa skinned	NS	NS	NS	NS	NS	S	S
Expanded Polystyrene			S	S	S		
Expanded Polystyrene—balsa skinned						S	S
Tailplane: Built-up, tissue covered	S	S	S	S	X	X	S
Built-up, nylon covered	NS	NS	NS	NS	NS	S	X
Solid sheet	X	X	X	X	S		
Fin: Built-up, tissue covered					S	X	X
Solid sheet	X	X	X	X	X	S	S

X = Recommended S = Suitable NS = Not suitable requirement that a single-channel radio controlled model must have a suitable reserve of inherent free flight stability must be observed.

Multi-channel aircraft design

The minimum size of model required to accommodate multi-channel radio is necessarily larger than for single-channel because of the greater bulk and weight of servos involved. Thus around 54 in span is a minimum size for six-channel working (rudder, elevator and throttle controls), with around 72 in span as an optimum for 'full house' controls (rudder, elevators, aileron and throttle controls). Since modern proportional radio works out lighter than the older reed-type 'multi' installations, 60 in span can be regarded as a practical minimum model size to consider, although the wing loading will inevitably be on the high side, resulting in a fast flying model.

There is also an upper limit to size where aerobatic performance will again begin to deteriorate, because of the lack of engine power. Production sizes of R/C aircraft engines stop at a nominal 0.65 cu in (10 cc) displacement although some more powerful engines are produced to meet the demands imposed by large models. Rarely, therefore, does one find a functional (i.e. aerobatic) type of R/C model much larger than about 68 in span.

The greater control coverage offered by 'multi' and particularly proportional to a large extent simplifies aircraft design problems. Virtually any type of aircraft can be flown successfully with 'full house' coverage (rudder, elevators, ailerons and motor speed), the onus for safe operation then relying on the skill of the pilot rather than the aerodynamic characteristics of the aircraft. The latter will only set limits as regards manoeuvrability.

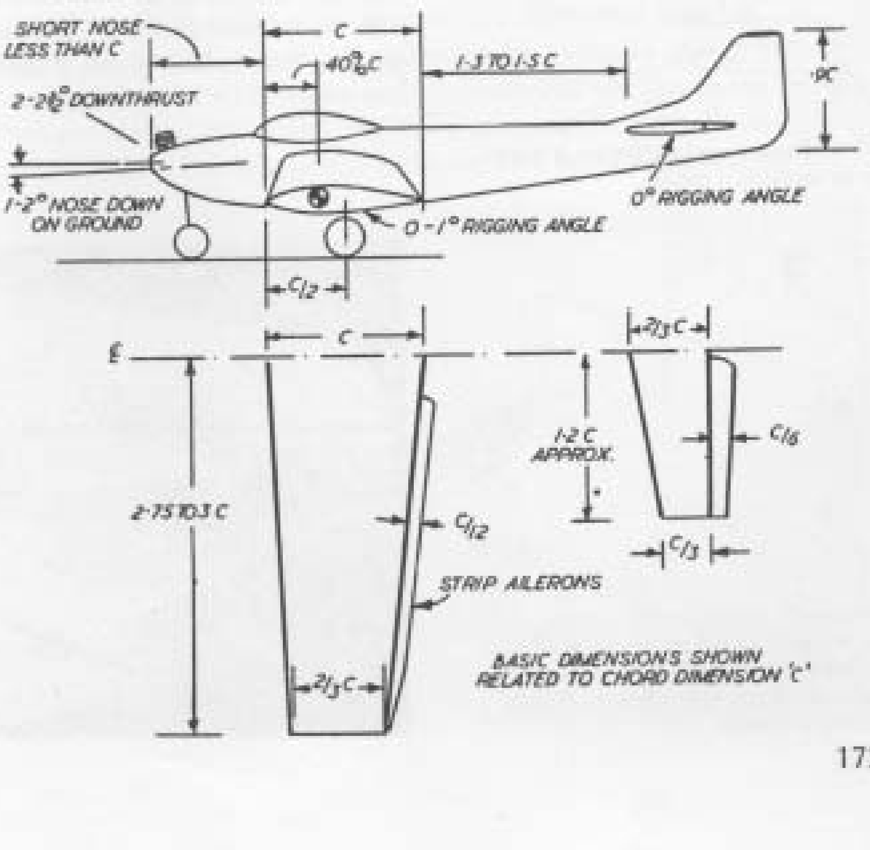
Functional aircraft designs are, therefore, only produced for specific purposes—the main type being the fully aerobatic model. Others may be designed for racing, or record-breaking purposes. The most popular form of 'racing' model is based on a semi-scale appearance, for flying at low levels around a course marked out by pylons around which the model has to turn. The control requirements of Pylon racers are thus more limited than fully aerobatic models, and outline shapes are influenced by scale requirements.

Functional aerobatic design with long moment arm, designed for proportional control. Radio Modeller photo.

Proportional (or 'multi') control, with coverage of rudder, elevator, ailerons and throttle, is the only adequate solution for a multi-engined model.

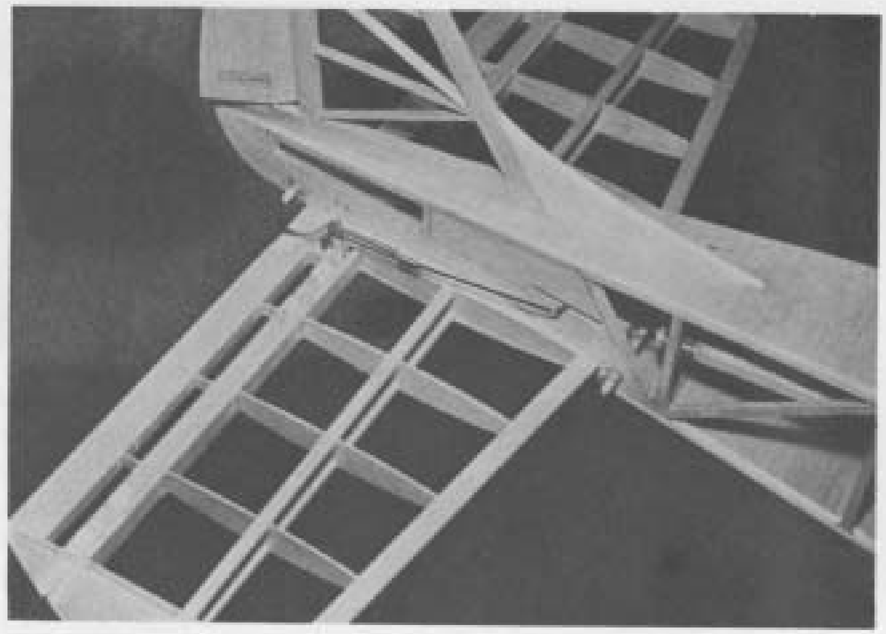
As far as aerobatic performance is concerned, the low wing layout has proved itself to be superior to all other configurations, especially with proportional controls. Design layout and proportions have, therefore, become more or less standardised along the lines shown in *figure 17.7*. Individual designs may show details differences, notably in wing platform shape and length of fuselage. Parallel chord wings were originally favoured, and also have the advantage of being easier to construct, but tapered planforms are now common. Theoretical reasons can be put forward to show a 'preference' for both equal taper and sweptback taper (e.g. all the taper on the leading edge). A sweptforward taper (i.e. all the taper on the leading edge) can introduce stability problems.

The question of fuselage length, governing the tail moment arm, is also a fairly open one. Choice is largely a matter of the individual designer's preference. Basically a short moment arm should give tighter loops and more rapid response to elevator; a long moment arm should give smoother elevator response but more elevator power. The overall



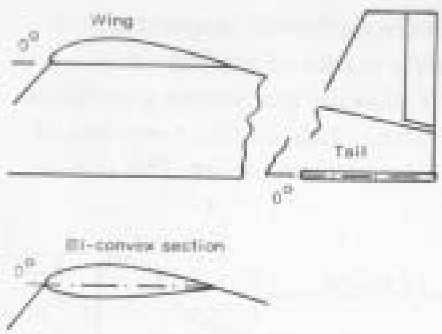
17.7 Typical design proportions for a 'multi' or proportional model aircraft. Here, though, there is much more licence for altering shapes and proportions.

Example of tail end construction using built-up tailplane and fin. Pushrod and elevator linkage is also seen. Radio Modeller photo.

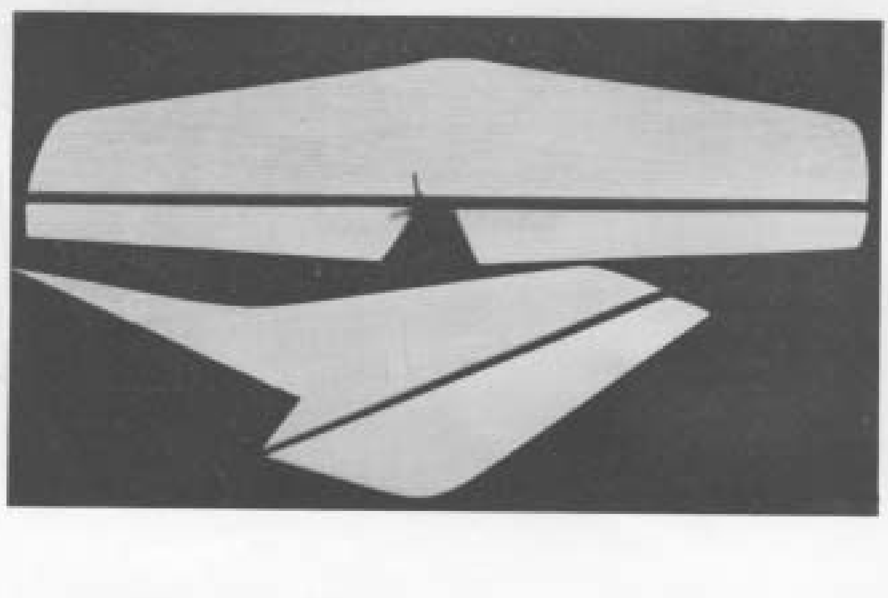


effect, however, is modified by the aerodynamics and rigging of the model. Thus a short moment arm is less critical, as regards trim; or equally, rather less responsive to fine trim.

Since a model can be flown under positive control all the time with 'full house' proportional, any inherent stability in the design can be reduced to a minimum, or even zero, invariably this favours the adoption of zero-zero rigging for the wing and tailplane, i.e. both wing and tailplane set at 0 degrees (*figure 17.8*). This means, in effect, that the model has no reserve of longitudinal stability and its attitude is thus controlled all the time by the position of the elevators, either by elevator movement or elevator trim, to 'line up' the flight path. Inherent *directional* and *lateral* stability is still, however, required in the design. The reason for this is explained in the section headed 'Ailerons'.



17.8 'Zeroed out' rigging on a 'multi' or proportional model.



Alternative construction widely favoured is to cut tail parts from light quarter-grain sheet balsa. Simpler and quicker to make, but heavier. Radio Modeller photo.

Elevator and rudder proportions

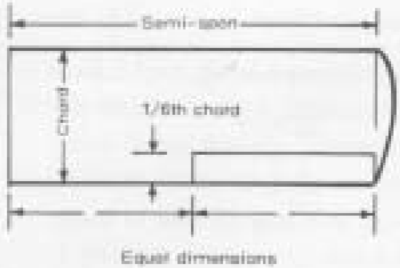
Elevator and rudder areas of the proportions shown in *figure 17.5* are generally satisfactory for all multi-channel models, with the movements indicated. Movement can be reduced, if response appears too drastic, but should not be increased over the recommended figure. If maximum movements give less response than required, this may be due to some inherent 'stabilising' feature in the design layout, or merely require a small increase in control surface area. Although full movements do not *have* to be used with proportional control it is desirable that the full movement should not produce *more* response than is required. This will avoid over-control being accidentally selected, and also produce the finest graduation of response over the complete movement of the control stick.

It is not necessary to employ either aerodynamic or mass balancing of model control surfaces. The power available from servos is more than adequate to overcome aerodynamic loading as the control is moved from its neutral position, i.e. no relief of loading by aerodynamic balancing is required. The system should also be quite rigid so that, with good hinge construction, flutter is unlikely to be a problem.

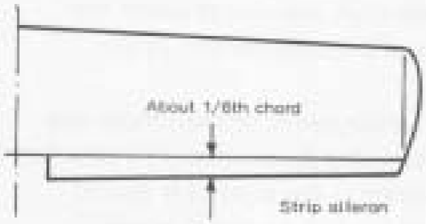
Ailerons

The direct response to aileron movement is that an aeroplane is induced to roll. Depending on the amount of aileron movement, this will put the aircraft into a banked turn (or with more severe movement make the model perform a complete roll about its rolling axis). Movement about the rolling axis, however, will induce reactions in the other two axes. Interaction can vary from very slight—e.g. the model performing a banked turn with little loss of directional stability and little loss of height—to complete instability resulting from excessive aileron forces. The latter is usually caused by lack of *directional* stability in the design. Thus a reserve of *directional stability* is an essential feature in any aircraft design. This is normally provided by a fin of suitable area.

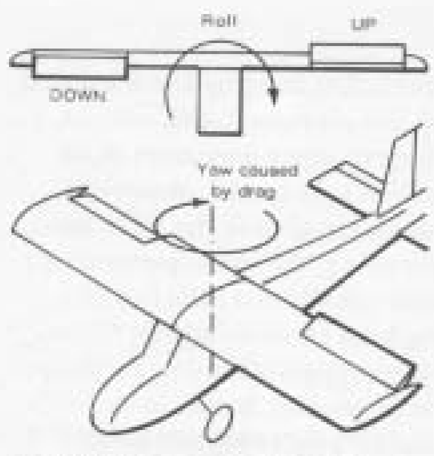
Typical functional aerobatic model layout for proportional control. Features low wing layout and tricycle undercarriage.



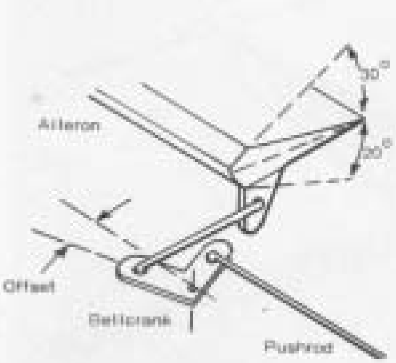
17.9 Typical inset aileron proportions.



17.10 Typical strip aileron proportions.



17.11 Down aileron movement tends to create drag, yawing the model into the opposite direction to the aileron induced turn.



17.12 Differential aileron movement—more up than down.

Lateral stability is governed largely by the wing dihedral, and here again a certain reserve of stability is needed to prevent slipping developing in a turn. Again, too, dihedral must be matched to fin area, as sideslipping will also affect directional stability.

The solution must therefore be a compromise: enough dihedral to provide the reserve of lateral stability required, but not so much lateral stability that the rolling action of the elevators is resisted. Too little dihedral will tend to induce instability developing during turns. Too much dihedral will tend to reduce the effectiveness of the ailerons as a control. The ideal solution is to reduce dihedral, and thus improve aileron performance, up to a point where instability is just starting to show up. This is then the limiting dihedral for that design.

Proportions for conventional inset ailerons on models tend to be similar to those on full size aircraft. Thus scale ailerons sizes should be quite satisfactory on a flying scale model. On freelance designs there is some advantage to be gained by increasing the aileron chord slightly (see *figure 17.9* for typical model proportions). The actual aileron area is not critical, as movement is more effective than area in developing aileron forces.

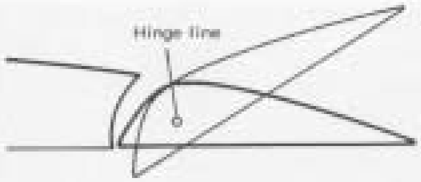
Inset ailerons are always fitted near the tips of the wings, and preferably extended right out to the top. In the case of biplanes, better response is produced if both top and bottom wings are fitted with ailerons of equal size.

An alternative type of aileron which has proved popular on model aircraft is the full span strip aileron. This is a narrow chord section, hinged directly to the trailing edge of the wing, and preferably taped in plan form from root to tip (*figure 17.10*). Better aileron response is claimed for this type of aileron, but the main advantage is the purely practical one of a strip aileron being easier to make and fit. Experience has ultimately shown that as regards performance there is little to choose between inset and strip ailerons. The strip aileron, however, does have rather less adverse yaw effect than inset ailerons, especially if well tapered towards the tip.

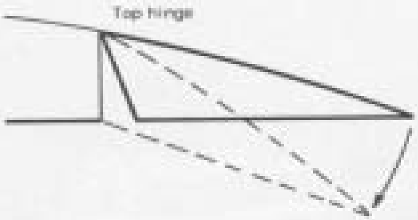
Yaw as well as roll is an inevitable response to aileron movement. The movement of one aileron up, and that of the opposite aileron down produces a dragging effect on the down aileron side (*figure 17.11*). It will also be appreciated from this diagram that the angle of attack of the wing tip on the 'down' elevator side is increased, and with excessive down movement the wing tip could be stalled. The resulting loss of lift would then produce a rolling moment in the *opposite* direction to that initiated by the original aileron movement.

To minimise the yawing effect, and reduce the possibility of stalling the inboard wing in a turn, ailerons are invariably operated with a *differential* movement—more 'up' movement than 'down' (*figure 17.12*). Typical *maximum* values are 30 degrees of up movement, and 20 degrees of down movement. These maximum movements are only likely to be required for producing rolls. Turns can be initiated with smaller movements.

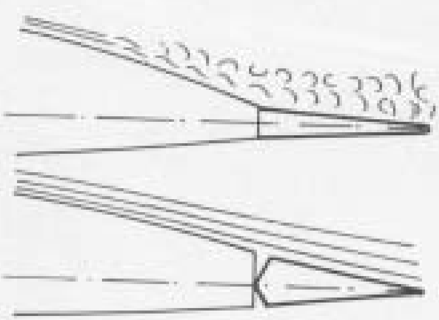
The leading edge of the aileron can also be shaped to provide the



17.13 Frise aileron shown in neutral and up positions.



17.14 Top-hinged aileron.



17.15 Masking effect of thick aerofoil section on a thin strip aileron.

same effect as differential movement in offsetting the adverse yaw effect. The *Frise* aileron is a typical example of how this can be done. The aileron leading edge is bevelled, and the hinge line moved aft, so that when the aileron is 'up' a proportion of the section projects below the bottom of the wing surface. The drag of this section helps counteract the drag of the 'down' aileron on the opposite wing.

Such complication of shape and hinge positioning is generally avoided on models. The simplest solution in the case of inset ailerons is usually a top hinged aileron, with enough chamfer on the leading edge to provide the necessary down movement (*figure 17.13*). The gap at the bottom of the section in other than the 'down' position is not likely to be significant, although it can be sealed with an overhung strip fairing. Other aileron forms are shown in *figure 17.14*.

The strip aileron is usually centre hinged, since it is mounted directly on a narrow depth of wing trailing edge. In this respect it can suffer from a disadvantage not suffered by inset ailerons. If the wing section is thick, the airflow over the after section is likely to be highly turbulent at almost all angles of attack. As a consequence the thin aileron section is effectively 'masked' by the thick aerofoil section in front of it, and may have a poor response as a consequence. It may be necessary in such cases to employ a substantially thicker section for the strip aileron so that it can conform to a 'complete' aerofoil profile (see *figure 17.15*).

Whilst radio controlled gliders have tended to become bigger and follow full size sailplane designs, there are the successful exceptions to this rule.

18 RADIO CONTROLLED MODEL BOATS

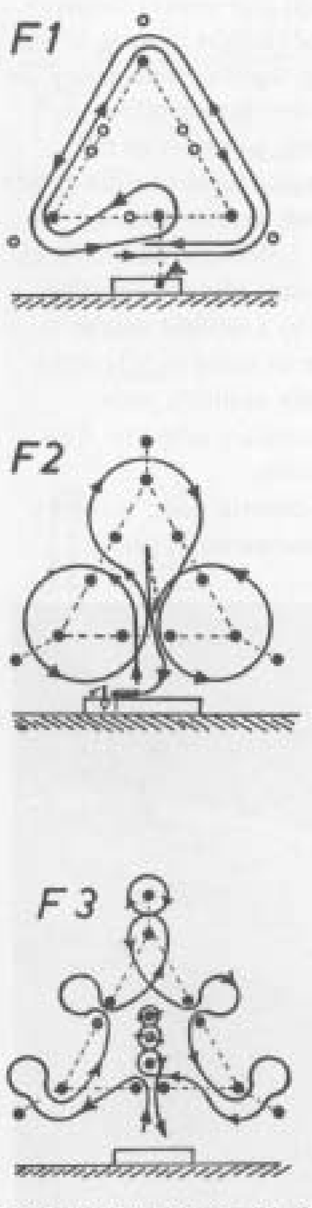
Model boats need fewer services for complete *functional* control than model aircraft. Thus the primary control is *rudder*. Only one other control is then *necessary* for 'complete' command—of motor speed in the case of a power driven boat, and of sail setting in the case of a model yacht. There is also one other major difference from aircraft. Response to control movement is slower, and since a boat travels only on a single surface, over-control or any interaction between controls is not likely to have drastic consequences.

Model boats can be divided broadly into three categories:
(1) slow speed boats driven by electric motors
(2) high speed boats driven by diesels, glow motors (or spark ignition motors in the case of larger hulls)
(3) yachts and other sailing craft.

There are other possibilities, but these fall into the general categories of 'slow' or 'high speed' boats, and control requirements are similar. Thus a steam-engined powered boat would inherently have the characteristics of a 'slow speed' boat. It is also possible to obtain high speed performance with electric motor power, in which case the control requirements would be similar to that of other 'high speed' boats.

Model boats can also be classified as 'contest' and 'non-contest' types. In the former category the boats are designed for competitive use, conforming to national or international specifications. The best known of the latter are the 'Naviga' radio classes:
F1-E30 electric speed model with a maximum power of 30 watts.
F1-E500 electric speed, power limited only to 42 volts.
F1-V2.5 i/c engines 0-2½ cc
F1-V5 i/c engines 2½-5 cc
F1-V15 i/c engines 5-15 cc
F2 scale models, split into: F2a length from 80 cm to 110 cm. F2b length from 110 cm to 170 cm. F2c length from 170 cm to 250 cm or 1/100th scale if larger.
F3 freelance steering, divided into: F3E electric steering boats. F3V i/c engined steering boats.
F4 Balloon bursting, open to any boat, 10 balloons in 3 minutes.
F5 radio yachts (triangular course, 150 m) classified: F5-DF International 10/40 class (1 .o.a. 1 m., sail area 40 sq dm). F5-DM Marbleheads. F5-D10 10-raters. F5-DX unrestricted class, save that sail area must not exceed 50 sq dm.
F6 group manoeuvres (or team events) involving several boats (7 mins)
F7 scale exhibition models capable of a number of functions. Time for demonstration 8 mins.

Contests in 'Naviga' classes are held on a triangular course with 30 metre legs. The manner in which the course has to be negotiated differs for speed, scale steering and 'open' steering (*figure 18.1*). Design of power boat hulls is influenced accordingly.



18.1 'Naviga' courses, F1, F2 and F3.

Single-channel controls

Single-channel control is attractive because of its relatively low cost and can provide 'complete', if not comprehensive functional coverage. A rudder-only system would be suitable for low speed boats, but the use of a compound main actuator and a secondary actuator to provide motor control is always to be preferred. Bulk and weight of equipment is not usually important in a slow speed boat. Escapements are seldom suitable as boat control actuators, even with small, light hulls. Thus *motorised* single-channel actuators are the general rule. These will require the use of a relay receiver, or a relayless receiver switching the main actuator through a slave relay.

With slow speed boats the rudder control can be either self-neutralising with a 'bang-bang' movement, or progressive. There are arguments—and preferences—favouring each type. In general, however, an S/N actuator is to be recommended. This will give central rudder with no control. The model can be trimmed for straight running in this condition, either offsetting the neutral position slightly, if necessary, or using fixed trim tabs or wedges to counteract any turning effect produced by propeller rotation. Control available will then be full rudder in either direction, giving more or less equal turns to right or left on command. Turn radius can then be decreased, as necessary, by manipulating the control button in a 'blipping' fashion, as described for single-channel aircraft (Chapter 11). The advantage of a self-centring rudder is that the craft can always be returned to a straight course simply by giving no signal. The other advantage of using an S/N actuator for the main service is that this type is readily available with additional switching built-in for operating a secondary actuator. Few progressive actuators are produced with this facility.

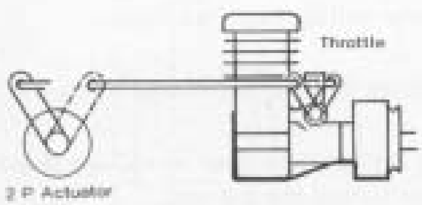
The use of a progressive actuator for rudder control does, in theory at least, mean that any degree of turn can be 'inched on', in either

Scale model boats powered by electric motors offer tremendous scope for radio control. Many kits are available for boats, often with preformed plastic hulls to save building time.

direction. However, with simple single-channel working the actual rudder position is never known. It can only be estimated by observing the response of the model. This means that numerous 'inching' movements may be required to set the model on a particular course, which will have to be repeated to take up another course.

The general tendency will be to steer an 'S' course rather than a straight course, with general lack of precision in directional control. This need not matter so much where the model itself has good directional stability. Thus a progressive actuator could be used for rudder-only control on a model yacht, using it basically as a *trim* control, rather than straightforward steering.

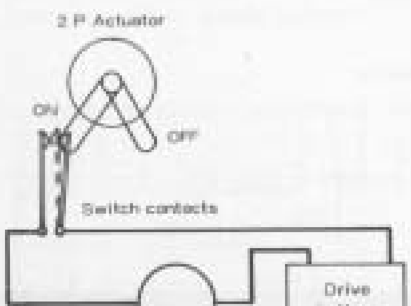
The faster power boat inevitably requires an S/N actuator for rudder control to produce an automatically 'safe' control position (neutral rudder) when control is released. The main problem here, as the speed of the model increases, is to balance the rudder size and position to give fully effective steering from a 'bang-bang' control movement without upsetting the stability of the hull. Too large a rudder and too much movement, for example, could even make a high speed model roll right over by forcing it into too tight a turn.



18.2 2-position throttle control for diesel or glow motors.

Stability in turns, and response to rudder movement, is largely governed by hull design. High speed hulls, and other 'performance-type designs are developed with the particular response characteristics required in mind. Single-channel control, which necessarily means bang-bang rudder movements, can still have limitations, however.

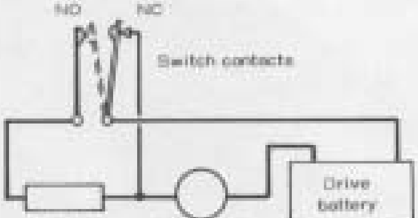
Speed control, operated by a secondary actuator, is essentially the same as for aircraft systems where the boat is powered by a diesel or glow motor (see Chapter 16). There is the choice of a 2P or 4P sequence actuator, the respective merits of which are largely dictated by the throttling characteristics of the engine used. Straightforward 'high' and 'low' speed controls, as given by a 2P actuator are the simplest, and usually the safest, to use on high speed craft.



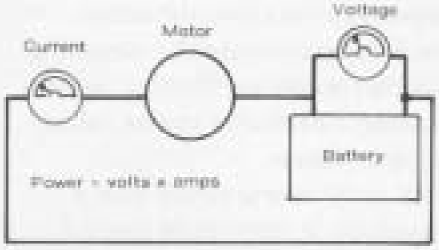
18.3 On-off switching controlled by a 2P actuator.

Speed control of electric-drive motors represents quite a different problem and there are several possibilities. All simple systems, however, must be based on switching the motor circuit. The direct way of doing this is to utilise the actuator movement positions to operate switches capable of carrying the motor current—preferably microswitches with a suitable current rating. A limited number of marine-type actuators are also available with built-in (or added-on) switchers. Switchers are, however, commonly home made.

A single switch can obviously provide 'run' and 'stop' control via a 2P actuator. Thus the secondary actuator movement, tripped by a 'quick blip' signal, gives either motor 'on' or 'stop' (*figure 18.3*). However, 'stop' is less useful as a control than 'slow'. A more attractive arrangement is use the NO contact of the switch to wire in a resistor. The NC position of the switch then provides fast running, and the alternative position connects the resistor in the motor circuit as a 'voltage dropper' make the motor run at a slower speed (*figure 18.4*).



18.4 Switching circuit giving slow speed in one switch position; fast in the other.



18.5 Current flowing in motor circuit, and battery voltage, can be measured with meters.

The value of resistor required can be calculated as follows:

(1) The current drawn by the motor under normal (full speed) running with the boat in the water must be measured. Call this I (fast) amps.

(2) The power of the motor under normal operating conditions is found by multiplying the running current I (fast) by the battery voltage (V). This will give motor input power in *watts*.

Note: the power calculated in this simple manner is not quite correct. Under *free* running conditions the current will be less than that measured with the boat held static in the water. Also the *effective* voltage across the motor will be less than the battery voltage. This means that the power calculated will be higher than the *true* free running power. The difference can be ignored, however.

(3) Decide on the 'low speed' required, e.g. half speed or one quarter speed. Since motor speed is more or less directly proportional to voltage, this will give a figure for *motor* voltage required for the selected slow speed.

(4) Deduct this from the battery voltage to find the voltage which has to be *dropped* by the resistor.

(5) Estimate the 'low speed' current on the same basis as voltage above, i.e. half the speed would be equivalent to half the current.

(6) The resistor value required then follows by dividing the voltage to be dropped (from (4)), by the 'low speed' current estimated in (5).

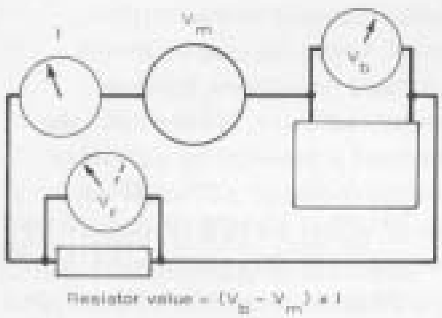
A worked-out example should make this clear. Suppose the motor is worked off a 10 volt battery and the measured current for fast running is 2 amps.

(1) I (fast) = 2 amps

(2) power = 10 volts x 2 amps = 20 watts

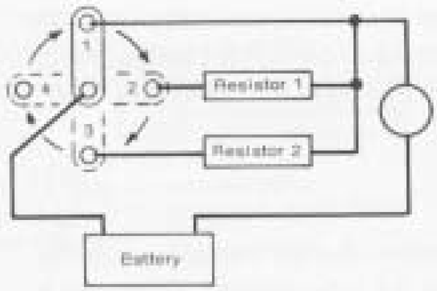
(3) 'Low speed' is to be *one half* speed. The motor voltage required will thus be 10 x ½ = 5 volts.

(4) The voltage to be dropped by the resistor is thus 10 – 5 = 5 volts.

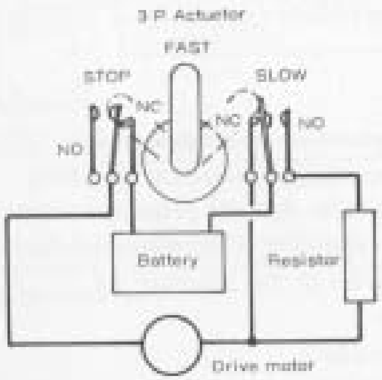


18.6 Dropping resistor value required is calculated from current and voltage readings.

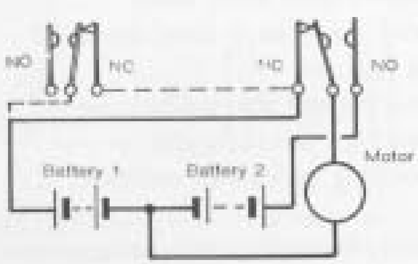
Example of moulded glass fibre hulls for radio controlled powerboats.



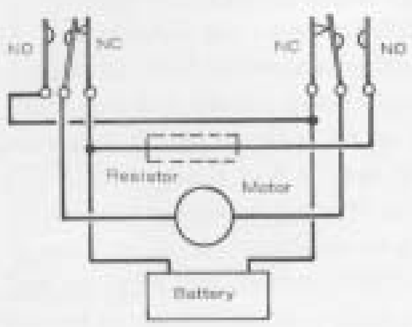
18.7 Variable speed control via separate dropping resistors, selected by position of sequence switcher. Position 4 is 'stop'.



18.8 Switching circuit for 3P acutator giving two motor speeds, and stop.



18.9 Circuit using two batteries for 'ahead' and 'astern' switching.



18.10 'Ahead' and 'astern' switching from a single battery.

(5) At half speed the motor will draw one half the fast running current, i.e. ½ x 2 = 1 amp.

(6) The value of the dropping resistor required is thus 5 ÷ 1 = 5 ohms.

One other point must be observed. This resistor will be dissipating a power equal to the voltage dropped and current flowing through it—in this case 5 x 1 = 5 watts. It is important that the type of resistor should have a rating at least equal to the calculated wattage, otherwise it will be in danger of burning out.

Use of a dropping resistor in this way is *wasteful* of battery power, but this is generally acceptable for straightforward speed control of electric motors. The principle can also be extended to multiple speed control by using a multi-position switch instead of a simple switch, which is stepped round one contact at a time, in sequence, by each 'motor speed' signal. Such a switch can be designed as a complete unit operated by an electromagnetic coil and rachet-and-pawl type mechanism, eliminating the need for a secondary actuator (i.e. it takes the place of the secondary actuator). In this form it is generally known as a *sequence switcher.*

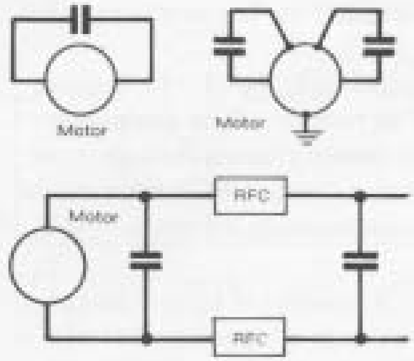
Each outlet can then have a different resistor connected to it, leaving one with no resistor (for 'full speed') and another disconnected (for motor 'stop') (*figure 18.7*). The arrangement tends to become unnecessarily complicated, however, as multi-stepped electric motor speed controls are seldom necessary.

One switch for changing over from 'fast' to 'slow', and another for providing 'stop' are usually all that is necessary. This switching system can readily be worked by a 3P selective actuator, using the intermediate or middle position of the actuator movement to give normal 'full speed' running (see *figure 18.8*). Regardless of the last signal given, when the motor is running 'full speed' the next signal will then give either 'stop' or 'slow'. Also the next signal from either stop' or 'slow' will be 'full speed'.

For many types of electric powered boats, switching facilities to provide 'ahead' and 'astern' may be preferable to forward speed control only. A basic approach here is to use two batteries, one for ahead and one for astern, using the switch movement to change from one battery to the other and at the same time reverse the polarity of the supply to the motor causing it to run in the opposite direction (*figure 18.9*). Using a 3P actuator and a second switch, a 'stop' position can also be added.

The advantage of using a separate battery for forward and reverse running is that the reverse battery can be of lower voltage, since normally lower speed running is required in reverse anyway. Speed in this case is dropped without the need for a dropping resistor.

'Ahead' and 'astern' switching can also be derived directly from a single battery, as shown in *figure 18.10*. With a 3P actuator, this can also provide a 'stop' position. Note that although this circuit provides reversion of battery polarity at the motor for running astern, if slower speed is required when running 'astern', then a dropping resistor will have to be included in this side of the circuit.



18.11 Three methods of suppression applicable to electric drive motors. RFC is a radio frequency choke (coil).

The circuits described, which cover the main types used with single-channel, have all dealt with the switching of permanent magnet motors. Motors with wound field coils as well as wound armatures may need different connections.

Suppression

With electric drive motors it is imperative that the motor be properly suppressed to avoid interference with the radio receiver. Treatment is the same as for motors used as actuators (see Chapter 15), but simple single-capacitor suppression is unlikely to be fully effective in the case of larger motors, or those drawing high currents. Much depends on the commutator design and brushgear of the motor. Typical drive motor suppression treatments are shown in *figure* 18.11.

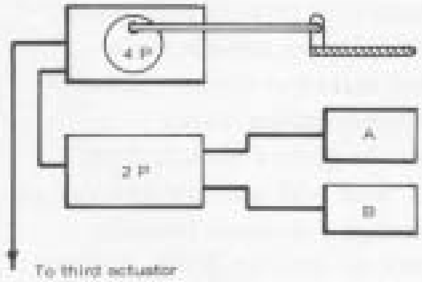
Extension of services

The larger size of slow moving boat, powered by an electric motor, lends itself to extension of the control services by sequence switching derived from the main actuator. It is advisable that the primary control, i.e. rudder, be kept out of the sequence extension. This means operating the rudder from the two 'main' positions of the actuator, i.e. selected by the simplest commands thus:
press and hold for right rudder (or left rudder)
press-release-press and hold for left rudder (or right rudder)

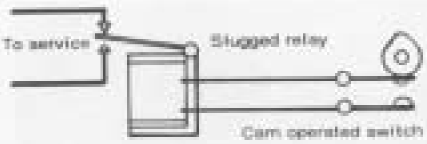
Two other positions are then available on a 4P actuator, both of which correspond to (substantially) neutral rudder position. These positions can be used to close electrical contacts when 'held'.
Press-release-press-release-press and hold would show close one set of auxiliary contacts, operating a second actuator.
Press-release-press-release-press-release-press and hold would close another set of auxiliary contacts, operating a third actuator.
There is also the possibility of incorporating 'quick-blip switching as well, to operate a fourth actuator.

One of these actuators would normally be used for drive motor switching (e.g. ahead-stop-astern) using a 3P actuator. It is preferable that this control be easily signalled, particularly as it is worked on a sequence basis, and so this would best be allocated to the 'quick-blip signal (selecting a type of main actuator which provides this facility).

Two other actuators are then available for operating additional services, and again each can provide further sequences. A 3P actuator, for example, can switch either of two additional circuits in a sequence of A on—both off—B on—both off—A on, etc. (*figure 18.12*). It is even possible to provide further cascading to use the A or B actuators to switch two *more* circuits in each case, further extending the services available from a single single-channel system. The difficulty, of course, is that signalling a particular service can be extremely cumbersome, and sequences may readily be 'lost'. Thus ancillary services provided by cascading actuators should be those which do not affect the control or safety of the boat. It does not really matter if a sequence is 'lost' and



18.12 Linking additional services via secondary actuators.

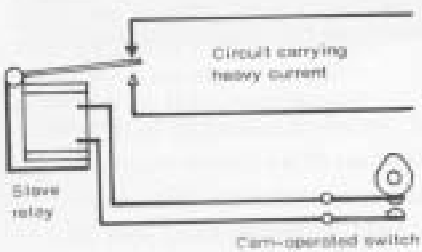


18.13 Slugged relay can delay pulling-in or dropping-out, depending on type used.

the command given raises or lowers a flag instead of blowing a siren, for instance.

Another problem can arise with extension or sequence switching. Using motorised actuators, a signal must be held for a certain time in order for the actuator circuit to remain complete during the full transit time of the actuator, otherwise the required movement will not be completed. To operate a motorised actuator from a 'quick blip signal, or any signal which is momentary rather than held, a form of hold or delay must be incorporated in the actuator circuit.

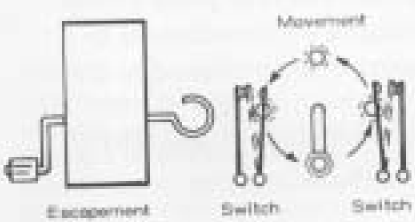
One way of doing this is to switch the actuator circuit through a slugged relay which has a delayed release or suitable period. The relay coil is connected to the command switching contacts, pulling the relay armature in when these contacts are closed. On release of signal the relay coil circuit is broken by the switching contacts opening, but the relay armature remains pulled in by residual magnetism for a further period of time, eventually releasing as the magnetism decays. Provided the delay time is suitable, the actuator circuit taken through the *relay* contacts thus remains closed for the transit time of the actuator (*figure 18.13*).



18.14 Slave relay with heavy-duty contacts should be used for switching large currents.

Electronic delay circuits can also be used, and motorised actuators designed for 'quick-blip' response normally have such circuits built in.

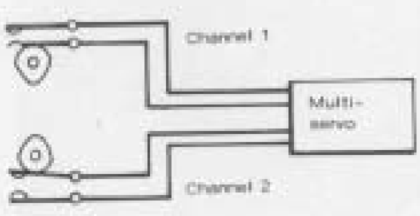
Switching circuits included on the main actuator may have to work through a relay, rather than directly to close a secondary actuator (or motor) circuit. Simple built-in switching contacts generally have a maximum current rating of about 2 amps, and may be less. If the actuator switched by these contacts draws a higher current, the contacts will be overloaded. A relay enables the higher current circuit of an actuator to be 'isolated from the contact circuit which then only has to carry enough current to operate the relay (*figure 18.14*).



18.15 Showing how the crank of an escapement can operate two sets of switching contacts. Contact springs must be light to avoid stalling the escapement movement.

Single-channel escapements can also be used directly as switchers (*figure 18.15*). An advantage here is that an escapement movement is rapid, and so it will readily trip from one position to the next on a momentary or 'blip' signal, eliminating any need for a delay relay or delay circuit, if the switching contacts control a motorised actuator, or electric motor. Again, however, it may be necessary to switch a motorised actuator circuit through a relay.

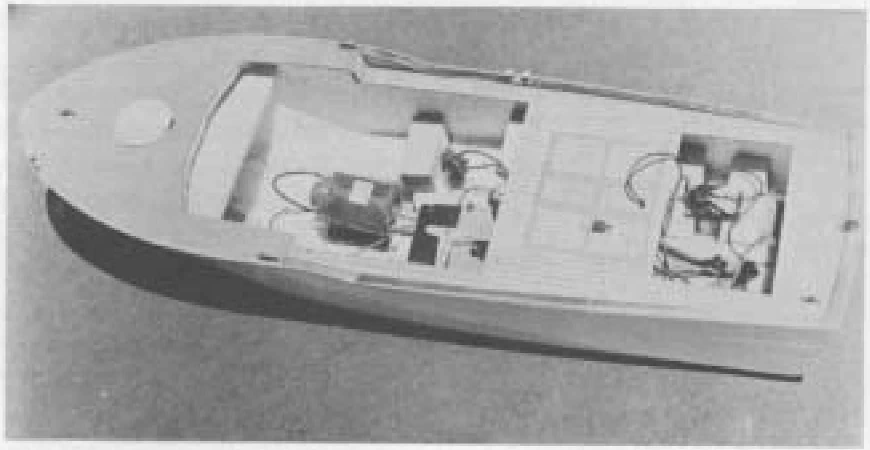
Twin switching circuits can, of course, be used to control a *multi -channel* actuator by providing the necessary reversal of current direction on alternate signals. In this respect the circuit is similar to that used for drive motor switching (*figure 18.16*).



18.16 Twin switching circuits controlling a multi-servo.

Another system favoured for the extension of control services with single-channel operation is to use one switching facility on the main actuator to control a sequence switcher. This can provide multiple switched outlets for operating ancillary services 1, 2, 3, 4 etc. in sequence (*figure 18.7*). Thus starting from an 'off' position (switching position not connected to anything) the first command signal for the switcher will complete the circuit for service 1, the next signal will complete the circuit for service 2, and so on. Again a delay relay (or delay circuit) may be needed for 'blip' signalling.

Simple radio installation in a small cruiser-type hull. Electric drive motor is seen amidships, with switching servo alongside. Rudder servo is seen in open hatch section aft.

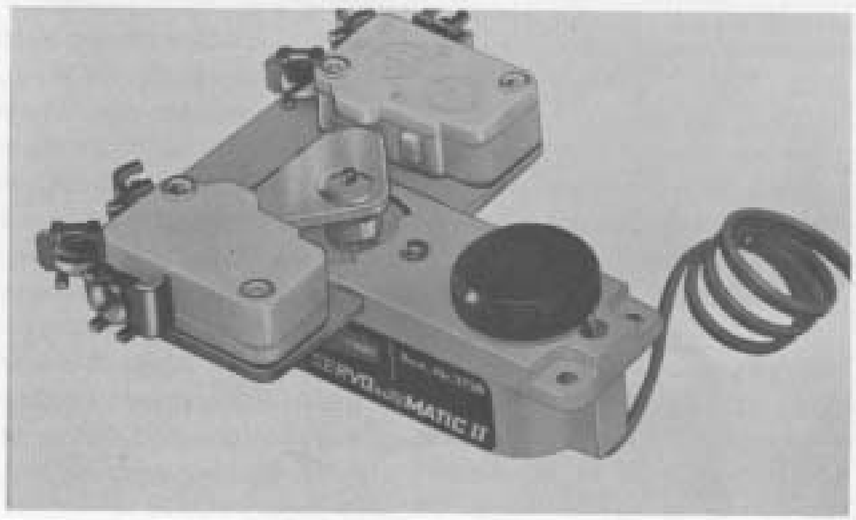


This system is generally superior to cascading actuators to provide ancillary services, although the construction of a suitable sequence switcher may be beyond the ability of many modellers. Virtually nothing is available in the commercial field, although some special boat-type main actuators do have a system of built-in sequence switches.

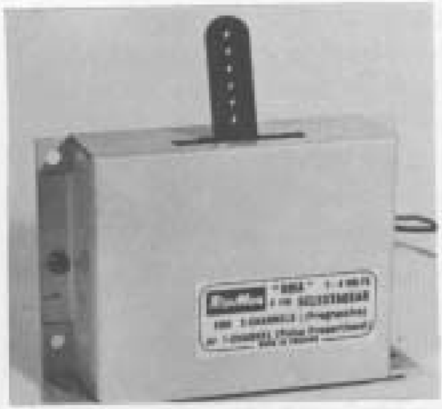
Selection of a particular sequence position is simplified by the use of a bleep box on the transmitter, which can also be fitted with a telephone-type dial. Theoretically, at least, the operator has only to dial the sequence number required, when the bleep box will transmit the necessary number of command signals to step the sequence switcher round to this position. In practice, such a system can prove fallible, with frequent loss of sequence and difficulty of re-positioning to restore the sequence position of the switcher to correspond to that of the transmitter control.

All multiple control systems derived from simple single-channel working, in fact, have this element of fallibility.

Tiny electric motors like this with plug-on gearboxes are very useful for powering ancillary services.



Example of 3P actuator fitted with microswitches. A number of actuator manufacturers offer these 'add on' switches.



What is basically a progressive-type 'multi' servo can also be used on single-channel pulse proportional.

Pulse proportional controls

Pulse proportional derived from single-channel equipment has proved quite successful on small model power boats with electric drive motors. The pulse-proportional actuator provides direct and reasonably proportional rudder movement, and can also incorporate switching facilities for electric drive motor switching.

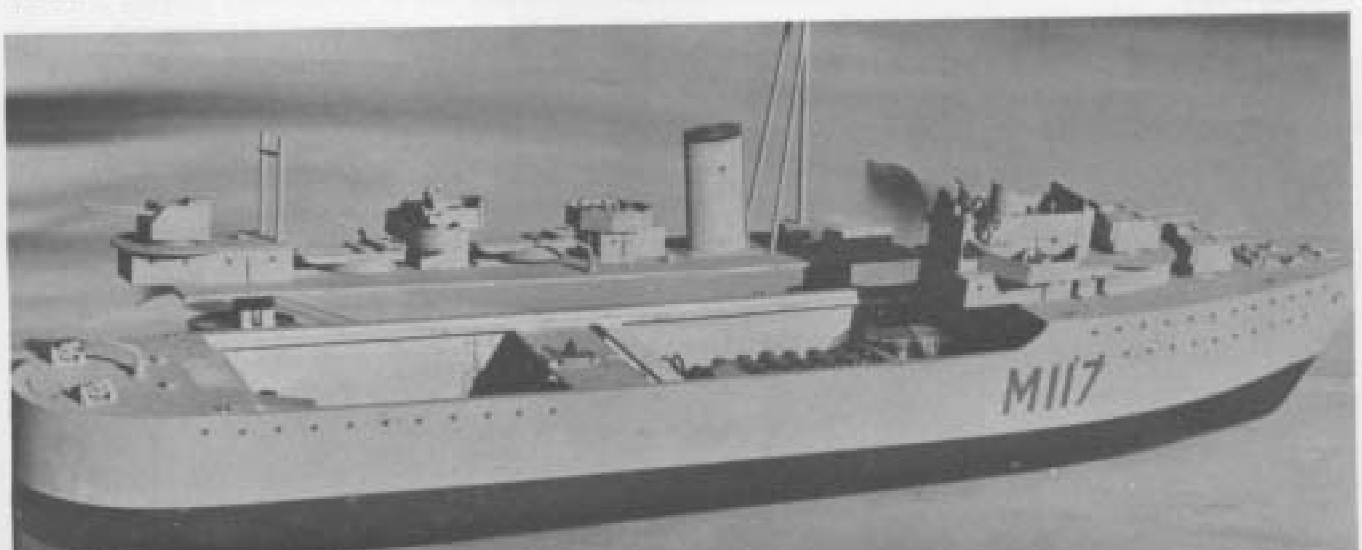
The two main limitations of pulse proportional rudder control are (1) that the current drain in the actuator motor circuit is high, and the actuator is working under rather drastic load conditions which can result in a relatively short life; and (2) that actual rudder movement can be affected greatly by the water load. The latter usually means that positioning is far less 'proportional' to control-stick movement than in aircraft installations using the same system. Otherwise the system is essentially the same as that described in Chapter 8.

Because of the relatively low actuator power available, and the continual oscillatory movement of the rudder, pulse proportional control is not suitable for larger high speed boats, e.g. those powered by internal combustion engines. It is suitable for smaller electric powered boats, particularly those which are slow speed types.

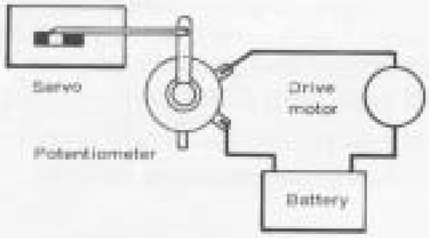
Multi-channel systems

Multi-channel systems have a considerable attraction for boat controls, even though 'proportional' rudder control is not possible. This is because the switching outputs provided by a multi-channel reed bank provide more versatility than true proportional systems for the operation of ancillary services. As with aircraft systems, however, they are not as good as true proportional controls for operation of the main functional control rudder.

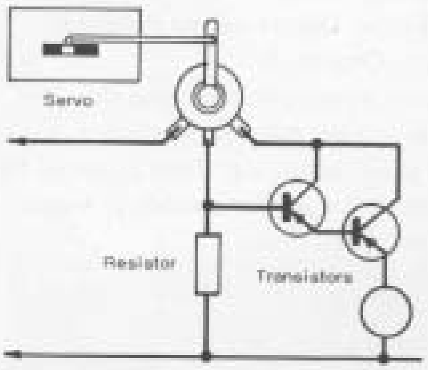
For rudder control, the choice lies between using a progressive multi-servo, or a 'bang-bang' type with self-centring on release of signal. Progressive control may be preferred for slow moving boats, but an S/N



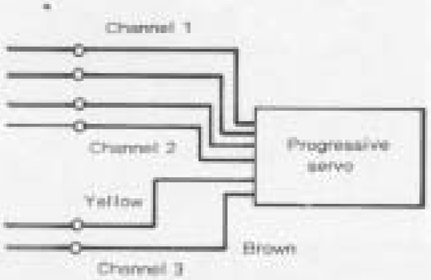
A removable deck section is always advisable to obtain ready access to the radio and battery installation on a boat. Make sure that such hatches or openings are watertight when the model is assembled.



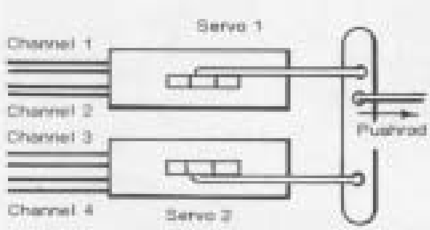
18.17 Variable motor speed control from a potentiometer driven by a progressive or proportional servo.



18.18 Simple electronic switcher circuit.



18.19 Three channel operation of progressive servo for self-centering.



18.20 Use of two servos for variable rudder positioning—working on the same principle of aircraft 'elevator trim' movement.

servo is almost invariably used for rudder control on faster models.

Motor speed control can be operated by a further channel (i.e. worked like a single-channel system); or by two additional channels. Thus 3-channel multi can provide complete functional control; but 4-channel is to be preferred on high speed models since this will also make the motor speed control fully positionable (see also Chapter 12).

The power available from a motorised servo, together with the selective (right or left) movement of a progressive type multi-servo can introduce advantages for electric drive motor control. For example, instead of a fixed value dropping resistor for speed control the servo can be used to drive a potentiometer for fully variable speed control. This can be a fully mechanical system (*figure 18.17*); or incorporate an electric switching circuit (*figure 18.18*), for infinitely variable speed control.

Additional channels available can be used to improve the quality of functional control. In many respects the use of a progressive servo for rudder control is superior since it enables different degrees of turn to be selected by 'inching' movements of the control stick, rather than by 'pulsing' the signal. The main limitation of the system is the lack of self-centring or return to neutral rudder position for straight steering, or recovery from over-control. With an additional channel available it is possible to add self-centring to a progressive servo, by the addition of the switching circuit shown in *figure 18.19.* Operation of the third channel will complete the switching circuit, which will then drive the servo motor to a central position and automatically switch off.

With only a 3-channel outfit, this system may be preferred, sacrificing motor control. A 4-channel outfit would enable self-centring rudder to be incorporated, and sequence operation of motor control.

An alternative use of 4-channels for functional control is to employ both *pairs* of channels for rudder control via S/N servos. These can be linked in a similar manner to an aircraft trim control, one servo providing small rudder movement and the other a larger movement (*figure 18.20*). Thus two degrees of turn can be immediately selected in either direction—a shallow turn and a steep turn. It is also possible to use the two servo movements to give 'sum' and difference' rudder positions, making *four* selectable rudder positions on each side. This should provide more than adequate flexibility of rudder control, with every position self-centring on release of signal(s). The main difference with 'sum' and 'difference' working is that for intermediate rudder positions set by 'difference' the two rudder control sticks must be moved in opposite directions, which is not a natural form of control movement.

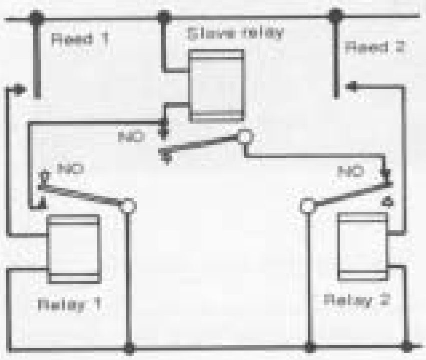
Instead of providing a 'trim' movement, the rudder may be split so that one part is operated by one actuator and the other part by the second actuator. Split rudders can be operated separately to provide different degrees of turn; simultaneously to provide a minimum radius turn; and in opposition to produce a shallow turn.

The main advantage of a 4-channel rudder control system over a 3-channel working of rudder is that the need for special contacts and modification of the reed bank circuit is avoided.

On the above basis, a 5- or 6-channel system will provide the best coverage of functional control requirements with multi working, the additional channel(s) being allocated to motor control.

Additional services

Similar considerations apply as in the case of single-channel controls. The main functional controls–rudder and motor control–should be independent of any additional services which are to be provided. Thus rudder and motor control should always be operated by separate channels, and only spare' channels left over in the outfit used for ancillary controls and services. *Each* 'spare' channel can then be used to operate an individual service on the basis of single-channel operation (i.e. via a single-channel actuator); or *pairs* of channels can be used to operate additional services via multi-channel servos. The former obviously doubled the number of separate services available. The number of services can be further increased by cascading or sequence switching, applied to a single channel. The more one departs from conventional 'multi' working, i.e. two channels controlling one mutli servo–however, the more one loses the basic advantage of 'multi' over single-channel in providing direct and selective switching in response to the command signal.



18.21 Latching circuit based on relays.

Relay latching

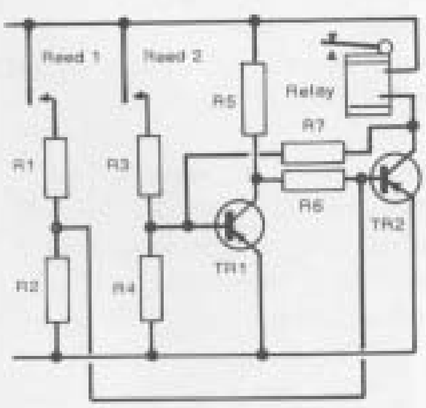
Multi-channel reed outputs readily enable the relays operated by individual reeds to be *latched* or held in, following a momentary signal. To achieve this a slave relay is introduced into the circuit embracing a pair of reeds and their respective switching relays (*figure 18.21*). Operation of reed I pulls in relay I, closing its contacts to energise the slave relay.

The slave relay contacts now complete a circuit through the slave relay coil and rely 2 contacts, so that on cessation of the command signal when relay 1 is de-energised, the slave relay continues to hold in. Operation of reed 2 will energise relay 2, breaking the slave relay coil circuit. Thus a signal on channel 1 latches the slave relay which is only released by the appearance of a signal on channel 2.

Note that it is the slave relay which acts as the 'switch' for the actuator circuit. The slave relay must therefore have two sets of contacts (one for 'latching' and the other switching the actuator circuit).

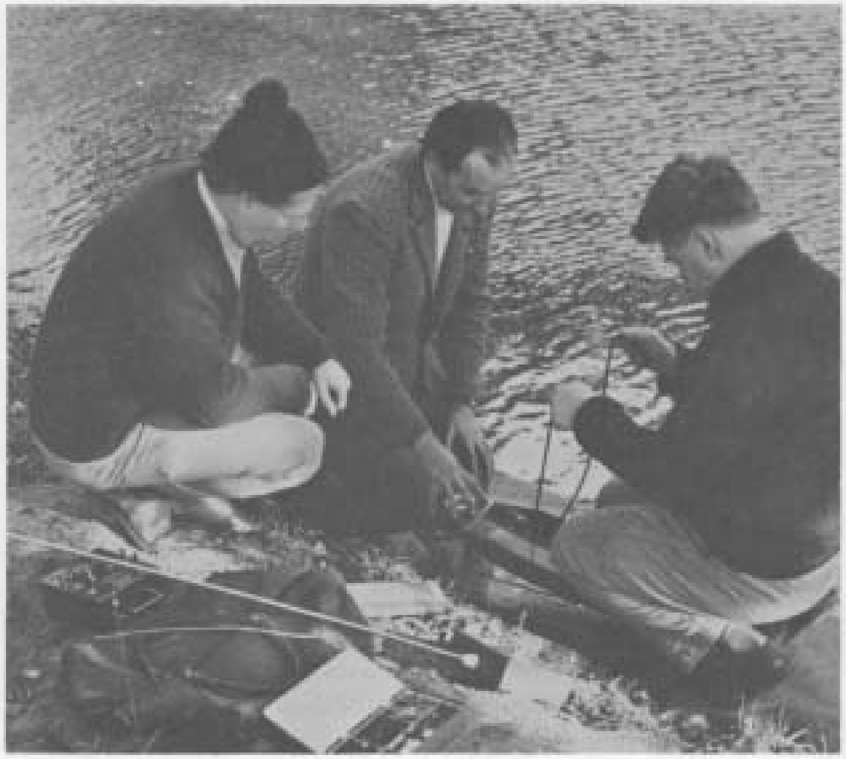
In the case of a relayless reed receiver a similar latching action can be provided electronically, using a circuit of the type shown in *figure 18.22*.

Such circuits are relatively simple to construct, mounting the components on a small Paxolin panel. Almost any type of AF transistor is suitable.



18.22 Electronic latching circuit with relay for output switching.

Diesels or glow motors are more powerful than electric motors and so the usual choice for fast powerboats. Starting is done by a cord, passed around the groove in the flywheel of the engine.



Proportional controls

Little need be said about proportional systems other than the obvious fact that they provide a superior type of rudder control to all other systems. Thus a '1 + 1' proportional outfit can provide complete rudder control, plus an additional control for single-channel working.

Proportional servos are invariably matched to a particular receiver, and choice is usually restricted to a single 'aircraft' type, which provides mechanical output movement, although alternative rotary and push-pull movements may be available. Ancillary services, therefore, normally have to be operated by mechanical switches worked by the servo output. There is little scope for adapting, or constructing, proportional servos incorporating special switching functions, except by a very experienced radio modeller.

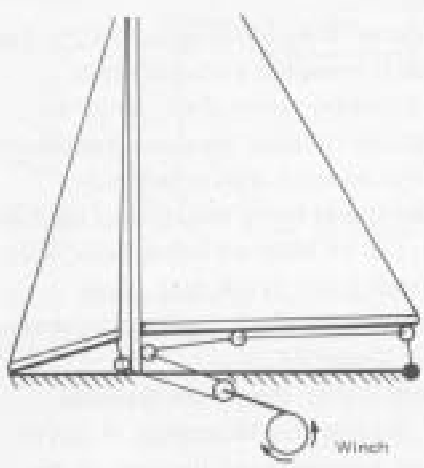
A limited number of proportional servos matched to specific commercial systems are, however, available for switching services. These are intended to be used instead of 'aircraft type' servos commanded by one of the system functions, e.g. to provide fully proportional electric drive motor speed control, in both directions, and stop.

Model yachts are a fascinating subject for proportional control, covering both steering and sail setting.

R/C Yachts

There is really no substitute for *proportional* rudder control on a model yacht. Single channel or S/N multi-rudder control is largely restricted to producing major changes in course, e.g. from one tack to another. Progressive rudder control is probably better, using multi, since this

18.23 Basic sheet hauling system.



18.24 With this sheet hauling system, jib and mainsail settings adjust themselves automatically.

does provide the more continual requirement of the directional control of a model yacht, i.e. 'trimming' the rudder to a suitable position. If additional channels are available, then the best arrangement is to combine a S/N or progressive servo for rudder control with a progressive servo to give trim. This will give the nearest approach to proportional control, but will require four channels to achieve. Simple pulse proportional rudder control is generally unsuitable, because of the rudder loads involved on a fast sailing yacht.

Rudder control can be allied to 'automatic' sail trimming control operated by a vane mechanism, although this is really a half-and-half solution. For complete functional control, sheet hauling needs to be added to rudder control.

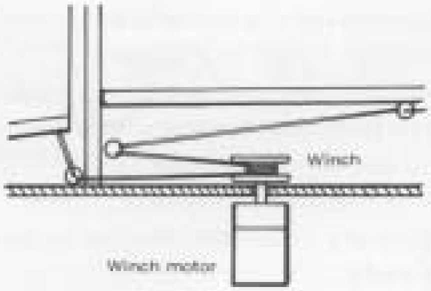
All sheet hauling systems are based on the same principle. Jib and main sheets are taken to a mechanical movement which either pulls in the sheets, or allows the sheets to pull out under the pressure on the sails (*figure 18.23*). The actual movement of each boom is controlled by the distance between the pivoting point and the attachment point of the winch. Thus if A is longer than B, the main boom would have more movement than the jib boom, following a movement of the controlling mechanism, and vice versa. In practice it is generally found best to make these lengths identical (i.e. A = B), so that each sail has the same amount of movement. This is not the invariable rule, however.

Another system which has found some favour in America is shown in *figure 18.24*. Here jib and main sheets are connected together and run over a pulley. This pulley is carried by the sheeting movement. Mainsail and jib settings are now 'automatically' variable at any particular setting. Thus an increase in wind pressure on the mainsail will tend to pull in the jib; and a decrease in mainsail pressure will set the jib more freely. This is known as a self-adjusting sail system. It is suitable for 'simple' sailing, but has severe limitations for racing or serious sailing.

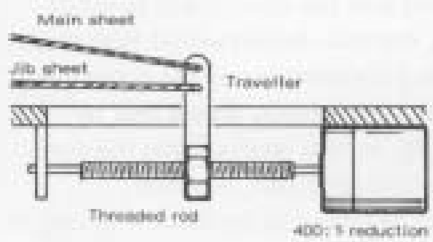
One of the simplest forms of sheet-hauling actuators is an electric motor driven winch. Because of the inherent high running speed of small electric motors reduction gearing is necessary to arrive at a practical winch speed. This will also have the advantage of multiplying the torque available from the motor. To haul in sheets on a larger yacht may take a pull force of as much as 10 pounds in a strong breeze. Transit time is not particularly important and can be as high as 10 seconds, if necessary, although 5-6 seconds is usually quoted as an optimum figure.

A further requirement is that the system be rigid. That is, wind pressure on the sails cannot 'drive' the actuator and so alter the sheet positions. A high reduction gearing will usually provide suitable irreversibility in the motion; and the use of a worm gear one stage in the train will virtually ensure complete irreversibility.

Winch-type actuators can be made from small electric motors fitted with suitable reduction gearing simply by attaching a drum to the motor output spindle. The drive needs to be progressive, and reversible, either by switching in the case of command by a single control channel; or directly selected by 2-channel multi or a single proportional



18.25 Deck-mounted winch for sheet hauling.



18.26 Traveller-type sheet hauling mechanism.

function. To prevent the motor stalling when reaching either end of its movement, the motor must also have a slipping clutch, or the motor circuit be fitted with limit switches which automatically switch off at the end of the movement (as with a progressive multi-servo, for example). Only limit switching will provide the necessary rigidity for a larger yacht. A slipping clutch might be acceptable in the case of a small yacht, but will still have to be set fairly tight. Thus the motor will probably be nearstalled at the end of its motion, drawing high current until the motor circuit is broken by release of the command signal.

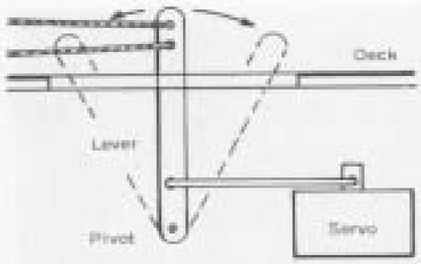
The advantage of a sail winch is that it can be installed neatly, with the motor below deck and only the winch above deck. It also lends itself to differential movements by using drums of different diameters for the jib and main sheets, mounted on the same spindle. The motor can be switched by a 3P progressive actuator, in the manner previously described for electric drive motor control.

An alternative system based on a motor is shown in *figure 18.25*. The motor drives a threaded rod, on which is mounted a traveller arm. Rotation of the threaded rod in one direction causes the traveller to move one way along the rod; and opposite rotation produces movement in the other direction. Movement of the traveller thus provides a push-pull motion for sheet hauling, the sheets being attached to the free end of the traveller. Again the system can be installed below deck, with either the traveller arm emerging through a slot in the deck (long enough to accommodate the traveller movement); or drawing the sheets through a suitable opening in the deck (*figure 18.26*).

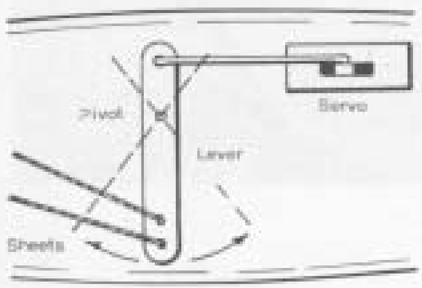
A particular advantage of this system is that, due to the traveller motion being linear, 'limit switching' is quite easy to arrange. It can be provided mechanically, for example, by turning down the ends of the threaded rod to form a plain section onto which the traveller runs at the ends of its travel. The motor can then continue to drive under light load with no further movement of the traveller. To ensure that the traveller immediately engages with the threaded rod when the motor reverses direction of rotation, a light spring can be fitted at each end to keep the traveller 'floating' against the end of the threaded section.

Lever-movement sheet hauling is another possibility. Here the push-pull movement is derived by a servo driving a pivoted lever. This

Sheet hauling winch and run of the jib and main sheets can be seen in this photo.



18.27 Sheet hauling by vertical, pivoted lever.



18.28 Sheet hauling by horizontal, pivoted lever mounted on deck.

lever can be vertically mounted and pivoted at the bottom, to provide fore and aft travel through a slot in the deck; or be a horizontal lever, nominally centre pivoted (*figure 18.28*). The latter is another type readily adapted to differential movements.

Arranging the sheet runs to provide the required movements is a matter of simple geometry. Each sheet is normally led through an eye mounted on the deck centreline. If both sheets are run directly from their respective eyes to a push-pull movement boom movements will be in opposition, e.g. hauling in the jib boom will slacken the main sheet, and vice versa. To produce similar movements—i.e. both booms either pulling in or moving out—one of the sheet runs will have to be doubled back so that both connect to the same side of the push-pull movement.

Boat installations

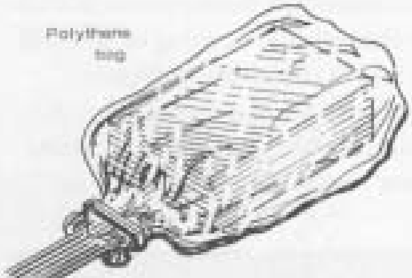
Dampness is the enemy of electronics—or even simple electrical circuits—and so radio control installations in boats require more careful treatment than given to aircraft. Ideally radio receiver, batteries and servos, should be installed in waterproof compartments; or better still, in waterproof containers. Failing that, the compartments in which these components are mounted should at least be splashproof, and free from the possibility of immersion in bilge water which may collect in the hull.

The simple method of 'waterproofing' the receiver and batteries by enclosing in polythene bags is often recommended. Such protection can be made waterproof by taking all wires through the opening of the bag, then binding this tightly over the wires with a rubber band (*figure 18.29*). Unfortunately this means bringing the aerial wire out with the current carrying wires, which is not desirable. Also a completely sealed packing can cause condensation to appear *inside* the bag at lower air

Another view of the same model, showing sheet hauling winch powered by its own motor. Rudder actuator is alongside.

Moulded glass fibre boat hulls save modellers a lot of time and effort and are available in a variety of designs and sizes.

temperatures. This possibility can be eliminated by including a sachet of silica gel inside the back, or opening the bag to allow it to 'breathe when the model is not in use.



18.29 The 'classic' method of waterproofing the radio side is to enclose the receiver in a polythene bag. This is not always the best method.

Where adequate space is available, receiver, batteries and on-off switch can be fitted inside a waterproof box, packed with foam rubber. Wiring can be taken through rubber grommets in the side of the box or preferably terminate in sockets on the side of the box to which external connection can be made with matching plugs. Plastic boxes are suitable for such purposes and the lid can be sealed with a binding of polythene or PVC adhesive tape.

In some cases it may be possible to mount receiver, batteries, switch all wiring and actuators in the same waterproof box, taking the out-put movements through rubber grommets. All anti-vibration mounting must then be done inside the box, so that the box itself can be rigidly mounted to ensure positive line up of the actuator movements. The particular advantage of such a system is that by incorporating a suitable coupling in the actuator movements outside the box the complete radio installation can be transferred from one model to another, with similar control layouts.

Quite commonly, however, especially on smaller models, the actuators or servos have to be mounted separately. They should be mounted high enough to be clear of any bilge water, and in a position where they can be protected from splash. It may be possible to provide almost complete protection with polythene sheeting loosely wrapping the complete actuator, and forming a closed bag by being bound to the output movement with a rubber band.

It is possible to produce a completely waterproof installation so that if the model sinks, for example, the radio equipment will remain protected and free from harm whilst the model is recovered. But this is difficult to achieve, and seldom really necessary for the average radio controlled boat. The simpler approach is to decide where water can splash, or appear inside the hull, during normal operation of the boat—including lifting in and out of the water—and provide 'water-proofing' or 'splashproofing' against such contingencies.

Rather more stringent precautions are necessary where the boat is operated in salt water, particularly to avoid dampness collecting inside the boat. Salt dampness can have a particularly corrosive effects on electrical contacts. Receiver relay contacts and reed bank contacts can be protected by sealing the complete units with a wrapping of poly-thene or PVC insulating tape—but actuator switching contacts can usually only be sealed by complete enclosure.

Commonsense will be a good guide to the best form of installation, plus practical experience which will inevitably be gained as to how dampness can affect radio installations, and how to avoid such troubles next time. The simplest installation is not always the best, as it usually is in the case of aircraft.

Getting ready for a speed run with a radio controlled model hydroplane.

Ultimate in radio controlled model cars is the scale (or near scale) racecar—operated in Grand Prix manner! Photo Radio Control.

19 R/C CARS AND VEHICLES

The application of radio control to model cars and other types of land vehicles is a field which remained relatively undeveloped up to about 1970. Prior to that most R/C cars were individually built, powered by electric motors and fitted out with non-proportional steering and forward-stop-reverse drive motor control. The availability of proportional radio, however, offered a type of steering and speed control suitable for high speed car operation. Commercial interest developed along these lines, producing a range of scale model racing cars powered by i/c engines (mainly glow motors), and capable of being operated as free running racers. This saw the start of radio controlled model car racing as a hobby-sport with an international following, based on a sophisticated type of model.

Apart from the performance and scale realism, (a high proportion of all males have fanciful ideas regarding their potential abilities as racing car drivers!) the attraction of the engine-powered, proportional controlled model car is that it well catered for on the commercial market. Numerous models are available in complete kit form, reducing building to mainly a matter of assembly, and component parts and body shells are available for the builder wishing to start from scratch, starting with his own ideas on chassis design. Standard proportional servos can be used for operating the controls. Aircraft type engines are used for the drive motor, fitted with a flywheel and driving through a centrifugal clutch and suitable reduction gearing to the driven wheels. Reduction gearing is essential because of the high running speed of i/c engines when developing maximum power. The combination of a throttled (R/C type) engine with a centrifugal clutch offers a complete motor speed control via a conventional proportional (or progressive) throttle action. At low speeds the centrifugal clutch is disengaged, allowing the motor to run with drive disconnected (clutch disengaged). An increase in motor speed will then cause the centrifugal clutch to engage at a particular speed. The remainder of the throttle range is then available for variable speed driving (clutch fully engaged over this range).

The use of an automatic clutch is generally to be preferred to a mechanical clutch which requires the use of a separate control, although separately-operated clutch controls have been widely used on engine-driven model cars.

The cars themselves are usually designed on 'full size' engineering lines, with sprung suspension for the front and rear wheels, and 'full size' geometry for the steering linkages. The steering servo output movement is coupled to this linkage through some simple form of shock absorber to avoid side loads on the wheels being transferred directly to the servo movement. One method of doing this is to mount the steering servo sideways on the chassis unit between the front wheels, with the output movement attached to the two steering arms via springs, which absorb the shock loads. A spreader bar can then be added to interconnect the steering links and keep the steering system rigid.

The third function required for 'complete' control is braking.

Typical prefabricated kit for a radio controlled race car.

Although the speed of the car can be controlled to a large extent by the throttle, closing the throttle too far would make the centrifugal clutch disengage and remove the 'engine braking' effect. Thus a mechanical brake is desirable. This can be a simple friction type, fitted to either pair of wheels (or even all four, if felt necessary). The *effect* of mechanical braking will vary with the speed and weight of the model and the type of surface over which it is running. Brakes, even proportionally operated, are generally the least effective of the controls, normally producing locked wheels and skidding at high speeds on smooth surfaces.

'Complete' control coverage can thus be given by a '2 + 1' proportional system; or a '3-function' system can provide proportional braking. Brakes can also be made available on a '2-function' system by using mechanical coupling to the throttle movement. Low speed throttle also pulls on the brakes. There are advantages of having brakes available as a separate control to throttle, however, for high speed driving.

Most of the earlier high speed R/C cars were relatively heavy, and sturdily constructed, weight being thought necessary to keep the rear drive wheels on the ground for good traction. Better performance is, however, usually achieved with lighter car weights, although the resulting construction is then more prone to crash damage. The 'mortality risk' of a high speed R/C car, in fact, is something on a par with high speed T/C aircraft, demanding considerable skill and fast reactions on the part of the 'driver' to avoid.

Simpler car models

The simpler car models are based on electric motor drives, often installed in plastic car models of suitable size or on scratch-built chassis units or 'pans' with plastic or wood body shells. Electric motors are simple to install in a small space, with the necessary reduction gearing, clean-running and easy to switch for stop-go, or forward-stop-reverse (see Chapter 18). Variable motor speed control is not necessary, nor in fact is proportional steering on a slow-speed car or land vehicle. Thus single-channel working is readily possible, selecting a suitable 'safe' running speed for the vehicle by the reduction ratio used.

The simplest single-channel system employs a motorised actuator for moving the steering, providing either right or left turns, self-centring to neutral (straight running) on release of signal. The addition of a second actuator operated by a 'third position' signal (preferably 'quick-blip') can then give the following alternative 'speed' controls, depending on the type of switching used:

(1) on or off, i.e. stop and go

(2) forward–stop–reverse (with reduced speed in reverse if desired. See Chapter 18)

(3) fast forward-slow forward-stop (using a 3P actuator but sacrificing 'reverse' in favour of an intermediate position giving reduced motor speed).

Such models generally have a limited interest, although they are useful for demonstration purposes. Commercial models of this type are also produced in 'ready-to-go' form, as a sophisticated type of toy. Individual builders working with single-channel radio are normally inclined to go further. They may extend speed control by utilising a sequence switcher for the secondary actuator, integrating power and steering, or aim for proportional steering using a single-channel pulse proportional system with a suitable actuator.

Non-proportional 'multi'

Multi-channel radio offers considerably more scope and extends control possibilities to engine powered cars, for which single-channel systems are basically unsuited. Multi-channel systems, however, are still not suitable for adequate control of high speed racing cars. There is no substitute for proportional in this class.

A 4-channel 'multi' system represents a minimum requirement, controlling two servos. One servo can then control steering and the other servo motor switching (in the case of electric motor drive), or throttle (in the case of an i/c engine). The use of a centrifugal clutch in the latter case eliminates the need for a further channel to operate a mechanical clutch.

Either 'bang-bang' or progressive servo movement can be used to operate the steering of an electric-powered vehicle. The choice depends largely on the type and scope of model, and which proves most successful at the speed at which the model operates. Selecting a type of servo which can work either with a self-centring or progressive action with a simple modification of wiring (see Chapter 9), enables both types of control to be tried out and compared.

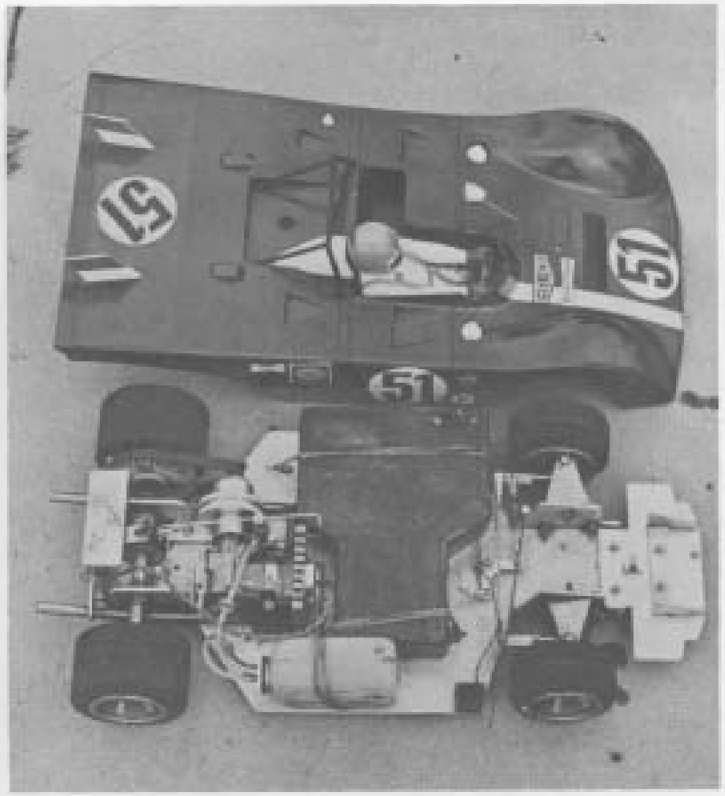
Pit scene at a model R/C car meeting.

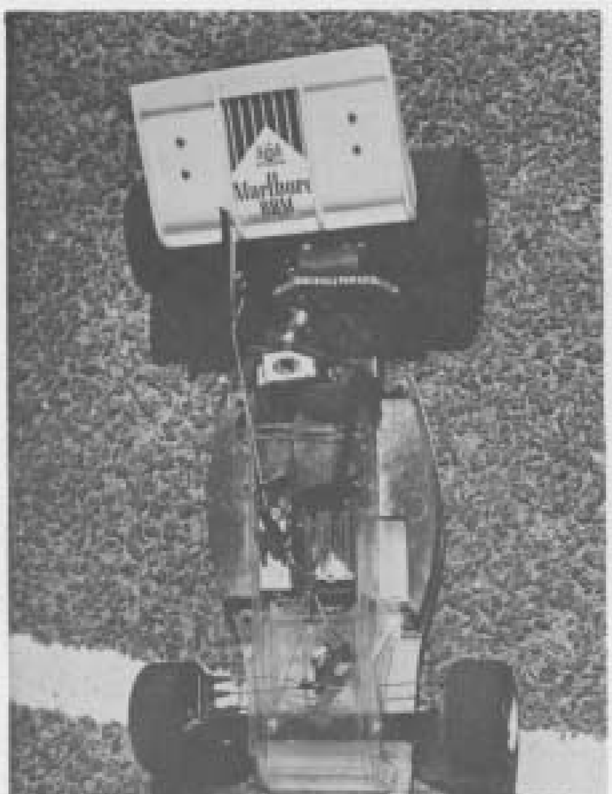
On slow-moving electric-powered vehicles, multi-channel radio can be worked on individual channels, each commanding a single channel actuator. Thus whilst it is desirable that steering be on 'direct' command, allocating two channels to control a multi servo, all the other channels available can be used separately for individual commands, e.g.

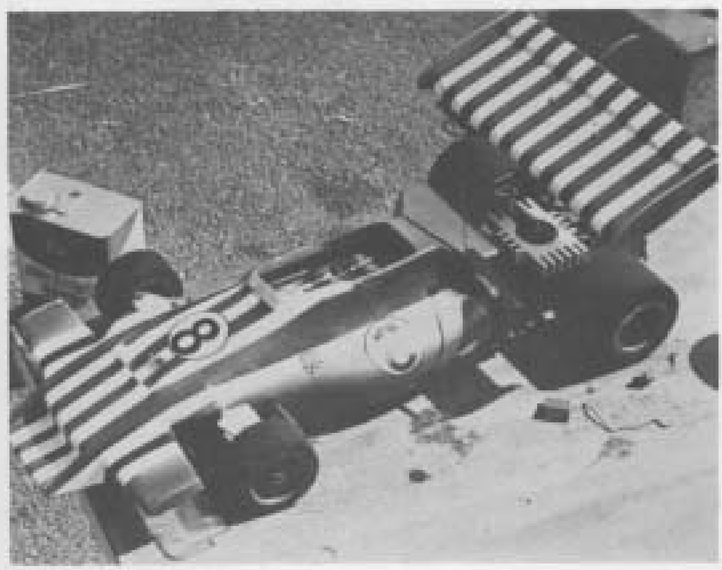
channel 3 motor sequence switching for 'speed' control
channel 4 switch lights on-off
channel 5 horn on-off
and so on.

The more complicated the control system planned, the more space will be at a premium to locate the necessary actuators etc. The body of the vehicle will also have to accommodate the receiver and receiver batteries; and drive motor batteries in the case of an electric-powered car. Some space saving is usually possible in the latter case by adopting nickel-cadmium accumulators instead of lead-acid accumulators, which are the normal choice for powering larger, electric-drive motors. Installation requirements are otherwise similar to those described for aircraft for wiring up etc., except that a fuse may be advisable in all electric motor circuits to give protection against potentially damaging high currents which might be produced by mechanical overload. This applies both to the drive motor and servo motors, as both drive motion and servo movements are more likely to be subject to heavy loads, or stalling by physical obstruction, than on other types of radio controlled models.

Perhaps a radio controlled car is even more fun when it is an amphibian! Radio Modeller photo.







Photos, Radio Control

Most modern radio control equipment is powered by nickel-cadmium sealed accumulators. A matching charger is needed to re-charge at regular intervals.

20 BATTERIES

All modern radio control units employ transistor circuits working off a low voltage supply (e.g., typically, 9 volts for transmitters and 3 to 6 volts for receivers). Choice of type of battery then lies between dry cells (dry batteries); and rechargeable batteries or nickel-cadmium accumulators. In the case of simple single-channel systems, dry batteries may be preferred as offering an economy in initial cost, and installed weight—pencells, for example, being a typical choice for receiver/actuator batteries. The higher current drain of motorised actuators, however, favours the use of accumulators, and with multiple-channel systems, employing several servos, the use of nickel-cadmium accumulators is virtually standard. Nobody operating proportional radio, for example, would normally consider using dry batteries, either for the receiver supply or for the transmitter.

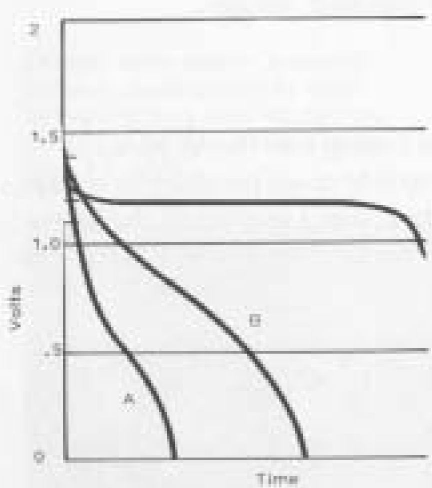
Nickel-cadmium accumulators

Nickel-cadmium batteries are commonly known as 'DEAC's', this being the name of the type originally manufactured. A number of other manufacturers now produce nickel-cadmium batteries of virtually identical type and size. The type normally used for radio control installations are the so-called button cells, in the shape of a flat disc. Each cell has a nominal voltage of 1.2 volts (compared with the 1.5 volts per cell of a dry battery). This is their only disadvantage compared with dry batteries: a greater number of individual cells have to be connected together to produce a higher voltage battery. They also cost considerably more than dry batteries, but this is not necessarily a disadvantage since a nickel-cadmium battery is rechargeable and has an almost indefinite life with normal usage.

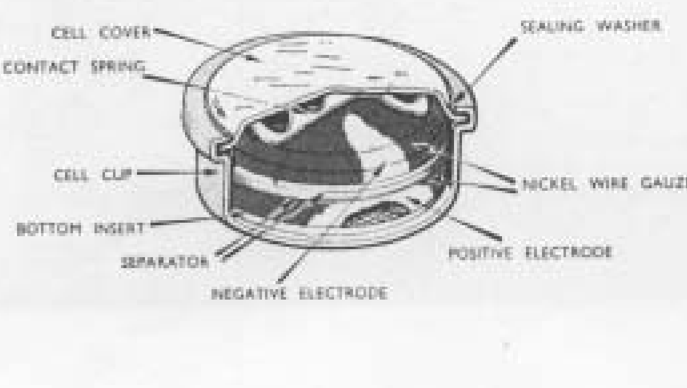
The specific advantages of nickel-cadmium batteries are:

(1) the discharge voltage is substantially constant, regardless of load, and remains constant up to the point where the battery has reached the point of being almost completely discharged. This is quite different to the discharge characteristics of a dry battery, where discharge voltage can vary with both time and load (see *figure 20.1*).

(2) The battery can meet high current drains without suffering the 'voltage drop' associated with a dry cell. This does not apply to all nickel-cadmium batteries, however. Some are designed for low current



20.1 Comparative performance of a dry cell on high discharge (A); dry cell on lower current drain (B); and a nickel-cadmium battery under high current drain (C).



20.2 Cut-away diagram of a button-type nickel-cadmium cell.

working, giving long discharge times. This is usually specified by the manufacturers. In the case of DEAC's, type DK is for low currents and type DKZ for high currents. Thus type DKZ only would be suitable for radio control installations.

(3) Each cell is fully sealed and is shockproof as well as leakproof. The constituents do not deteriorate with time, so no maintenance is required other than recharging at necessary intervals.

The capacity of button-type cells ranges from about 0.1 ampere-hours up to about 1.75 ampere-hours, according to size. The two favoured sizes are the DEAC 225 (or near equivalent in other makes), and the DEAC 500 (or equivalent), of 0.225 and 0.5 ampere-hours capacity, respectively. These cover the needs of most transmitters and receivers, although if larger capacity batteries are required for transmitters, cylindrical cells may be preferable.

Button cells are available as single cells, or as made-up batteries comprising two, three or more cells welded together with series connection. Thus equivalent battery voltages are:

no. of cells	2	3	4	5	6	7	8
voltage	2.4	3.6	4.8	6.0	7.2	8.4	9.6

Most modern transmitter and receiver circuits, and actuators, are designed to operate with one of these 'standard' voltages.

Recharging

Battery chargers are normally designed to plug into the AC mains supply and incorporate a transformer to step down the charging voltage to the level required to match the battery, plus a rectifier to change the AC current to DC when applied across the terminals of the battery. The

Silver-zinc accumulator (left) and lead-acid accumulators are the normal choice for batteries for drive motors on electric-powered boats. They are not used as radio batteries.

Battery chargers are inexpensive, reliable units, plugging into mains electricity.

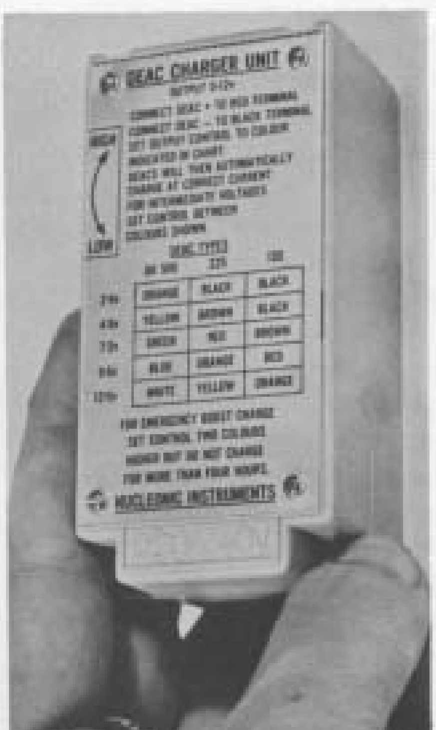
optimum 'charging voltage' in the case of nickel-cadmium batteries is about 2.4 volts per cell (in the battery). However, it is also necessary to include a resistor in the circuit to limit the *charging current*. The recommended charging current, in amps, is found by dividing the ampere-hour capacity of the cell by 10. Multiply this figure by 1000 to convert to milliamps. Thus a '225' size cell, with a capacity of 0.225 ampere-hours, would require a charging current of $0.225 \div 10 = 0.0225$ amps or 22.5 milliamps.

The time to complete a charge, starting with a fully discharged battery, is then 14 hours. However, batteries are never fully discharged in use. They are always recharged before they have reached their 'end point' where voltage drops off rapidly, to avoid this possibility of abrupt battery failure in use. It is thus difficult to decide how much charge a 'partially discharged' battery requires as there is no ready means of deciding how much of the capacity has been used up.

Fortunately this question is not as difficult as it appears. At the charging rate specified a nickel-cadmium battery can safely accept a 100 per cent overcharge, e.g. charging for 28 hours. Thus a full 14 hour charge can be given to a battery which is known to be fairly well discharged; or say a 10 hour charge to one when not extensively used.

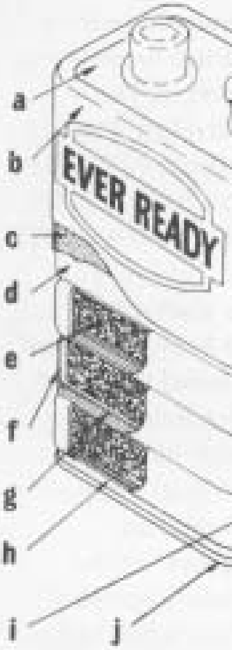
Once fully charged a nickel-cadmium battery will hold its charge, but suffer a loss of capacity of the order of 5 per cent per week. Normally, therefore, batteries are best charged up a day or so before required for use; and if not used for a week or so after being charged, a short recharge can be given to make up for the likely capacity loss. Allow a 10 per cent capacity loss in this case, to be on the safe side, for estimating recharge time.

Chargers often provide a range of different charging rates to match different battery sizes—in this case DEAC's in three sizes, and voltages from 2.4 to 12.



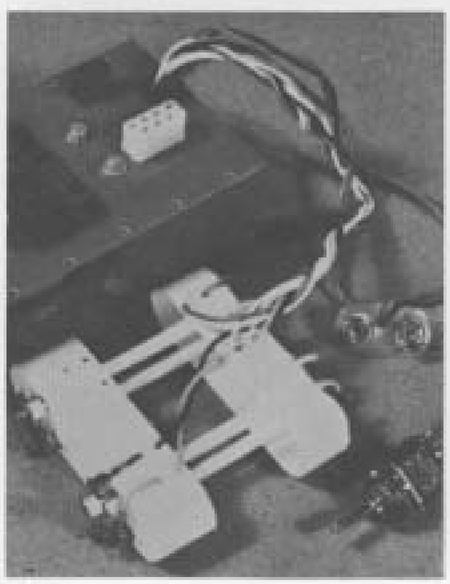
Nickel-cadmium batteries can be charged at higher rates than that specified, with a corresponding shortening of charging time required. However, charging time now becomes more critical, as overcharging can generate sufficient internal heat to warp and permanently damage the internal members, and even cause the casing to swell. Charging currents of up to 20 times the recommended rate can be used in an emergency, for rapid charge—and this can even be done direct from a large lead-acid accumulator of sufficient voltage. Both a variable resistor and an ammeter should be included in the circuit to check that this maximum current is not exceeded, and the charging time limited. Charging should be stopped at once if the battery shows signs of serious overheating.

Suitable chargers for nickel-cadmium batteries of standard voltages are readily available, and are quite inexpensive. Such chargers simply plug into the AC mains, with different outlet terminals (or switching) for connecting to different sizes of nickel-cadmium batteries at recommended charging currents. These are normally quite foolproof in operation, and very reliable.



20.3 Layer type carbon-zinc battery.
- a. top plate with snap-fastener connectors
- b. metal jacket
- c. wax coating
- d. plastic cell container
- e. depolariser
- f. paper tray
- g. electrolyte impregnated paper
- h. carbon coated zinc electrode
- i. PVC covered wire
- j. plastic bottom plate

20.4 Example of a battery box designed to take four pencells. The terminals are connected to a wiring harness.



The most popular size of small dry battery for simple single-channel radio installations is the pencell (U12 or equivalent). These are best fitted in proprietary battery boxes, designed to accommodate two, three or four cells, giving 3, 4.5 or 6 volt batteries, respectively (*figure 20.4*). This avoids having to solder on wires to connect two or more cells in series to make up a battery pack.

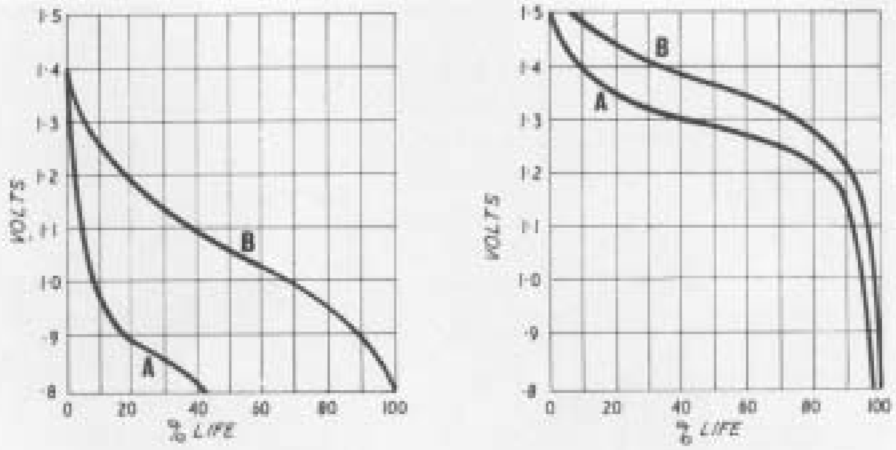
Dry cells are made in two basic types: 'standard' and 'high power', the latter normally designated by 'HP', (e.g. HP12 instead of U12). The 'HP' cell has a far superior performance to a 'standard' cell where current drain is fairly high, and is thus always preferred for radio control work. The 'HP' cell is also made with leakproof construction. That is, the casing will not be eaten through, allowing the corrosive contents to ooze out, as can all too easily happen to an ordinary dry cell which is left in situ and forgotten.

Where dry cells are used for the receiver the other golden rule is that new, fresh cells should always be used at the start of each day's working. If fairly lengthy flights are involved, it may even be advisable to change dry batteries after every flight. Once used, all such dry batteries should be discarded for future radio operation. They are not necessarily useless, however. There will probably be plenty of capacity left in them for use in torches, or even in a small transistor radio.

The high throw-away rate necessary with dry cells with frequent radio control operation is a strong argument in favour of adopting nickel-cadmium batteries from the start. The same limitation does not necessarily apply to dry batteries used in single-channel transmitters as here a larger battery can be employed, with a consequently higher capacity. If the transmitter is not fitted with an indicator showing the state of the battery, battery voltage should be checked periodically. Measure the voltage across the terminals of the battery with the transmitter switched on. Once this shows a marked drop from the original voltage, the battery must be changed. Always replace with the type of battery specified by the transmitter manufacturers, as this will be matched on the current drain of the circuit. A change to another battery type, even if the same voltage, for example replacing a PP9 battery with a PP3 could produce loss of transmitter power and a very short battery life. The PP9 battery is rated for up to 50 milliamps current drain (and the transmitter circuit may actually draw more than this). The PP3 battery, on the other hand, is not really suitable for current drains much in excess of 10 milliamps. Drawing higher currents from it can pull the working voltage right down, and dramatically reduce battery life.

Certain other types of dry batteries may be considered for radio control work, particularly in pencell size. The main one is the *alkaline-manganese* battery, which offers a much greater capacity for the same physical size and less 'drop off' of voltage under load. It is more suited to higher current drains than even the 'HP' battery, and would be a better choice apart from the fact that it is considerably more costly and

20.5 Comparison of performance of standard U2 cell (A) and high power HP2 cell (B). Left hand graph shows conditions of high current drain (cells discharging through a resistance of 2 ohms for 30 minutes a day). Right hand graph shows low current drain application (cells discharging through a resistance of 300 ohms for 2 hours a day). *Reproduced from Dry Cells and Batteries, published by Model & Allied Publications.*



again has to be discarded before fully exhausted. Nominal cell voltage is again 1.5 volts. It will have about eight to ten times the life of a 'standard' dry cell under current drains associated with single-channel receiver circuits; and possibly four to five times the life of an 'HP' cell. The main difficulty is deciding when an alkaline-manganese battery has reached the end of its reliable life (for radio working). A reasonable check is to measure the voltage across the battery with the receiver circuit switched on and 'triggered' by a transmitter signal so that it is in the condition of drawing maximum current. Provided the indicated battery voltage is greater than 1.1 volts per cell, the battery still has some 'safe' life left in it.

Simple form of multimeter which reads 10, 50, 250 or 500 volts, AC or DC; also three current ranges; and provision to use as an ohmmeter.

Scale aircraft types are claiming more and more interest. Note dummy cylinders of balsa behind engine to give a realistic four-in-line appearance. But practical modelling features are retained, like the wings held on by rubber bands. Radio Modeller photo.

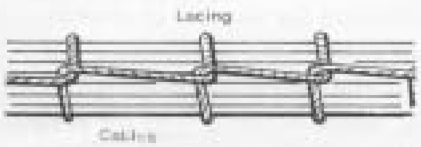
21 WORKSHOP NOTES

Wiring

Most modern commercial radio control equipment is 'prewired', meaning that all interconnecting leads are already connected to matching plugs and sockets. Connecting up the circuit during installation is then simply a matter of plugging together the appropriate plugs and sockets and mistakes are virtually impossible.

Where individual installations are concerned, the same practice should be followed. All the leads from individual units should be terminated on multi-pin plugs or sockets, as appropriate, rather than wired direct between units. This enables individual units to be disconnected readily, should this become necessary (to remove, for example, a suspected faulty unit for checking, or to substitute a replacement). All wiring connections to plug or socket terminals *must* be soldered. The use of screw-type connectors instead is quite unsatisfactory as these can prove unreliable in service.

One basic rule also applies when wiring to plugs or sockets. Wiring which carries *battery* connections should always be connected to *sockets*. This will eliminate any chance of shorting the battery circuit when the plug and socket are not connected.

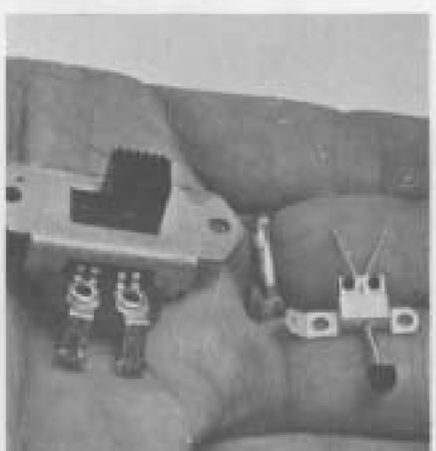


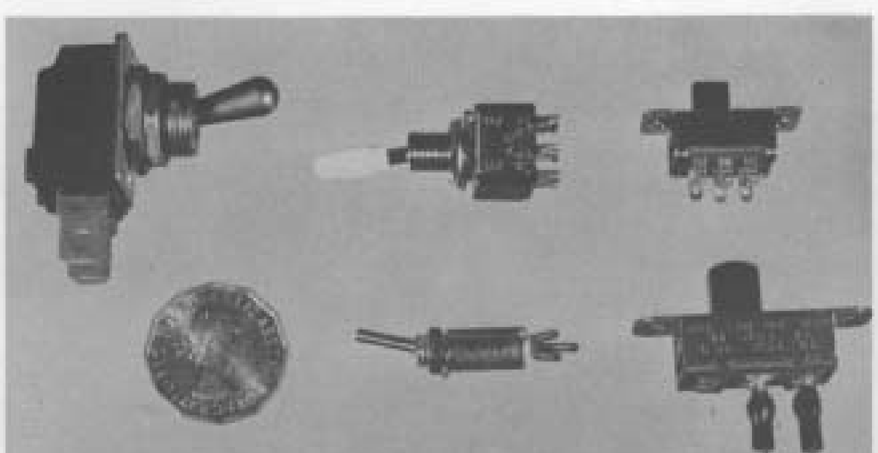
21.1 Simple 'knots' like these are adequate for cable lacing.

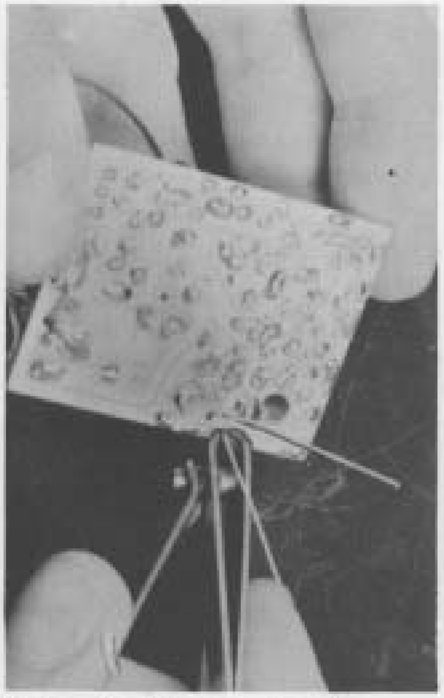
Plugs and sockets

A large variety of miniature plugs and sockets are available, most of which have been specially designed for radio control model installations. These are usually in 3-pin (three connections) size upwards to 7-pin (seven connections). All are 'polarised' in some manner, making it impossible to fit the plug and socket together other than in one particular way. The only real limitation of miniaturised plugs and sockets is that the individual connection pins are small and close together, and extreme care may be needed when soldering the wires in place—really neat and efficient soldering. Some modellers prefer to use larger plugs and sockets to avoid this problem.

Examples of miniature switches. The choice available is often bewildering. Choosing the smallest and lightest type is not always advisable.







Neat method of cutting off surplus lead lengths when assembling a printed circuit—using nail clippers!

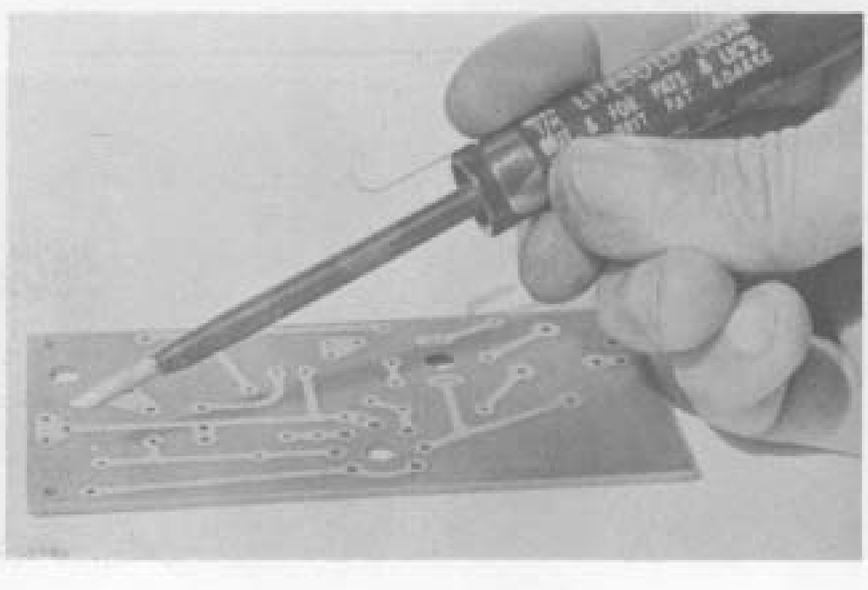
Ideally plugs and sockets should be mechanically bound together once installation is complete. Also plugs and sockets should be supported, not left to hang free. One solution is to mount all sockets on a separate panel, securely mounted in the model. Proprietary servo trays, designed to accommodate specific types of servos, may have sockets or socket points incorporated in the length of the tray. A very straightforward solution for mounting plugs and sockets, and at the same time locking them together, is to fit a length of servo tape at a suitable point in the model. Plugs and sockets are then simply pressed onto the servo type.

Wire sizes

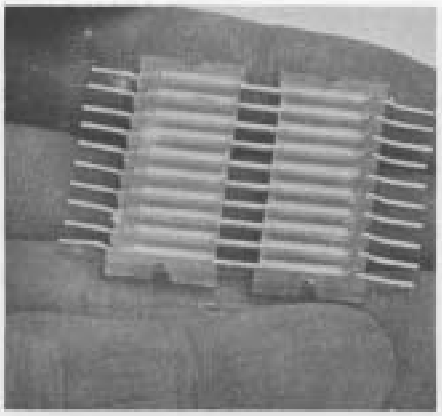
Stranded insulated wire should always be used for circuit wiring. Small diameter stranded wire is normally designated by two numbers separated by an oblique. The first number indicates the number of strands and the second number the diameter of each strand or individual wire in inches. Thus 12/004 wire would comprise twelve strands of 0.004 in diameter wire, in an insulated covering. Recommended sizes for general wiring are 12/004 or 14/0076. The latter is to be preferred for escapement wiring connections or other low voltage circuits where wiring resistance must be kept to a minimum.

Insulated wire of this type is readily available in a range of different insulation colours, i.e. red, black, blue, yellow, white, green, orange, brown and grey. This enables circuit wiring to be colour coded for ease of checking. It is imperative to adopt colour coding for wiring to plugs and sockets, for example, in order to be sure that the through connections match.

In addition to single wires, groups of colour-coded wires assembled in a common outer are also available. These are generally known as cables and may be round or flat, with up to 9 or 10 individual colour-coded wires in the cable. The use of cable eliminates the need for 'cabling up'



This is the right size of iron for normal soldering work. A smaller iron with a smaller bit would be needed for working on crowded printed circuits.



Multi-pin plug-and-socket connectors simplify wiring, but always use a recommended type. Bind together for additional security.

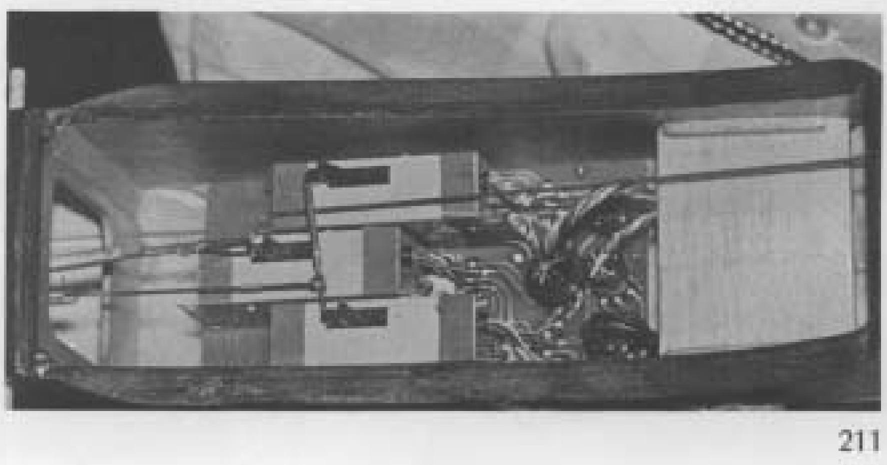
runs of individual wires by lacings or bindings, but round cabling is not always convenient to use where individual wires have to be taken out at different points along the cable run. Flat cabling is considerably more versatile in this respect.

Soldering irons and solder

Miniature electric soldering irons should be used for making all soldered connections. The heat generated by the bit of an electric iron is nominally specified by its wattage. A 10 or 15 watt iron is generally suitable for making wiring connections, and is suitable for use with bit sizes from 3/64 in diameter to 3/16 in diameter. A 25 watt iron is the largest size that could be used, especially on printed circuit panels. On the other hand, a small iron is not necessarily the best answer. It will lose its heat rapidly, needing a considerable pause between making consecutive joints for the bit to heat up again—and there is considerable danger of producing 'dry' joints if the job is hurried, or not tackled properly.

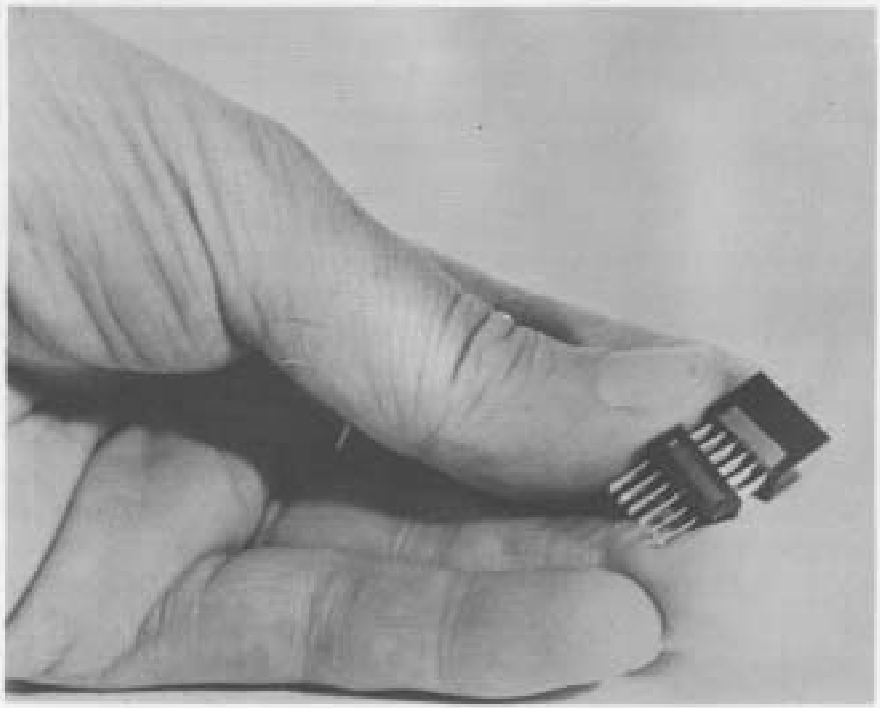
Only resin-cored solder should be used, preferably of 60/40 type which is produced for high quality electrical work. The numbers designate the tin/lead ratio of the solder. The higher the tin content the lower the melting point of the solder. This means that satisfactory joints can be produced with a lower bit temperature, reducing the risk of damage to components through overheating. The difference in melting point of a 60/40 solder and a 40/60 solder, for example, is 45 degrees C.

The right combination of iron wattage and bit size can readily be judged by the time it takes to complete a soldered joint. The iron must be allowed sufficient time to reach full bit temperature, which can be judged by the fact that solder applied to the tip of the bit will melt immediately and flow over the tip. The time to complete a soldered joint should then be three or four seconds, no more. If the joint does take longer to complete, and has been properly prepared by cleaning as necessary, then either the iron has not had enough time to heat up, or the bit is too small for the joint area involved (i.e. too much heat is being conducted away from the bit, cooling it down). In either case poor or 'dry' joints will result.

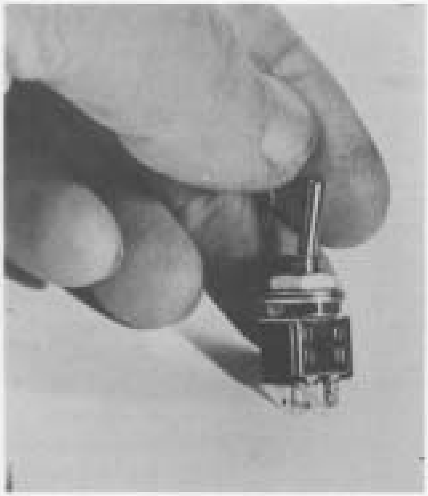


Neat installation with short cable runs plugging into sockets on a printed circuit mounting panel.

Supreme examples of the radio modellers' art like these may take thousands of hours to complete. Failure of a small radio component, or a plug and socket connection which comes apart in flight, could cause a complete write-off. Check—and re-check—all connections regularly.

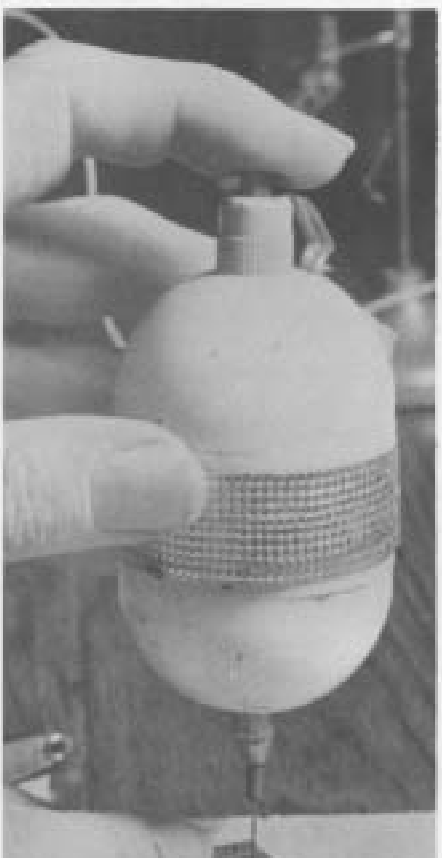


Photos. Radio Modeller



Toggle-action switch may be for circuits carrying higher currents.

Small electric motor 'power' drill is a handy tool for drilling printed circuit panels. Always use a very sharp drill, and work with the copper side up.



On-off switches

The choice for an on-off switch lies between a toggle (lever action) and slide type. General recommendations are that a toggle switch is better for switching higher currents, although it is usually bulkier and heavier than a slide switch. A slide switch is held to be less reliable, although this depends very much on the individual design of the switch. Slide switches with a true wiping action have self-cleaning contacts and can be equally, or even more reliable than toggle switches. Slide switches are usually preferred.

The main enemies of a switch are vibration and damp or contamination. Neither type should be susceptible to vibration on a model installation and can be rigidly mounted. To avoid damp or other contamination to the switch, all switches are best mounted internally, with their movement operated by an extension rod taken to the outside at a suitable point. This opening can be sealed with a simple grommet. However on-off switches are successfully mounted emerging from the outside of a model aircraft fuselage, and provided the area is not in the way of engine exhaust spray, seldom seem to give trouble. External mounting on a boat, on the other hand, is very likely to give trouble as it is difficult to find a location which is positively free from spray at all times.

Receivers using a single battery supply need only a single-pole on-off switch. If a separate servo battery is involved in the receiver installation a double-pole on-off switch should be used to switch this second battery separately, and simultaneously from the one switch.

On older valve circuits both a HT and LT battery are involved. Theoretically, at least, it is only necessary to switch the low tension battery on-off as no current can flow through the high tension circuit without the low tension supply being present. This is not good practice, however, since it leaves the high tension battery potentially 'live' and it could discharge through a circuit fault (e.g. a faulty electrolytic capacitor). Since the negative side of both batteries is common (i.e. connected together) a single-pole switch can conveniently be inserted in this common negative lead. If a separate actuator battery circuit is also to be switched, then a double pole switch is required. This would be applicable in receiver circuits only, and valve receivers have long since ceased to be used for practical radio control installations.

INDEX

R H Warring is well known for his writings on modelling and electronic subjects, with many articles and books to his credit. He has also been actively concerned with the design, production and testing of commercial model kits and radio control equipment.