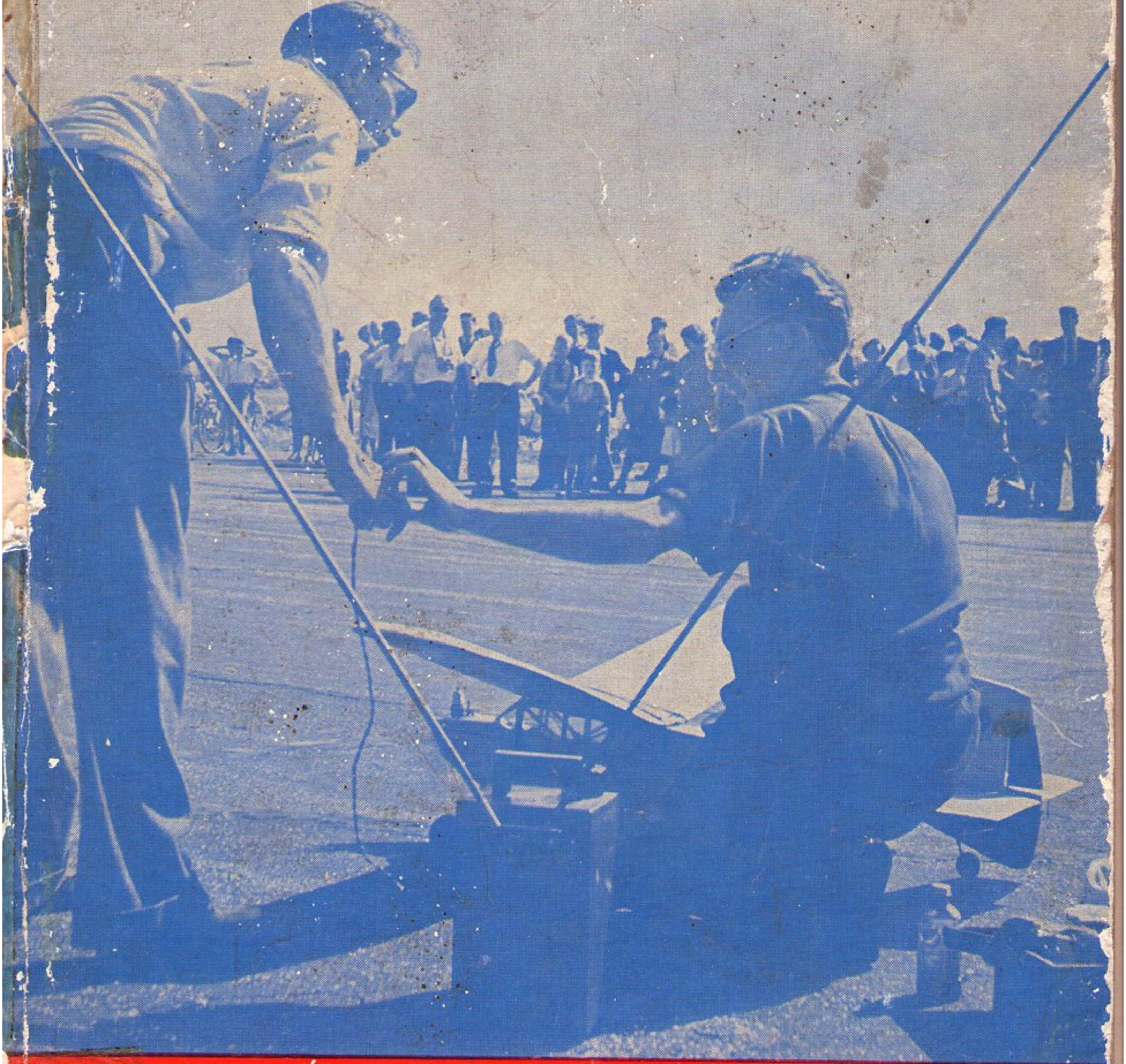
RADIO CONTROL of MODEL AIRCRAFT



REVISED EDITION 7'6 by G. SOMMERHOFF

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OF

MODEL AIRCRAFT

by

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LONDON
PERCIVAL MARSHALL & Co. Ltd.

FIRST PUBLISHED, MARCH 1954
REVISED AND REPRINTED, JULY 1954
REVISED AND REPRINTED, SEPTEMBER 1957

Printed in Great Britain at the Ditchling Press, Ditchling, Hassocks, Sussex, and published by Percival Marshall & Co. Ltd., 19 and 20 Noel Street, London, W.1.

PREFACE

There is no doubt that model control by radio is a new and fascinating hobby which has come to stay. And it is more than a hobby, for it is difficult to think of a better training ground for the young engineer in this electronic age.

If radio control of model aircraft is perhaps the most exciting branch of this hobby, it is also the one in which the beginner most frequently meets with disappointing results. In the author's experience one of the main reasons for this is that the newcomer so often tries to run before he can walk, and dreams of advanced multi-control systems instead of concentrating at first only on simple rudder control. This invariably means courting disaster.

In the present revised edition of his 'Radio Control of Model Aircraft' the author has therefore omitted the discussion of complicated multi-control systems and has confined himself to the simple systems only. But these he has endeavoured to explain in as much detail as possible.

Particular emphasis has been placed on the avoidance of breakdowns and crashes and the risk of serious damage in a crash. A common fault of contemporary designs of model aircraft is an inadequate allowance for safety factors. This is true both for amateur and professional designs. In the author's experience, for instance, it is quite possible to design models which, short of a vertical power-dive on to hard soil or a crash into a brick wall, are virtually crash-proof. There is all the difference in the world between a model that has to be constantly patched up and one that merely has to be serviced at regular intervals.

The author wishes to express his gratitude to the members of the Dragon School Science Club for their enthusiastic and regular assistance in all his experiments.

Oxford, June 1957.

G.S.

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CHAPTER I

INTRODUCTION

1.1. The Basic Components of a Radio Control System

Radio control of model aircraft means that the operator on the ground can exercise some degree of control over his airborne model by means of radio signals. He can influence the position of one or more control surfaces on the model, such as the rudder or the elevator, and sometimes he can also control the speed of the engine or cause it to cut out. Radio control is not confined to power flight; it has also been used with success on model gliders.

A radio control system that can only operate one control on the model, such as the rudder or engine cut-out, is called a *single-control system*; when more than one control can be actuated independently or, as is sometimes said, when more than one *function* can be controlled, we have a *multi-control system.*

The two most important components of a radio control system are the *transmitter* on the ground which generates and radiates the radio signals and the *receiver* in the aircraft which picks up the signals and converts them into useful pulses of electrical energy. But the transmitter must be associated with a device which converts our commands into the right kind of radio signal. This is called the *coding* device or *coder*. The simplest form of coder is an ordinary morse key. And the receiver must be followed up by a device that interprets the signals and switches them through to the control station which is to be brought into action; finally, at this control station there must be a mechanism which converts electrical impulses into useful mechanical energy (e.g. a motor or escapement). The former is called the 'decoding device' or *decoder*; the latter is conveniently spoken of as the *translating system.* The decoder and translating system together are sometimes called the *intergear.*

The main units used in a radio control system may therefore be represented as in the block diagram of Fig. 1.1. The components shown are as follows:

(A) The *coder* which controls the radio signals in accordance with our commands;

(B) The *transmitter* which generates the signals and sends them to the flying model;

(C) The *receiver* in the aircraft;

(D) The *decoder* which sorts out the different signals and causes electrical energy to flow to the desired translating system;

(E) The *translating systems* which convert this flow of electrical energy into the actual movement of a control surface on the aircraft or into an engine control operation.

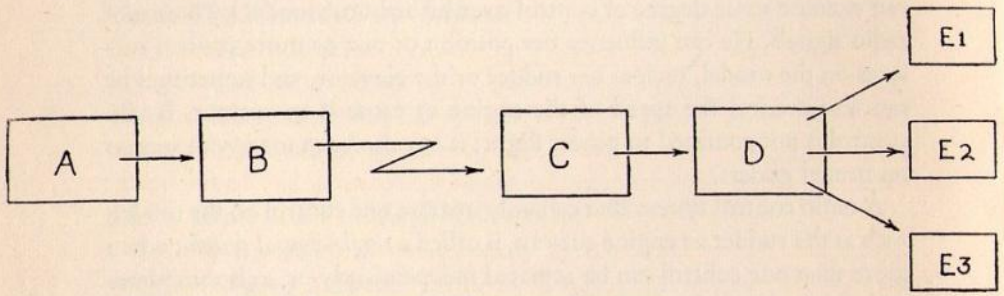


Fig. 1.1. *Block diagram of radio control system.*

All these components will be considered in detail later on. Our first concern is the actual radio link and the type of signal that is sent from the transmitter on the ground to the receiver in the aircraft. These signals are of paramount importance. They are also the subject of certain Post Office regulations which must be given a prominent place in any introduction to radio control.

1.2. The Nature of the Radio Signals

The transmitter signals are always in the form of electromagnetic waves. The intrinsic nature of these radio waves is by no means an easy thing to explain, nor is it essential for the modeller that he should master all the intricacies of electromagnetic theory. A simple comparison with ocean waves will suffice to explain all that has to be explained at this early stage. In the case of ocean waves we have a certain variable quantity, viz.

the height of the water level, whose magnitude differs from place to place and which undergoes certain periodic variations in time: at any given point the water level periodically rises and falls. Similarly, in the case of electromagnetic waves there is a certain variable quantity whose magnitude differs from place to place and which undergoes periodic fluctuations. This quantity is the so-called *strength* of the *electromagnetic field*. The existence of the electromagnetic fields is a fact of nature as fundamental as the existence of gravity; only that, whereas the strength of gravity or the 'gravitational field' is tied up with the presence of massive bodies, the strength of an electromagnetic field is tied up with the presence of electrical charges or currents, in this case with those of the radio transmitter. The term 'field' in this context simply means a region in space in which under certain conditions certain things will happen. Thus, by the 'gravitational field' of the earth we simply mean that there is a region of space surrounding the earth where any concrete object will be attracted by the earth and start moving towards it. Similarly, by the 'electromagnetic field' of a transmitter we mean an area surrounding the transmitter in which its presence produces certain effects, e.g. causes the needle on a field strength meter to move, or causes a noise in the headphones of a certain type of receiver.

To return to the ocean waves. There is a certain relation between the length of the waves, their speed and their 'frequency', which also exists for electromagnetic waves and which is quite fundamental in radio. This relation is best explained with the aid of Fig. 1.2. Let us assume that we have a train of exactly similar ocean waves, as shown in this figure; that these waves have a length l (measured from wave-top to wave-top) and that they travel with a velocity v. Now let us think of just one definite point in the ocean, the point A. How many waves will pass that point in

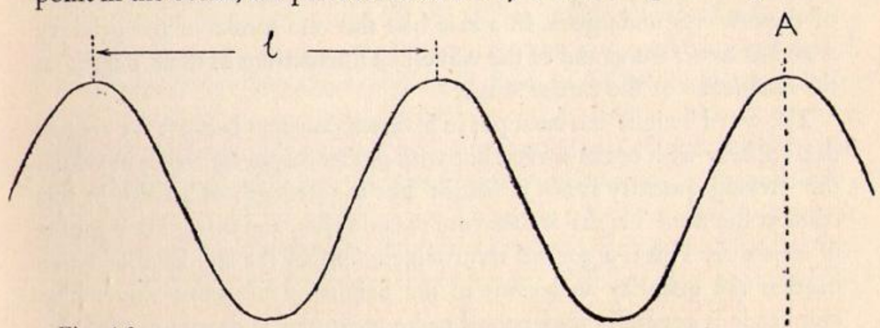


Fig. 1.2.

each second? If v is measured in metres per second and l in metres, the answer is $\frac{v}{l}$. This number of waves passing *A* per second is called the *frequency* of the waves. If the frequency is f, we have therefore

$$f = \frac{v}{l} \quad \text{or} \quad f \times l = v$$

This relation also holds for radio waves and here the matter is further simplified by the fact that all radio waves travel with the same velocity; this velocity is the same as that of light (which also consists of electromagnetic waves), viz. 300,000,000 metres per second. If, therefore, we measure the length of radio waves in metres, we have the simple relation that

$$\text{wavelength} \times \text{frequency} = 300{,}000{,}000$$

For instance, if we know that a transmitter sends out radio waves which have a length of 150 metres, we can calculate from this relation that these waves have a frequency of 2,000,000 waves per second. Actually, the term 'waves per second' is not used in radio engineering. Instead one speaks of *cycles per second* or *cps*. And since the frequency often runs into rather large numbers, a further unit has become established, viz. the *megacycle per second* or Mcps.:

1 megacycle per second = 1,000,000 cycles per second.

In the above example, therefore, we have a frequency of 2 Mcps.

A transmitter may send out waves in which it is possible to distinguish more than one kind of wavelength and frequency. A very important case of this type is illustrated in Fig. 1.3. Here we have primary waves with the wavelength l and the 'height' of these waves undergoes wave-like fluctuations whose wavelength is much larger, viz. L. We are dealing with two frequencies in this case: the fundamental frequency of the primary waves and the frequency of the wave-like fluctuations which the 'height' of these waves undergoes. In a case like this one speaks of the primary waves as *carrier waves* and of the wave-like fluctuations in their 'height' as the *modulation* of the carrier wave.

The word 'height' has been put in inverted commas because we are not dealing here with ocean waves, but with electromagnetic waves in which the varying quantity is not a 'height' but the strength of a field. In this context the term 'height' is therefore meaningless, and instead one speaks of *amplitude*. This is a general term which denotes for any kind of wave motion the quantity analogous to the height of an ocean wave. The amplitude is generally understood to be measured as shown in Fig. 1.3.

A modulated carrier wave may therefore be described as a wave whose amplitude undergoes periodic fluctuations.

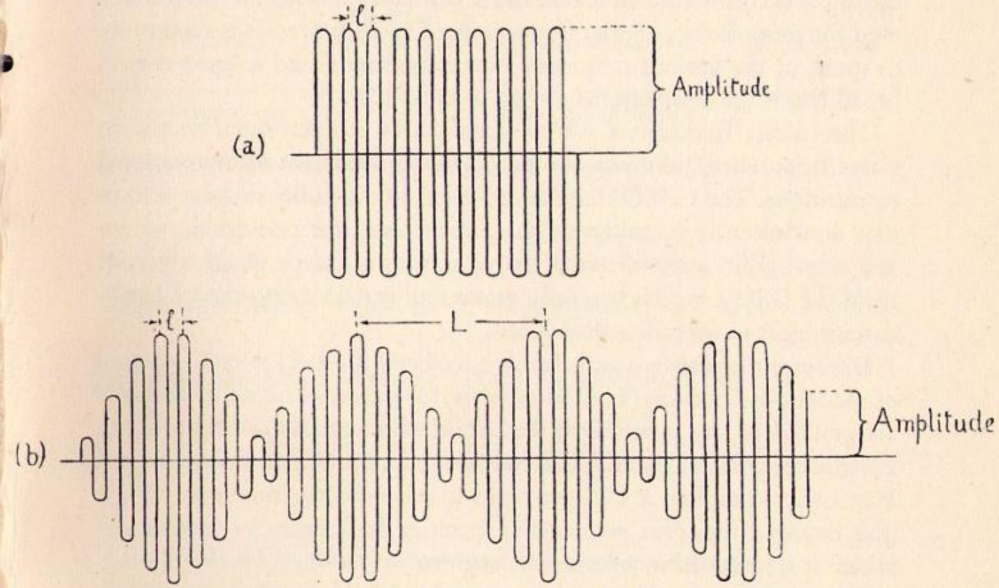


Fig. 1.3. (a) *non-modulated*, (b) *modulated carrier wave*.

The question of modulated carrier waves is particularly important in radio because if a number of radio transmitters are to transmit simultaneously without mutual interference it is essential that each one should send out only one type of carrier waves, i.e. carrier waves of one single wavelength and frequency.

Now any broadcasting station must be able to send out a great number of different frequencies, viz. all the different frequencies which correspond to the sound-waves of the musical notes and speech sounds which it is intended to broadcast. All these frequencies lie in the audible or 'audio' range, i.e. between 20 and 10,000 cps. And the main way in which this is achieved, subject to the paramount demand that each station should transmit only on one fixed carrier wavelength, is to transmit a modulated carrier wave which has a fixed carrier frequency but whose modulation fluctuates with frequencies which correspond to the frequencies of the soundwaves to be broadcast. This is called *audio-modulation*.

Table 1 gives a comparison of the main ranges within which lie the frequencies of the carrier waves of radio transmitters used for broadcasting and communication and also a comparison with the frequencies used for modulation, i.e. the frequencies of soundwaves. It is customary to speak of the various frequency ranges as 'bands' and to give certain broad bands the designations shown in table 1.

The carrier frequencies which transmitters are permitted to use in Great Britain are laid down by the G.P.O. on the basis of international conventions. The G.P.O. regulations concern the radio amateur also in that until recently members of the public were not permitted to own and work radio transmitters of any description except under a licence from the G.P.O. which was only granted to certain categories of candidates subject to special examinations.

But since the war two wavebands have been allotted for radio control of models, and licences (valid for 5 years) for transmitting on these bands are granted to any member of the public who applies in writing to the Postmaster-General, Radio and Accommodation Department, General Post Office, London, E.C.1, provided that he also encloses a fee of £1 (this covers a five-year period) and specifies the locality or localities at which it is intended to operate the station.

The modeller should note, however, that the licence imposes certain provisions and limitations regarding the maximum power of his transmitter and the general operation of his equipment. It is in the interest of the whole model control movement that these restrictions, particularly those relating to transmitter power and frequency, should be strictly observed by all persons concerned.

The two frequency bands allotted for radio control of models are:

26.96 to 27.28 Mcps, and

464 to 465 Mcps.

It should also be noted that these wavebands may not be used for communication work.

TABLE 1

Frequency Band	Electrical Wavelength (meters)	Name of Band	Abbreviation	
20—10,000 cps	—	Audio (Sound waves)	a.f.	
30,000—300,000 cps	10,000—1,000	Low Frequency or Long Waves	l.f.	r.f. (radio frequency)
300,000 cps—3 Mcps	1,000—100	Medium Frequency or Medium Waves	m.f.	r.f. (radio frequency)
3 Mcps—30 Mcps	100—10	High Frequency or Short Waves	h.f.	r.f. (radio frequency)
30 Mcps—300 Mcps	10—1	Very High Frequency	v.h.f.	r.f. (radio frequency)
300—3 000 Mcps	1.—0.1	Ultra-High Frequency	u.h.f.	r.f. (radio frequency)

1.3. Types of Systems employed for Radio Control

Both modulated and unmodulated radio waves have been used for radio control of models in general.

In a system using modulated carrier waves as signals between transmitter and receiver, the receiving and decoding apparatus is made to respond differently to different modulation frequencies. Thus a modulated carrier wave of one modulation frequency would actuate one control on the model and the same carrier wave with another modulation frequency would operate another control. In one commercial system of this kind the frequencies are sorted out at the receiving end with the aid of tuned 'reeds' analogous to tuning-forks. These systems have come to be known as *reed control* systems and at the time of writing a complete outfit for this type of radio control of models is obtainable on the market.

But these so-called 'frequency selective' systems are on the whole very much more complicated, heavy and expensive than systems working with unmodulated carrier waves. And since the latter can supply most of the needs of the aeromodeller there is little scope for reed control equipment in aeromodelling; its proper application lies more in the control of model power boats and yachts.

In systems using unmodulated carrier waves the transmitter is made to radiate shorter or longer bursts or *pulses* of carrier waves. (Fig. 1.3.) The receiving and decoding apparatus is then made either to respond simply to single pulses, or to respond in different ways to pulses of different length and spacing. Pulses of carrier waves are also sometimes spoken of as *marks* and the intervals between them as *spaces*. In some systems the response of the receiving and decoding apparatus is made to depend upon the ratio between the length of the marks and the length of the spaces, i.e. upon the *mark-space ratio*.

These are only examples of the great variety of different systems which have been tried for controlling models by radio. But in comparison with model power boats, yachts and cars, the model aeroplane makes very special demands on any radio control system and only a very restricted number of systems have proved practicable for airborne models.

The airborne radio equipment must be light; it must be completely reliable; it must be simple and easily tested or checked on the field; it must be easily removable from the aircraft; it must be easily accessible in the aircraft; it must be able to withstand shock and engine vibration; it must respond quickly and visibly to the operator's commands (for unlike a real pilot the operator here has not got the 'feel' of the aircraft); the commands must be easy to give and involve a minimum risk of confusion; the financial loss incurred by the owner in a heavy crash must not be excessive, and, altogether, the cost of the equipment must not be out of proportion to the results that can be expected from it.

These demands impose severe restrictions on the number of control systems which are practicable and only the acid test of experience can decide which systems are capable of meeting all these requirements. In any case the beginner is strongly advised to tackle only the simplest systems at first.

CHAPTER 2

BASIC ELECTRONICS AND SOME ELEMENTARY APPLICATIONS

The aim of this chapter is to introduce the aeromodeller who has no previous experience or knowledge of radio to those fundamental facts and relationships in electronics which will enable him to build and run his equipment efficiently, to understand the functions which the main components of the system fulfil, to understand and remedy the most common faults that may develop and to design simple networks himself. It will not give him a complete understanding of all the intricate processes which may be involved in radio transmission and reception even at this comparatively simple level. For this he must refer to other technical literature.

2.1. Electric Currents

All electric effects depend ultimately on the atomic structure of matter, and to understand the meaning of 'electric current' or 'electric charge' it is necessary to visualise the model of the atom as conceived by the physicist. All matter is composed of atoms and the atoms in turn are composed of three types of fundamental particles. The centre of an atom is occupied by a stable core, the 'nucleus'; this is made up of an aggregation of relatively dense particles: the 'neutrons' and the 'protons'. The number of protons is different for each chemical element and characteristic of it. Thus all hydrogen atoms have one proton, all helium atoms have two, etc. Around this nucleus travel a definite number of much lighter particles, the 'electrons', on definite orbits or shells—not unlike the manner in which the planets travel around the sun. Protons and electrons show certain effects which are not shown by the neutrons, in that two single protons will repel one another and two single electrons will repel one another, but any single proton will attract any single electron in its neighbourhood, and vice versa. These effects are called their 'electric' effects, and protons are said to have a *positive* electric charge while electrons are represented as *negative* electric charges. The normal condition of an atom is the one in which it contains as many electrons as protons; in this neutral condition the atom has the least electric effects on bodies outside itself and, in turn, is least affected by outside electrical charges. An object composed of many atoms, or the surface of such an object, is said to have a positive electric charge if on balance it contains more protons than electrons; it is said to have a negative charge if on balance it contains more electrons than protons. An object may contain as many electrons as protons, but for some chemical or physical reason the electrons may all be slightly displaced towards one side of the object and the protons towards the other, so that one surface may contain electrons in greater density and the opposite surface contain protons in greater density. In that case we have an object one surface of which is negatively charged and the opposite surface positively. In a torchlight battery, for instance, certain chemical processes result in the electrons having a numerical density greater than that of the protons on the one terminal and a lesser density on the other. The one terminal, therefore, is said to be negative, the other positive. In an ordinary dry cell the outer metal casing acts as negative terminal, the central capped carbon rod as positive terminal. (See Fig. 2.1.)

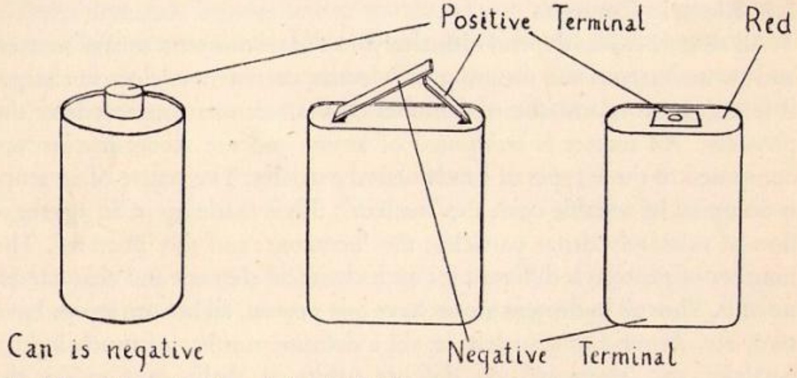


Fig. 2.1. *The polarity of dry batteries.*

Some substances contain not only planetary electrons, i.e. electrons

which are confined to the orbit of an atom, but also free electrons; that is to say, they contain electrons which can move freely between the atoms or from atom to atom. Such substances are called *electric conductors*. In such substances under certain circumstances we can get a flow or migration of electrons through the substance, and we then speak of an *electric current*. All metals are conductors in this sense. An electric current therefore represents a flow of electrons. Substances through which electrons cannot flow are called *non-conductors*.

If we connect the two terminals of a battery by a piece of copper wire, we make a path along which the excessive electrons on the negative terminal can flow across to the positive terminal and make up the deficiency of electrons which exists there. Such a path capable of carrying an electric current is called a *circuit*. In this case the circuit is a very simple one consisting of a single loop. But circuits may be very much more complicated and may consist of many interconnected loops in which each loop is capable of carrying an electric current.

There are two important quantities which can be measured in connection with electrical charges and currents. The one quantity is measured in *volts* and expresses how *keen* the electrons are to get from one point of circuit to another; for instance, from one terminal on a battery to another. Thus if we compare a battery of 3 volts with one of 1.5 volts we can say that in the first the electrons on the negative (—) terminal are twice as keen to get over to the positive (+) terminal of the battery than in the second. This 'keenness' is technically called the *electromotive force* or *potential difference* between the two points of the circuit. The potential difference between two terminals of a battery is the greater the less current flows at the time between the terminals; it is greatest when no current flows. Hence by the voltage of a battery one usually understands the number of volts it has in the absence of a current.

The second important quantity concerns the *amount* of electricity that flows through a part of a circuit, e.g. through a wire. This is measured in *ampères*, or *amps* for short. Thus twice as many electrons per second flow through a wire which carries 6 amps of current than through one which carries only 3 amps. There are also two smaller units: the *milliampère* and *microampère*.

1 ampère = 1,000 milliampères = 1,000,000 microampères.

If two batteries are connected *in series*, as shown in Fig. 2.2, the potential difference between the terminals A and B will be the sum of the voltages of the two batteries. Thus since each of the two cells shown has $1\frac{1}{2}$ volts, there will be 3 volts between the points A and B.

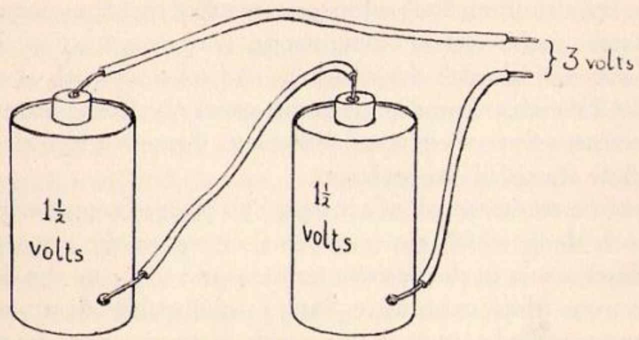


Fig. 2.2. *Two dry cells in series.*

But if the two cells are connected *in parallel* as in Fig. 2.3, the voltage between A and B will be $1\frac{1}{2}$ volts only, but they will be able to supply twice the amount of current, i.e twice the number of amps., without ill effect on their life.

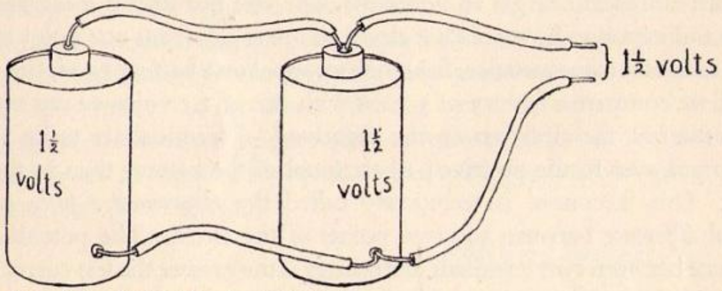
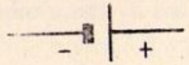


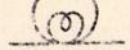
Fig. 2.3. *Dry cells in parallel.*

In a battery the same terminal always has the same polarity: either it is positive or it is negative. If a bulb is connected to a battery, therefore, the current always flows the same way round, always in the same direction. But the terminals of a bicycle dynamo, for instance, always change their polarity at each half-revolution of the small magnet inside the dynamo. Each terminal in this case will be positive one moment and negative the next. The current supplied by the dynamo does not, therefore, always flow in the same direction but constantly reverses its direction. Such a current is known as an *alternating current* or simply A.C. This is distinguished from the *direct current* or D.C. which is given by a battery.

To simplify the drawing of diagrams of electrical circuits special symbols and conventions are used. Thus the cell of a battery is represented by the symbol



and a bulb by



In these theoretical diagrams any direct path between two electrical components is represented by a straight or angular line, but the actual course taken by that line need not bear any relation to the actual course taken by the conducting wires which connect the components of the circuits. The theoretical diagrams of Fig. 2.5, for instance, are all correct representations of the circuit shown in Fig. 2.4.

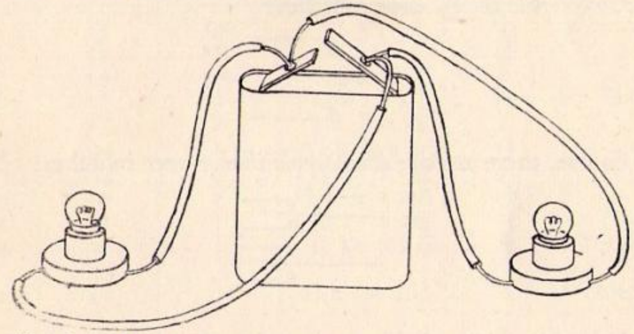


Fig. 2.4. *Two lights in parallel.*

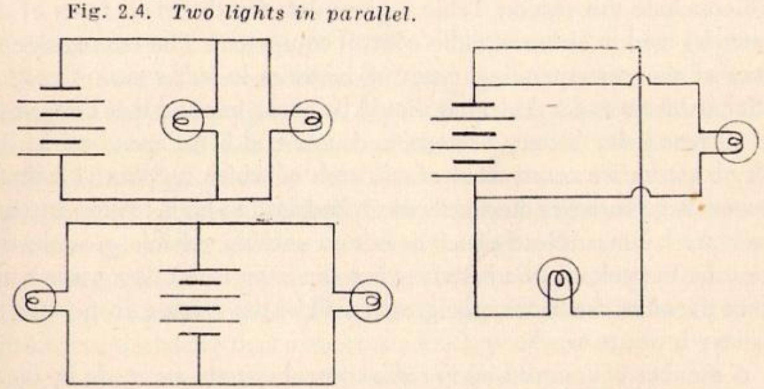
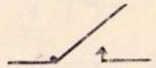
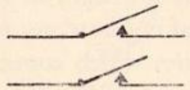


Fig. 2.5. *Some of the possible alternative ways of representing in graphical symbols the circuit of Fig. 2.4. Such representations are called 'theoretical circuits'.*

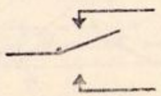
Switches are used to make or to break a path for an electrical current i.e. to close or open a circuit. A simple switch which just makes or breaks a single pathway is represented by the symbol



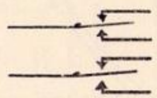
This is called a *single-pole single-throw* switch. In some switches two independent pathways are made or broken simultaneously. These are *double-pole single-throw* switches:



Then there are switches which in breaking one circuit make another; these are *single-pole change-over* switches:



And, of course, there are the *double-pole change-over* switches:



To conclude this section Table 2 gives data for the main types of dry batteries used in airborne radio control equipment. The reference numbers of the corresponding types of batteries in other makes may be obtained from radio dealers. It should be borne in mind that the amount of current a dry battery delivers, and its useful life, depend on its size. Dry batteries are constructed of *cells* each of which supplies $1\frac{1}{2}$ volts. In low-voltage batteries these cells are cylindrical, in high-tension batteries they are laminar. Note that it is not an entirely reliable procedure to measure the voltage of a battery when the latter is not doing any work, since the older the battery the greater will be the voltage drop when the battery is put to work.

A number of connections in radio control systems are made by means of plugs which fit into suitable sockets. A very good type of miniature plug, having from 2 to 5 pins, is obtainable from all dealers in radio spares.

They are supplied with or without protective caps. But modellers are strongly advised always to buy the caps as well since nothing is more annoying than having a connecting wire break on the field. As an example of the graphical symbols used for representing a plug and socket, that for a three-pin plug and socket is given below (the left-hand side represents the socket).

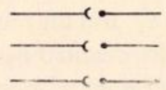


TABLE 2

Commercial batteries for R.C. receivers

Ever Ready	Voltage	Max Current M.A.	Dimensions in inches	Weight in ounces	Terminals
D 29	$1\frac{1}{2}$	350	1×3	3	Centre contact
U 11	$1\frac{1}{2}$	150	$1 \times 1\frac{7}{8}$	$1\frac{1}{2}$	,, ,,
U 2	$1\frac{1}{2}$	300	$1\frac{3}{8} \times 2\frac{3}{8}$	3	,, ,,
B 120	15	3	$1\frac{5}{16} \times 1 \times 1\frac{9}{16}$	$1\frac{3}{8}$	End caps
B 121	15	2	$1\frac{1}{8} \times \frac{11}{16} \times 1\frac{1}{2}$	1	,, ,,
B 122	$22\frac{1}{2}$	2	$1\frac{1}{8} \times \frac{11}{16} \times 2$	$1\frac{1}{2}$	,, ,,
B 110	$22\frac{1}{2}$	3	$1\frac{5}{16} \times 1 \times 2\frac{3}{16}$	3	,, ,,
B 123	30	2	$1\frac{1}{8} \times \frac{11}{16} \times 2\frac{9}{16}$	$1\frac{3}{4}$	,, ,,
B 105	30	3	$1\frac{5}{16} \times 1 \times 2\frac{3}{16}$	$3\frac{1}{2}$	,, ,,
B 119	30	3	$1\frac{11}{32} \times 1 \times 3\frac{11}{32}$	$3\frac{1}{2}$	Three pin socket
B 112	45	4	$2\frac{1}{2} \times 1 \times 4\frac{1}{16}$	8	Three pin socket

2.2. Resistance

The amount of current flowing through a conductor, for instance through a length of copper wire, depends not only on the potential difference between the ends of the conductor, i.e. on the number of volts, but also on the length of the conductor, on its cross-section and on the material of which it is composed. Other things being equal, less current flows through a long and thin wire than through a short and thick wire; less current flows through an iron wire than through a copper wire.

This fact is summed up by saying that a long and thin wire has a greater *resistance* to electricity than a short and thick wire, that an iron wire has a greater resistance than a copper wire of equal size.

The resistance of a conductor or circuit is measured in *ohms*. When an electrical pressure of 1 volt is required to force a current of 1 ampère through a conductor or circuit, that conductor or circuit is said to have a resistance of 1 ohm. For instance, a length of 9.7 feet of No. 30 copper wire has a resistance of about 1 ohm; a torchlight bulb has a resistance of something like 10 or 20 ohms. A larger unit frequently used in radio is the megohm:

1 megohm = 1,000,000 ohms.

The usual symbol for ohm is Ω, and for megohm **MΩ**. There is also the kilo-ohm (1,000 ohm), usually denoted by the letter 'K'.

A very simple but very important relation exists in any circuit between current, voltage and resistance: viz. the current is always equal to the voltage divided by the resistance.

$$\text{current} = \frac{\text{voltage}}{\text{resistance}}$$

or

$$I = \frac{E}{R}$$

where I is the current measured in amps, E the voltage measured in volts and R the resistance measured in ohms. This is known as *Ohm's Law*. For instance, if a battery of 3 volts supplies a bulb which has a resistance of 6 ohms, we can calculate from Ohm's Law that a current of $\frac{1}{2}$ amp will flow through the bulb.

A special name is given to the number obtained if the voltage of a circuit is multiplied by the current. This is called the number of *watts* of the circuit. In the case just mentioned, therefore, we have $1\frac{1}{2}$ watts.

$$I \times E = W$$

where W is the number of watts.

To reduce the current it is often necessary to include in a circuit special conductors which have a high resistance. Special high-resistance conductors are manufactured for this purpose and are known as *resistors*. The resistors commonly used in radio are small cylinders of a special composition which may be obtained in a great variety of resistance values, anything from a few ohms to several megohms. On commercial resistors special colour markings are used to indicate their resistance. Marking

may be effected by using one colour for the body, one for the tip and one for a spot or band. In that case the colour of the body indicates the first figure of the number of ohms of the resistor according to the colour code shown below; the colour of the tip indicates the second figure of that number according to the same code; and the spot or band indicates the number of O's which are to follow these two figures, again according to the same code.

Black	0	Red	2	Yellow	4	Blue	6
Brown	1	Orange	3	Green	5	Violet	7
Grey	8					White	9

If in addition the resistors have a gold tip this means that they have a tolerance of + 5%; silver indicates + 10%; and in the absence of these markings the resistor is understood to have + 20% tolerance.

In the second method of marking, three or more bands of colour are used and the body colour has no significance. Fig. 2.6 gives an example of the two alternative ways of marking a resistor of 47,000 ohms and 5% tolerance.

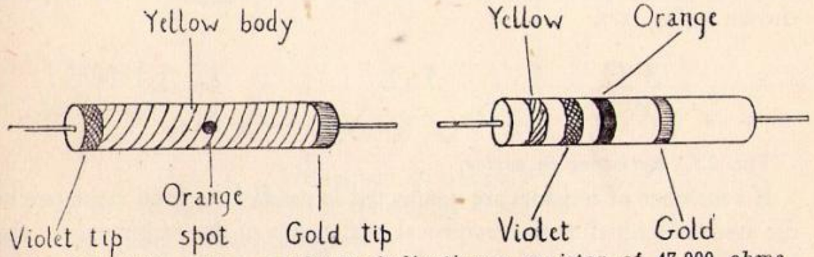


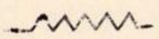
Fig. 2.6. *Alternative markings indicating a resistor of 47,000 ohms and 5 per cent tolerance*

A resistor cannot carry an unlimited amount of current without ill effect. A heavy current requires a resistor with a large body. For his airborne equipment the modeller will therefore want to buy the lightest resistors which are able to carry the required current. This means that before buying a resistor he should make a rough calculation of the required wattage; this is done by multiplying the voltage at the ends of the resistor by the current which according to Ohm's Law must flow through it.

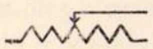
For instance, it is safe to connect a 100 ohm resistor of the $\frac{1}{2}$ watt type across the terminals of a battery of 6 volts, because according to Ohm's Law the current will be .06 amps and the wattage therefore .36 watts. But a similar resistor of the $\frac{1}{4}$ watt type would not be safe in this position.

Some resistors allow a variable portion of the resistor be to tapped off. These are known as *potentiometers.* Here the body of the resistor is usually wirewound and circular and is tapped off by a revolving contact arm; the whole is housed in a bakelite casing.

The graphic symbol for a resistor is



and for a potentiometer



Accordingly a potentiometer has three terminals; of these the central one connects to the moving arm.

If a number of resistors are connected *in series* the total resistance of the chain is equal to the sum of the individual resistances. An example is shown in Fig. 2.7.

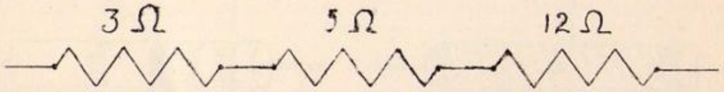
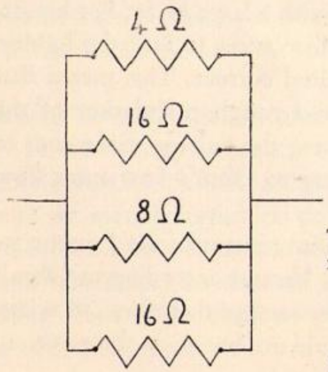


Fig. 2.7. *Resistors in series.*

If a number of resistors are connected *in parallel* the total resistance of the system is equal to the reciprocal of the sum of the reciprocals of the individual resistances. Fig. 2.8 shows what is meant by resistors 'in parallel' and how to calculate the total resistance of such a unit.



Total resistance is $\dfrac{1}{\frac{1}{4} + \frac{1}{16} + \frac{1}{8} + \frac{1}{16}} = \dfrac{1}{\frac{1}{2}} = 2$ ohms

Fig. 2.8. *Resistors in parallel.*

Resistors are very cheap components and the radio enthusiast will usually make a point of keeping a fair variety of them in stock. Useful experimental resistors of a few ohms can be made easily by cutting suitable lengths of the nichrome spirals which are sold for electric heaters. For this purpose the writer always keeps a few small 600 watt spirals in stock.

To *measure* the resistance of a resistor (or of any other electrical component) one connects the resistor in series with an ampère meter or milliampère meter across a battery of known voltage and measures the current that flows through the circuit. (See Fig. 2.9.) Ohm's Law then enables one to calculate the total resistance of the unknown resistor plus meter, and if the resistance of the latter is known, the resistance of the former is easy to calculate.*

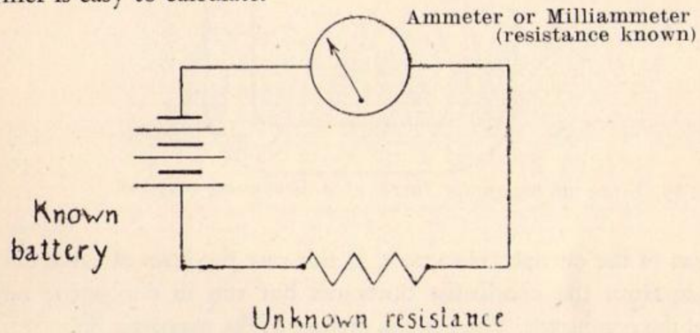


Fig. 2.9. *Simple circuit for measuring a resistor.*

2.3. Coils and Electromagnets

The space surrounding a magnet is permeated by *magnetic lines of force,* so-called, which emanate from the magnet and, for instance, cause a piece of iron to be attracted by the magnet and to move towards it. If a sheet of cardboard is placed over a magnet and iron filings sprinkled onto this, the filings will arrange themselves along the lines of force and thus make them visible. The general picture of the lines of force of a horseshoe magnet, as revealed by this method, is shown in Fig. 2.10. The lines are said to run from the north pole of the magnet to the south pole. The space surrounding the magnet and containing these lines of force is called the *magnetic field* of the magnet.

When an electric current flows through a conductor it also gives rise to a magnetic field and the conductor becomes magnetic throughout the

* Provided, of course, the internal resistance of the battery can be ignored in comparison.

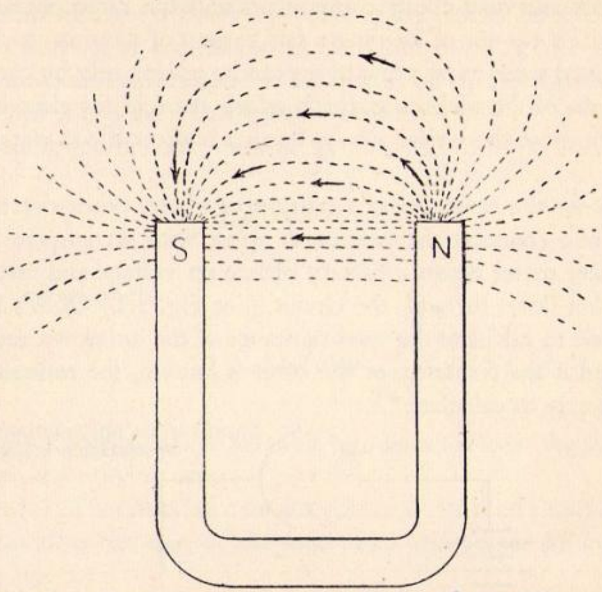


Fig. 2.10. *Lines of magnetic force of a U-shaped magnet.*

duration of the current. However, in this case the lines of force do not emanate from the conductor outwards but run in concentric circles around the conductor. The general picture of the magnetic lines of force surrounding a conductor while a current flows through it is shown in Fig. 2.11.

Moving electricity causes a magnetic field, therefore. And the opposite is also true: a moving magnetic field (i.e. a magnetic field containing

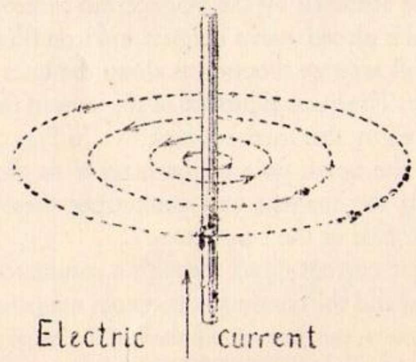


Fig. 2.11. *The magnetic field of force of a straight conductor.*

moving lines of force) gives rise to an electric current in any conductor which is cut by the moving lines of force. This is called *electromagnetic induction.*

If a length of electric wire is wound into a coil and a current sent through it, the magnetic fields of the successive turns of the coil reinforce one another and a comparatively strong magnetic field results whose lines of force runs as shown in Fig. 2.12a.

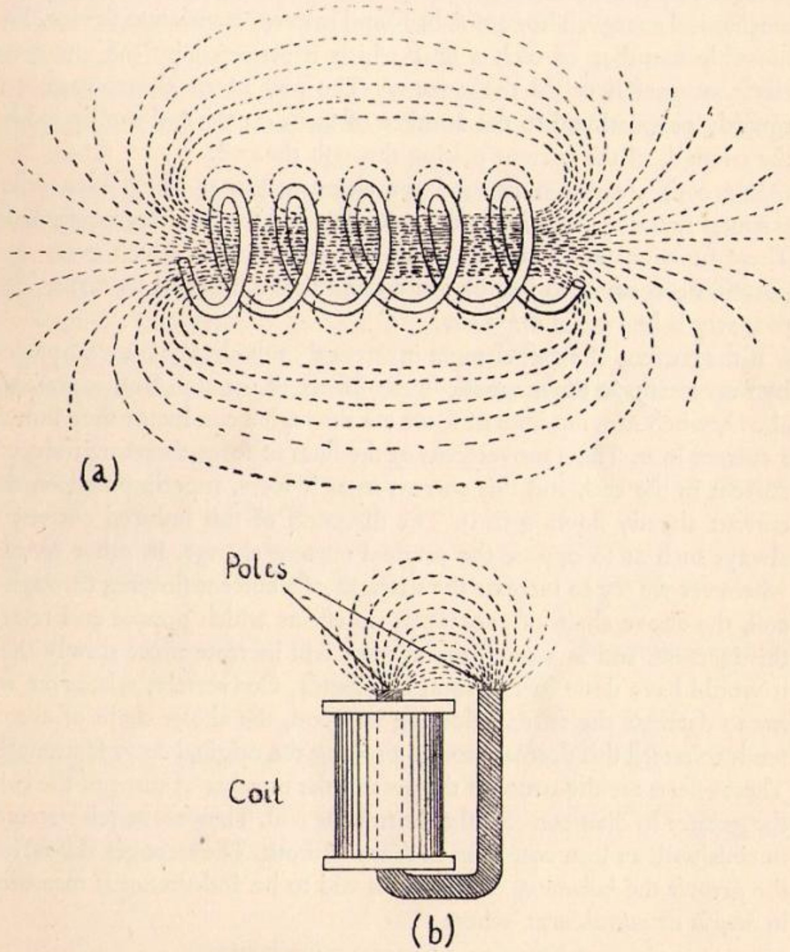


Fig. 2.12. *The field of force of* (a) *a simple coil,* (b) *an electromagnet with U-shaped core.*

If such a coil is given a soft iron core this will become magnetised by the magnetic field of the current, and will be magnetic while the current lasts; but it will lose almost all of its magnetism when the current ceases. The core of such an *electromagnet* may be either straight or U-shaped. In the former case the pattern of the lines of force will be that of a bar magnet, in the latter case roughly that of a horseshoe magnet (Fig. 2.12b).

Electromagnets are essential components in radio control systems because they provide the best manner of converting electrical energy into mechanical energy. They are to be found in every translating device. The movable member of such a unit which is attracted by the energised electromagnet is called the *armature*. The pull of an electromagnet is roughly proportional to the number of turns on the coil multiplied by the strength of the current passing through the coil.

But coils are not only used for electromagnets. They have other essential functions to fulfil in the receiving and transmitting equipment. These functions are based on an important property which every coil possesses according to its dimensions and the number of its turns. This property is known as *inductance*.

If the current of a coil changes in strength, this change is accompanied by movements in the magnetic lines of force of the coil. But, as was said above, when moving lines of force cut through a conductor they induce a current in it. These movements of the lines of force therefore induce a current in the coil, and this current is, as it were, superimposed on the current already flowing in it. The direction of this induced current is always such as to oppose the original current change. In other words, whenever we try to increase the strength of a current flowing through a coil, the above chain of events sets up effects which oppose and retard this increase, and as a result the current will increase more slowly than it would have done in a straight conductor. Conversely, whenever we try to decrease the current flowing in a coil, the above chain of events tends to retard this decrease and to prolong the original current strength. These effects are the stronger the greater the number of turns of the coil, the greater its diameter and the shorter the coil. They are much stronger in coils with an iron core than in those without. The stronger this effect, the greater the *inductance* of the coil is said to be. Inductance is measured in *henrys* or *microhenrys*, where

$$1 \text{ henry} = 1{,}000{,}000 \text{ microhenrys}.$$

One of the effects of inductance is, that a coil will resist an alternating current more strongly than a direct current, and an alternating current with rapid alternations more than one with slow alternations. A coil, therefore, which has a resistance of 1,000 ohm for a direct current will have more than a 1,000 ohm for an alternating current, and this additional resistance depends on the frequency of the alternations. The resistance of a circuit to alternating current is called *impedance*.

Sometimes coils are inserted into a circuit for the sole purpose of creating an extra resistance against alternating current in the circuit. Such coils are called *chokes*. If they have a small inductance and are only designed to bar high frequency currents in the circuit, they are known as *high frequency chokes* and may be distinguished from the *low frequency chokes* which have a sufficient impedance also to resist low frequency currents effectively.

If two coils are placed adjacent to one another so that each is situated in the magnetic field of the other, fluctuations in the current strength in the one coil will induce similar fluctuations in the second coil, for the latter will be affected by the fluctuations set up in the magnetic field of the former. This *mutual inductance* is the strongest if the coils are aligned along the same axis as in Fig. 2.13 (a); it has the least effect if the axes of the two coils are perpendicular to one another. (Fig. 2.13 (b).) It follows

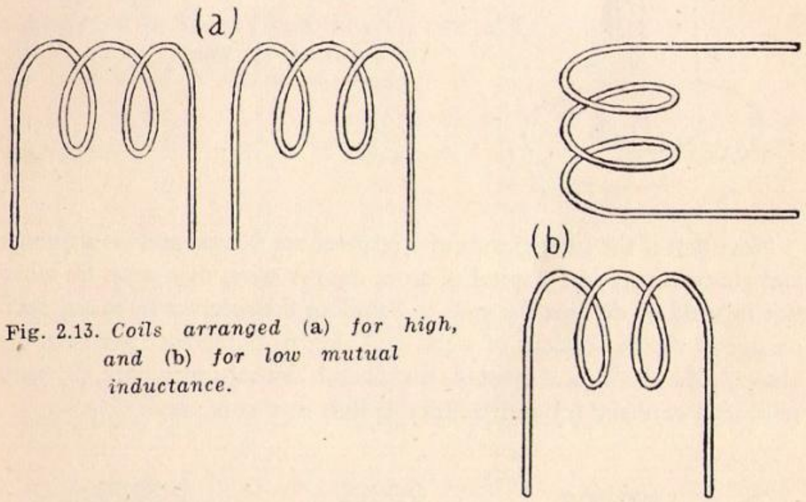


Fig. 2.13. *Coils arranged (a) for high, and (b) for low mutual inductance.*

that if there is to be no mutual interference between two closely placed coils they should be mounted as in Fig. 2.13 (b).

The function of coils in *tuning* circuits of receivers will be discussed below. On the wavelengths used for radio control these coils usually consist of only a few turns of wire, wound in a single layer. The approximate inductance of such a coil may be calculated from the following formula due to J. H. Reyner:

$$L = \frac{1}{5} \cdot \frac{N^2D^2}{3.5D + 8S}$$

where N = number of turns; S = length of coil in inches; D = diameter and L = inductance in microhenrys. The formula is often useful when it is desired for reasons of space to replace a coil by one of different dimension but the same inductance.

Tuning coils with a *variable inductance* may be obtained on the market in the form of coils with an adjustable dust iron core. (Fig. 2.14.)

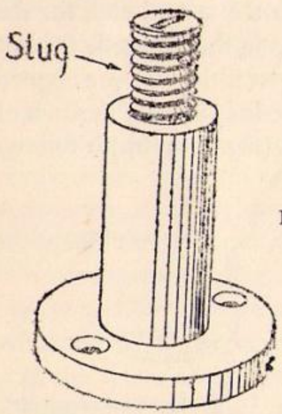


Fig. 2.14. *Bakelite Coil Former with Threaded and Adjustable Dust Iron Core ('Slug').*

Note that if the tuning coils of a receiver are not wound on a former and consist simply of a spiral of stout copper wire, care must be taken not to bend or deform the coils in handling the receiver since any such change in the dimensions of a coil will alter its inductance (see formula above). The theoretical symbols for (a) coils without iron core, (b) with solid iron core and (c) with adjustable dust iron core, are

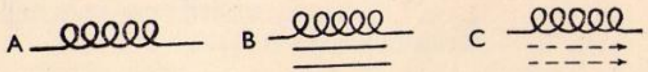


TABLE 3

Copper Wire Data

S.W.G.	Diameter	Resistance in ohms per 1000 yds
10	.1280	1.8657
11	.1160	2.272
12	.1040	2.826
13	.0920	3.612
14	.0800	4.776
15	.0720	5.897
16	.0640	6.611
17	.0560	9.747
18	.0480	13.27
19	.0400	19.10
20	.0360	23.59
21	.0320	29.85
22	.0280	38.99
23	.0240	53.07
24	.0220	63.16
25	.0200	76.42
26	.0180	94.35
27	.0164	113.6
28	.0148	139.6
29	.0136	165.3
30	.0124	198.8
31	.0116	227.2
32	.0108	262.1
33	.0100	305.7
34	.0092	361.2
35	.0084	433.2
36	.0076	529.2
37	.0068	661.1
38	.0060	849.1
39	.0052	1130
40	.0048	1327
41	.0044	1579
42	.0040	1910
43	.0036	2359
44	.0032	2985
45	.0028	3899
46	.0024	5307
47	.0020	7642
48	.0016	11941

2.4. Escapements and Relays

2.4.1. Escapements

The nature of electromagnets was discussed in the preceding section. Their most important applications in airborne radio equipment are in escapements and relays. The function of an *escapement* is to use an electric impulse for the release of machanical energy. It enables a comparatively weak electric current to release the stored mechanical energy of (say) a rubber motor by trigger action. The mechanical power necessary to move the rudder of an R/C model is not usually derived from an electric motor, for motors and batteries are comparatively heavy units. Instead, the usual practice is to use a tensioned rubber motor as source of power and to use electrical energy merely to control the step by step release of this stored energy. In some heavier units a clockwork motor is used instead of rubber.

Fig. 2.15a shows a common type of four-position escapement. It consists of an electromagnet (E), a spring-tensioned armature (A) with two claws and a starwheel (S) which is tensioned by a rubber motor (not shown) and engaged by either the one or the other claw of the armature. When the magnet is energised by an electric current it attracts the arm of the armature and the claw of this arm releases the starwheel. Driven by the rubber motor in the direction shown, this wheel then executes nearly a quarter turn and is brought to a stop by the second claw. When the current ceases the armature is released and returns to its rest position. The starwheel is now retained in its new position by the first claw. The manner in which such an escapement can be used to move the rudder of a model will be discussed in a later section.

A more popular form of escapement for rudder control is the *self-centring escapement.* Here the starwheel has only two arms. In consequence, when the current ceases and the armature jumps back the starwheel executes another quarter turn before it is caught by the first claw. The rest position of the starwheel is therefore always with the arms as shown in Fig. 2.15 (b) except that for the duration of a current in the electromagnet it occupies the position shown in broken lines. The starwheel is linked to the rudder of the model in such a way that the rudder is central when the starwheel is in the rest position but it is in the off-right or off-left position when the arms are at the quarter turn.

Since it requires far less current to hold the armature on to the pole pieces of the magnet than to pull it there, these escapements are often

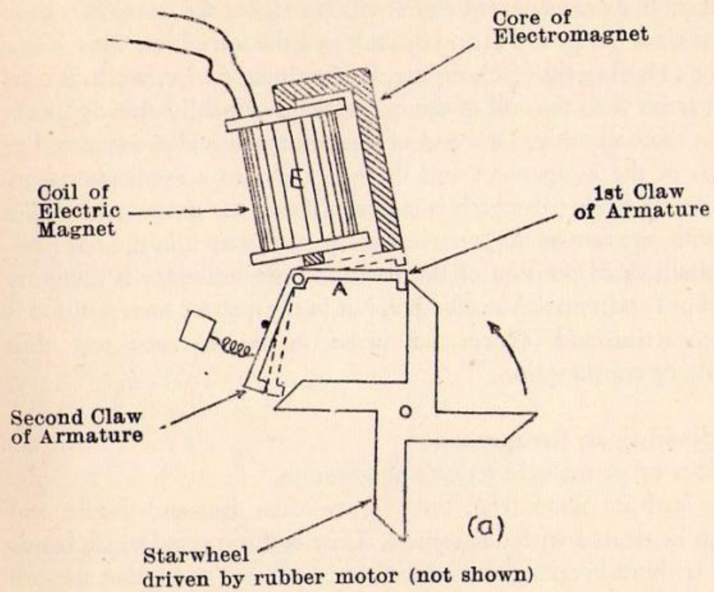


Fig. 2.15. (a) *Four-position Escapement.*

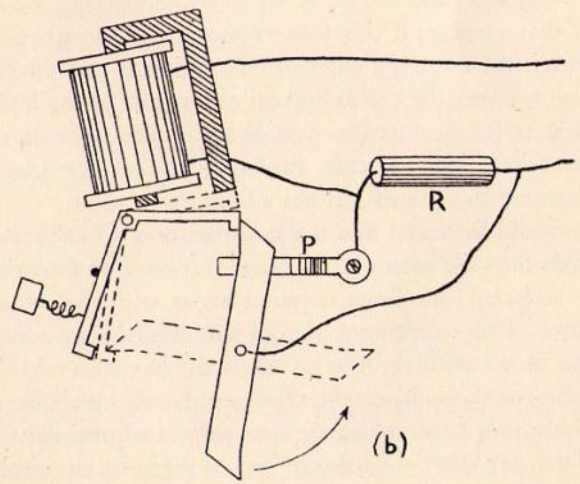


Fig. 2.15. (b) *Self-centring Escapement with current-saving device.*

furnished with a *current saving device* which reduces the current as soon as the first claw has pulled in and has released the starwheel. This device consists of a small resistor (R), or length of resistance wire, which is connected in series with the coil of the magnet and is usually already incorporated in the coil body. One end of this resistance is also connected to the chassis of the escapement and the other end to a small phosphor-bronze contact blade (p) which is insulated from the chassis and makes contact with one arm of the starwheel when the latter is in the rest position. In the normal position of the starwheel the resistance is therefore shortened out and remains ineffective, but in the quarter turn position it is put into action and reduces the current in the electromagnet, thus saving battery consumption.

2.4.2. Adjusting an Escapement

A number of points here require observation.

(1) The lead-out wires from the coil are often thin and fragile, and must be treated with due respect. They will not stand much bending without breaking. It is therefore important to see that the coil is fixed really firmly and unable to rotate.

(2) The escapement used in model aircraft are usually designed for 3 or $4\frac{1}{2}$ volts and should be tested by connecting them to a battery of that voltage. If this fails to energise the magnet, check with a meter and a battery whether a current can pass through the relay. If not, either the coil is burned out or one of the lead-out wires is broken. If a current does pass, but fails to energise the magnet, there must be a short-circuit. Probably one of the lead-out wires is touching the chassis and has a faulty insulation.

(3) It should be noted that if the armature is set at twice the distance from the pole pieces of the magnet it requires four times the force to attract it; the force required varies with the square of the distance. The escapement should therefore be so adjusted that the armature has the shortest travel consistent with a reliable mechanical action of the escapement. The gap should be about $\frac{1}{16}$ in. to $\frac{3}{32}$ in. The spring tension also requires careful adjustment.

(4) If the starwheel is tensioned too strongly by the rubber motor its friction with the claw may become too great to enable the latter to pull in when the magnet is energised. The manufacturer's instruction as to the best size of rubber motor should therefore be

followed carefully. Usually the motor consists of a single loop of $\frac{1}{8}$in. or $\frac{3}{16}$in. rubber strip. The length of this loop should be about 20% above the distance between the hooks that hold it.

(5) To reduce the wear on the claws it pays to bend the arms of the starwheel slightly so that they do not all strike the claw at the same point.

(6) The face of the arm striking the claw and the face of the claw at that point should be exactly square to the line of travel of the claw, so that the blow from the arm will not knock the claw aside. The correct geometrical relationships between the faces and pivots of the claws and starwheel to insure reliable action are shown in Fig. 2.15c.

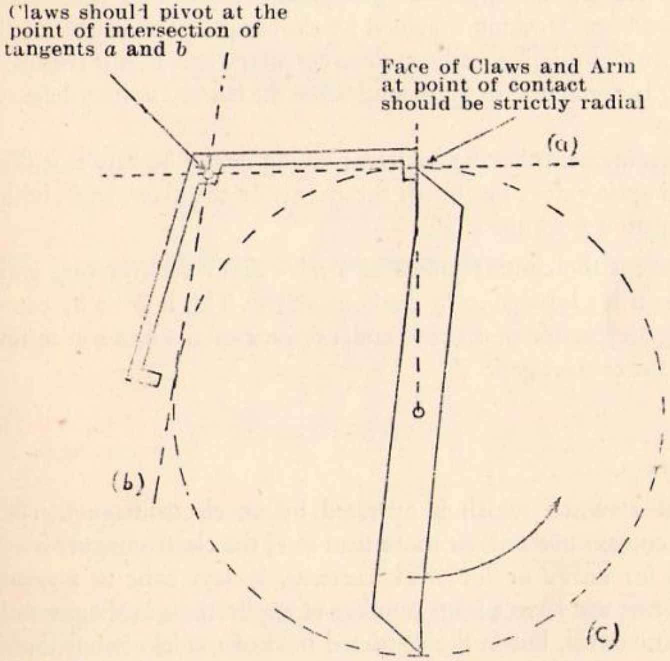


Fig. 2.15. (c) *The geometry of escapements.* (a) *and* (b) *are the tangents to the circle at the points were the arms make contact with the claws.*

(7) In escapements in which the coil is secured to the chassis by a steel screw the latter should never be replaced by a brass one, since it may form an essential link in the magnetic circuit of the electromagnet.

(8) If the armature sticks to the magnet after the current has ceased (this being due to a little residual magnetism in the core), this may be cured by slightly increasing the spring tension of the armature. should this fail to have the desired effect, the faces of the pole pieces may be ground very slightly angular so that the armature touches them along a thin edge only.

(9) The fate of a model may depend on the reliable action of an escapement. In buying or making an escapement, therefore, particular attention should be given to the mechanical soundness and smooth action of the unit. It should be responsive and have a good safety margin so that it continues to act reliably on run-down batteries. In this respect the larger designs usually score over the more compact ones. Nothing is gained by choosing a particularly small or lightweight design, only to discover afterwards that it requires heavier batteries or fails to respond when the battery voltage begins to drop.

10) With escapements having a current-saving device beware that the contact spring does not touch the chassis or the claw, and check its insulation from the chassis.

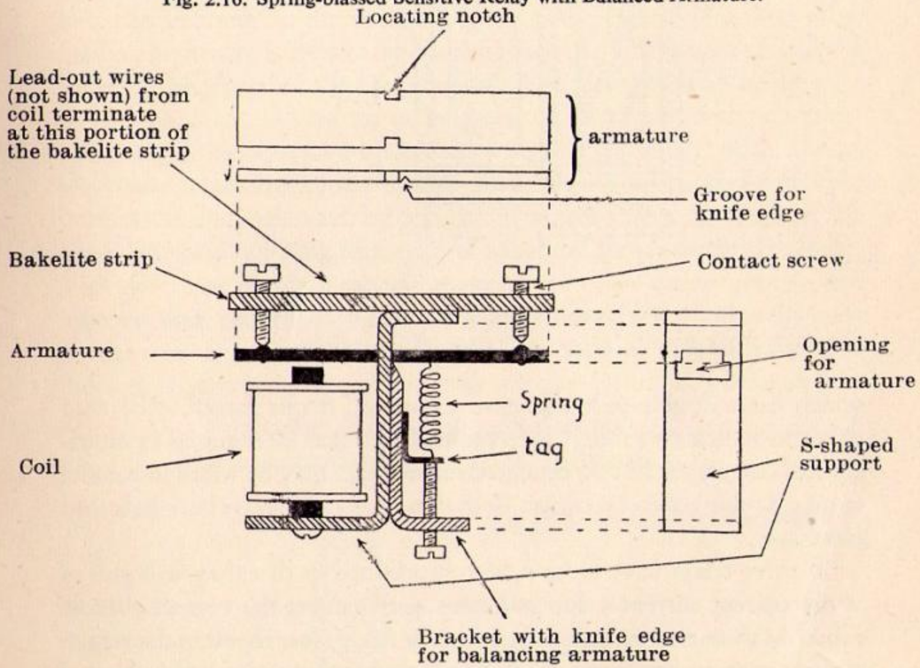
(11) To prevent the contact points of a relay from deteriorating and sticking it is advisable to fit *spark suppressors.* This is done by connecting a capacitor of 0.1 mfd and a resistor of 100 ohms in series across the contact gap.

2.4.3. Relays

A relay is a switch which is operated by an electromagnet. The switch may contain one pole or more than one; the electromagnet may be designed for heavy or for weak currents. Relays exist in a great variety of forms and have a large number of applications in the general field of radio control, but in the restricted field of model aircraft there is only one type of relay that has universal application. This is the *sensitive relay* with either a single- or double-pole change-over switch. The electromagnet of this relay contains one or more coils wound with a very great number of turns of very fine wire and will therefore respond to very weak currents or very small changes in a standing current. The relay is used to enable the small output of the receiver in the model to switch on the heavier currents which are required for operating the actual control surfaces.

When the current through the electromagnet stops, or drops below a given value, the switch must return to its original position. This is achieved either by means of a spring or a permanent magnetic field. In the first case we have the *spring-biased relays* (Fig. 2.16), in the second case the so-called *polarised relays* (Fig. 2.17). These are on the whole more reliable.

Fig. 2.16. Spring-biassed Sensitive Relay with Balanced Armature.



In each case the switching member is formed by the pivoted armature of the electromagnet. If the armature is pivoted at its centre, it is called a *balanced armature*. A relay with a balanced armature is much to be preferred in radio control of model aircraft because it is much less likely to be affected by engine vibrations.

Various sensitive relays are obtainable on the market. Only two of these are polarised: a 'Tri-ang' and an 'E.D.' relay. The 'Tri-ang' relay is also the only sensitive relay on the market (at the time of writing)

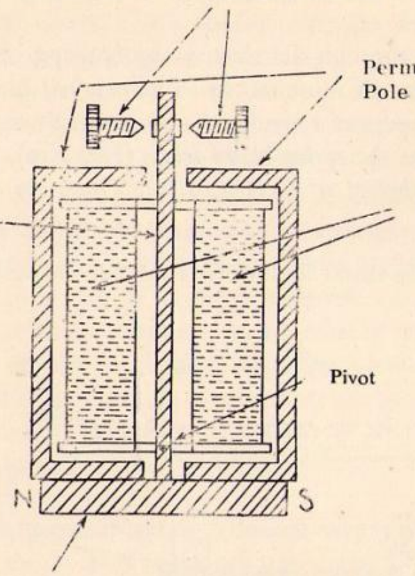


Fig. 2.17. (d) *Sensitive polarized relay (cross-section).*

which has a double-pole change-over action. It can therefore be used either to switch two things independently (as may be required in multi-control circuits) or its two change-over switches may be wired in parallel to give double contact security. Both these polarised relays have balanced armatures.

Sensitive relays have to be delicately adjusted so that they will pull in at the correct current value and drop out again at the correct current value. As these two current values may be fairly close together the airgap at the contact points may have to be less than .005in. On a spring-biassed relay the adjustment is made by altering the spring-tension and the position of the contact screws. On a polarised relay only the contact screws need altering.

The contact points of sensitive relays must always be kept scrupulously clean as there is only a moderate contact pressure. They should be cleaned periodically with an absolutely clean feeler gauge which has been wiped in methylated spirits and is moistened with the spirits for cleaning the points.

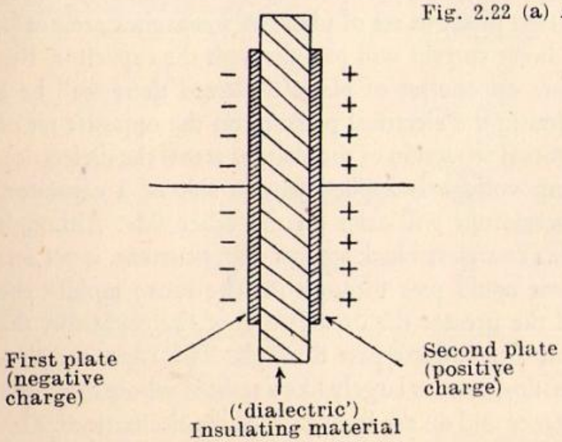
2.5. Capacitors (Condensers)

If two metal plates are placed in close proximity without making electrical contact and are separated only by a thin layer of insulating material, their capacity for holding electricity becomes very greatly increased. For if one of the plates is charged with negative and the other with positive electricity (Fig. 2.18 a) the two charges will attract each other across the insulation and, as it were, hold each other in position. This capacity for holding electrical charges varies directly as the areas of the plates facing each other and inversely as the distance separating them. It is also affected by the material between the plates. This device for holding electricity is called a *capacitor* or *condenser*. The insulating material between the plates is called the *dielectric*. The dielectric may be air.

Two methods are used for making capacitors which combine a comparatively large capacitance (i.e. ability to hold electricity) with a comparatively small size. In the first method two sets of parallel plates are interleaved and separated by insulating material (Fig. 2.18 b). In the second method two long thin strips of metal foil are sandwiched together with two strips of thin insulating material and rolled tightly into a small tube. At each end of this tube a wire protrudes which is internally connected with one of the two metal foils (Fig. 2.19 a). The capacitance of radio capacitors is measured in *farads*, *microfarads* (mf) or *picafarads* (pf).

1 farad = 1,000,000 microfarads.
1 microfarad = 1,000,000 picafarads.

Fig. 2.22 (a) *A simple capacitor.*



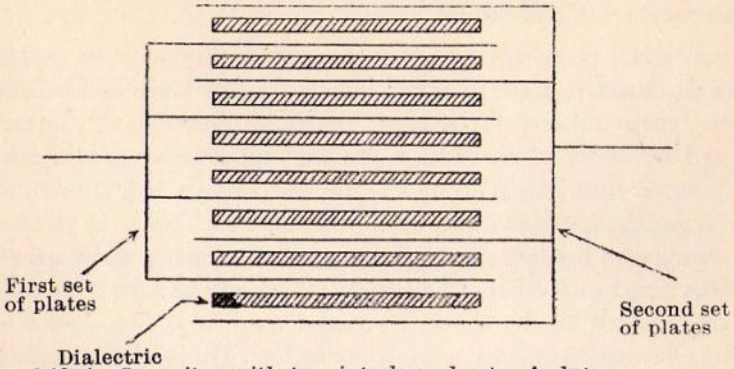


Fig. 2.18 (b) *Capacitor with two interleaved sets of plates.*

For some purposes it is necessary to have capacitors whose capacity can be varied. These *variable capacitors* are usually based on the principle shown in Fig. 2.18 (b), and the required variation in capacitance is obtained either by varying the distance of the plates (compression types) or by varying the area over which the plates face one another. A common capacitor of the last type for high frequencies is the *beehive capacitor* (Fig. 2.19 c) in which two sets of concentric cylindrical plates are interleaved without touching. The air between them serves as dielectric. The space between the plates is very small and care must be taken that the condenser is not deformed by the application of tools since this might bring the opposite sets of plates into contact. The more the two sets of plates overlap, the greater is the capacity of the condenser.

One of the most important properties of capacitors has not yet been mentioned. Since the two plates or set of plates of a capacitor are not in electrical contact, no direct current will pass through the capacitor. But if the electrical pressure on one set of plates is altered there will be a corresponding alteration in the electrical pressure on the opposite set of plates (owing to the mutual attraction of the charges across the dielectric). Hence if an alternating voltage is applied to one side of a capacitor, analogous voltage fluctuations will arise on the other side. Although therefore a capacitor is a complete block against direct current, it yet acts as if alternating current could pass through it. The more rapidly the current alternates and the greater the capacitance of the capacitor, the better will the current alternations pass through. The capacitor thus behaves towards alternating current largely like a resistor whose resistance depends on the capacitance and on the frequency of the alternations. This

resistance towards alternating current is again called the *impedance* of the capacitor (see §2.3). (See page 23).

A type of fixed (i.e. not variable) capacitor which has important applications in radio is the *electrolytic capacitor.* It has a much higher capacitance than other fixed capacitors. In construction it is similar to the tubular fixed capacitors mentioned above, but the positive plate is made of pure aluminium and the dielectric consists of a very thin film which is formed on the aluminium foil by virtue of the presence between the plates of a liquid of paste-like electrolyte. In the *dry* electrolytic condensers the electrolyte is absorbed in porous paper and held in position adjacent to the aluminium foil by this paper. This is the type commonly used in radio. An electrolytic capacitor therefore has a *polarity*; that is to

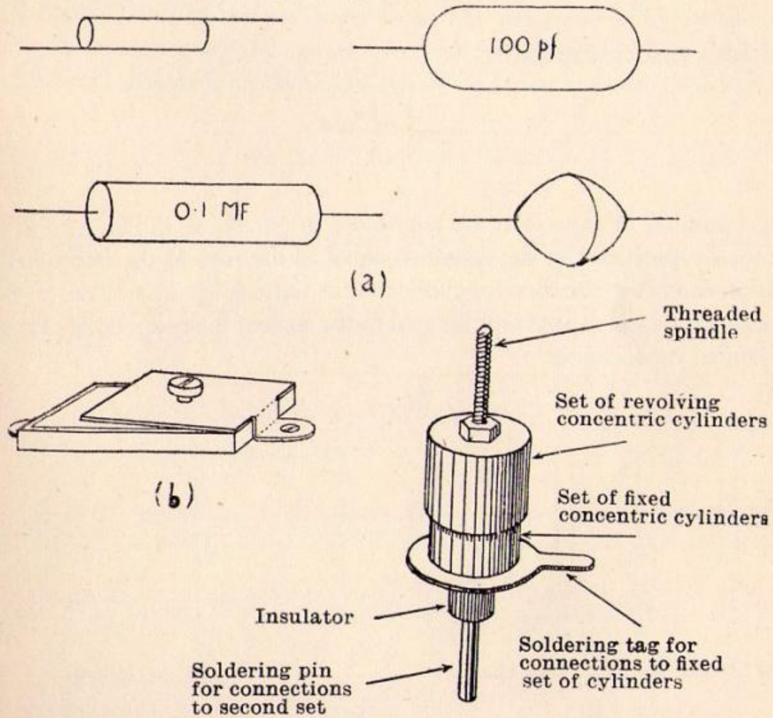
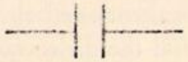


Fig. 2.23. (a) *Types of fixed capacitors.*
(b) *Compression type variable capacitor or 'trimmer'.*
(c) *Beehive capacitor or 'trimmer'.*

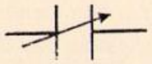
say, the capacitor only works properly if the positive side of the circuit is connected to the correct terminal. In fact, reversing the connections on an electrolytic capacitor may destroy it. Its terminals are therefore always marked by a '+' and '—', or by a colour code: red for positive and black for negative.

The theoretical symbol for a non-electrolytic fixed capacitor is:



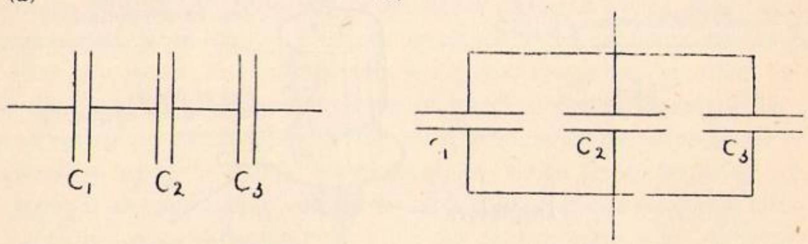
for an electrolytic capacitor it is:

and for a variable capacitor:



If a number of capacitors are connected in parallel as in Fig. 2.20 (b), the total capacitance of the system is equal to the sum of the individual capacitances. If capacitors are connected in series (Fig. 2.20 a) the reciprocal of the total capacitance is equal to the sum of the reciprocals of the individual capacitances.

(a) (b)



Total capacitance of this chain

$$= \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

Total capacitance

$$= C_1 + C_2 + C_3$$

Fig. 2.20. *Capacitors* (a) *in series, and* (b) *in parallel.*

The energy of the electricity held in a capacitor varies as the capacitance and as the square of the applied voltage. If electrolytic capacitors of something like 25 mf or 50 mf are used in conjunction with voltages of 30–60 volts the stored energy of the capacitor is sufficient to cause an escapement or relay to pull in with strong positive action. For instance if, in the circuit of Fig. 2.21, B is a battery of 60 volts, C a capacitor of 50 mf and L the coil of an ordinary escapement as used in model control, then in position 1 of the change-over switch S the condenser will be charged by the battery through the resistor R; if the switch is then moved to position 2 the charged capacitor will instantaneously discharge through L with a powerful impulse and actuate the escapement. Thus if R is large the energy from a comparatively weak but steady current from the battery can be lumped together and be delivered to the escapement in sufficiently strong and concentrated doses to actuate it. Capacitors used in this manner will in the sequel be referred to as a *driving capacitor.*

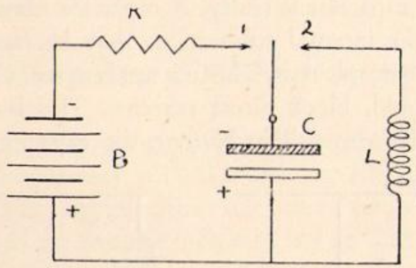


Fig. 2.21. *Circuit for a driving capacitor.*

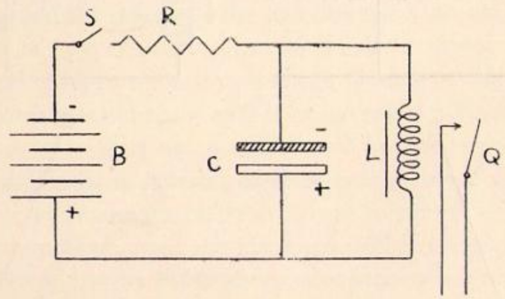


Fig. 2.22. *Circuit for delaying the action of a relay.*

The circuit of Fig. 2.22 is similar but here the capacitor fulfils a different function. L is now the coil of a relay which is sufficiently sensitive to respond to the current delivered by battery through the resistor R. But when the switch is closed this will not at once cause the relay to pull in as the initial current will be absorbed in charging the capacitor. The effect of the capacitor is, therefore, to delay the action of the relay. This also applies when the switch again breaks the circuit. The relay will not drop out until the charged capacitor has discharged through the relay. The time required for this depends on the resistance of L. If B has 30 volts, C 100 mf, R 5,000 ohms and L 5,000 ohms, for instance, a delay of about 1½ seconds results. The capacitor in this circuit is known as a *delaying capacitor*. A relay delayed in this manner is called a *slugged relay*.

These are two examples of the varied functions which capacitors can fulfil. Another important function will be discussed in the next section.

Testing capacitors. The procedure for determining the capacitance of a capacitor is somewhat complicated and is rarely required in ordinary model work. But it frequently happens that a modeller wants to know whether a certain capacitor is faulty. A capacitor may have an internal short-circuit, or the internal connections may be faulty. This can be determined by two simple tests. The first test is to see whether the capacitor does, as it should, block direct currents. This is simply done by connecting in series a torchlight battery, the capacitor to be tested, a

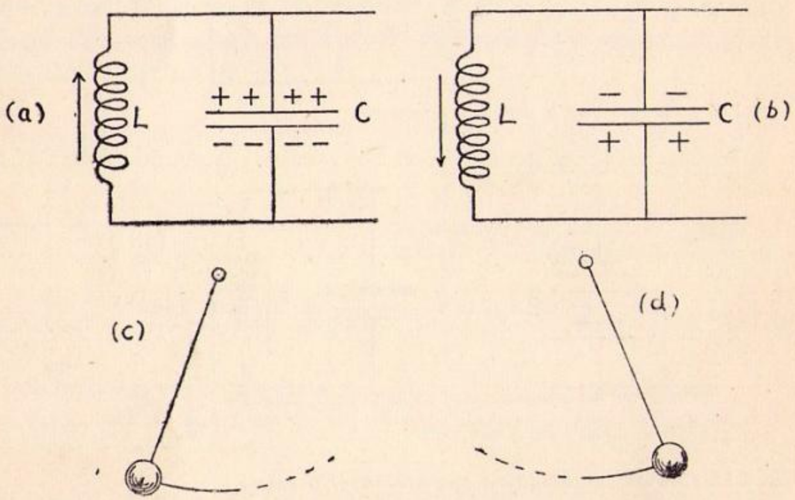


Fig. 2.23. *Analogy between oscillating circuit and a swinging pendulum.*

milliammeter and a resistor of (say) 1,000 ohms to protect the meter. If the capacitor is all right no current should flow in this circuit. Electrolytic capacitors form an exception to this since they have an initial forming current of a few milliamps which, however, declines rapidly and after a couple of seconds is reduced to a leakage current of no more than one tenth of a milliampère. The second test is to see whether the capacitor will pass high-frequency alternating currents. The easiest way to do this is to make use of the fact that the aerial currents of an ordinary wireless set are high-frequency currents. A simple test therefore is to disconnect the (external) aerial from a wireless set and to insert the condenser between the aerial and the set. If the condenser is all right the set should give the same or almost same reception as if the aerial were connected directly to the set (although with capacitors of less than 100 pf some reduction in volume is to be expected). Use this method to compare a suspect capacitor with one of the same capacity which is known to be sound.

2.6. The Natural Frequency of a Coil and Capacitor Combination: Resonance

When a coil and a capacitor are connected in parallel (Fig. 2.23 a and b), a set of conditions may prevail which are analogous to those of a swinging pendulum. Suppose that for some reason the capacitor has become charged in the manner indicated in Fig. 2.23 (a). The capacitor will then discharge through the coil. We should expect this discharging stream of electrons to cease as soon as the surplus electrons of the negative plate have reached the positive plate and cancelled out the initial charge. But, as shown in §2.3, the effect of a coil is first to oppose the growth of the current and then to oppose its decline. Owing to the coil therefore this electron stream will behave as if it had a heavy mass and inertia: for like any object of weight and inertia it will appear to resist being put into motion and, once in motion, to resist being slowed down. In other words, the coil will cause the electron stream to overshoot the mark and after having been discharged the capacitor will become charged in the opposite way (Fig. 2.23 b). Now the reverse process begins, and the same set of events are repeated. Like a pendulum set in motion, the current will swing to and fro; that is to say, we shall have an alternating current. And, as with a pendulum, the frequency of these alterations—or *oscillations*, as they are called—will be constant and will be determined by the magnitudes of the system, i.e. by the capacitance of the capacitor and the inductance of the coil. This constant frequency of the oscillations is called the *natural frequency* of the circuit.

The analogy with a swinging pendulum goes further. A pendulum will not start swinging unless its equilibrium has been disturbed by an external force, and once it swings, its oscillations will gradually die down unless they receive correctly timed boosts from without. Similarly, our circuit will not start oscillating unless the capacitor has received an initial charge, and the oscillations will gradually die down unless they receive correctly timed boosts from without—that is to say, unless an alternating voltage is applied whose frequency bears the right relation to the natural frequency of the circuit. For instance, if a small alternating voltage is applied to the circuit of Fig. 2.23 whose frequency equals the natural frequency of that circuit, the latter will at once start oscillating and these oscillations will quickly build up to the maximum amplitude which the energy losses in the circuit permit. This state of affairs is called *resonance*.

The natural frequency of a circuit consisting of a coil and capacitor is given by the formula

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

where fr is the natural frequency in cycles per second, L is the inductance of the coil in henrys and C the capacitance in farads.

The circuit properties outlined above are used both in transmitters and in receivers. They enable waves of definite frequency and wavelength to be generated in transmitters, and they enable receivers to be tuned to the reception of these definite wavelengths.

2.7. Valves and Valve Oscillators

The greater the temperature of a substance, the greater is the commotion among its atoms and electrons. It is not surprising therefore that if a body is heated in a vacuum it throws off electrons and will become surrounded by a cloud of these emitted electrons. If in the neighbourhood of the electron cloud there is a second, positively charged body, the electrons will be attracted towards this. And if the latter consists of a conductor which derives its positive charge from a high-voltage battery whose negative terminal is connected to the heated body, a continuous

electron stream results which flows from the heated body through the vacuum to the positive conductor. This is the basic effect used in radio valves. The heated body may be either a glowing filament of some metal alloy ('directly heated valves') or a separate chemical substance indirectly heated by such a filament ('indirectly heated valves').

The simplest valve contains no more than these two components enclosed in a vacuum tube: an electrically heated filament and a metal plate (usually a cylinder) surrounding the filament, both being connected to external terminals. A valve of this type is known as a *diode*. Diagrammatically it may be represented as in Fig. 2.24 (a). The plate (A) is known as the *anode* and the filament (F) forms the *cathode*. If the diode valve is connected up as in Fig. 2.24 (b), an electron stream of several milliamps will flow through the valve in the manner already explained. This current is called the *anode current*. B1 is the *low-tension* (*L.T.*) *battery* which serves to heat the filament. B2 is the *high-tension* (*H.T.*) *battery* whose function is to keep the anode positively charged. The meter M measures the anode current.

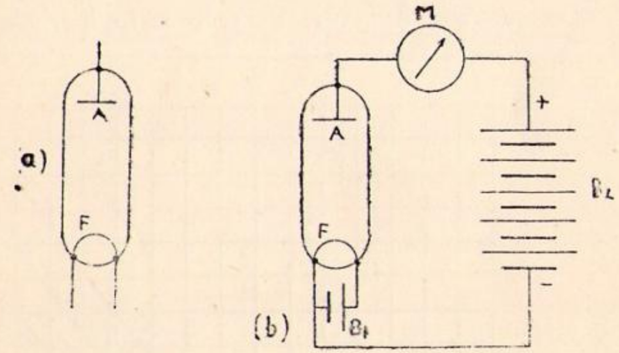


Fig. 2.24. *The Diode Valve.*

The main function of diodes in radio systems is that of rectifier, since they can pass a current only in one direction (from cathode to anode). As such they have no application in the radio systems to be discussed in this book.

Far more important in radio is the *triode valve*. This is an elaboration of the diode and differs in having a metal grid between the filament and the anode. The grid has an external terminal and this makes it possible to exercise a very sensitive control over the anode current. For if the grid is given a negative charge it will counteract the attraction of the anode on the electron clouds, and hence the anode current will drop in value or cease altogether. Conversely, if the grid is given a positive charge it will reinforce the attraction of the anode and thus raise the anode current. This control is so sensitive that even very small fluctuations in the grid voltage may cause comparatively large fluctuations in the anode current. A triode may therefore be used as an *amplifier* for the very small electric fluctuations which the reception of radio waves sets up in a radio receiver.

(a)

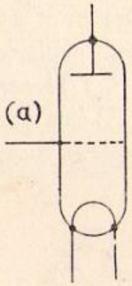
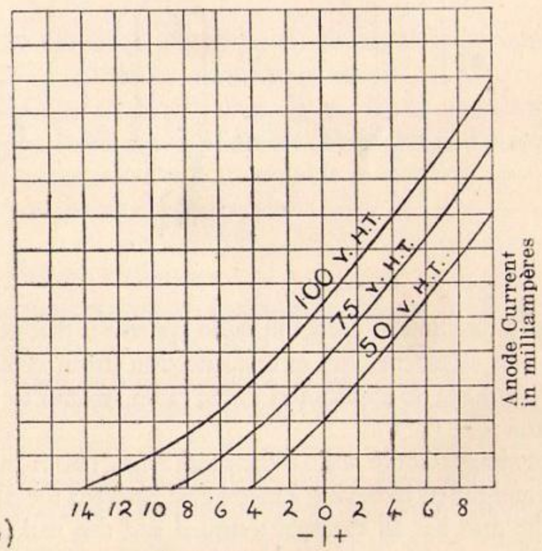


Fig. 2.25. *The Triode Valve. The three graphs illustrate the relation between grid voltage and anode current for three different anode voltages.*



(b)

The theoretical diagram of a triode is given in Fig. 2.25, and the figure also illustrates graphically the manner in which the anode current of an average triode may depend both on the voltages applied to the grid and those applied to the anode.

Amplification is only one of a number of functions triodes can fulfil in radio systems. Another important function is 'detection', so-called, of modulated carrier frequencies (§1.2); but since the detailed discussion of the complex R/C systems which use modulated carriers falls outside the scope of this book, this function of triodes will be passed over. A third important function is to act as *oscillator*, i.e. as generator of oscillations in an oscillatory circuit (§2.6). This is the most important function of triodes in the R/C systems which form the subject of this book.

Fig. 2.26 shows the essentials of a simple oscillator circuit. On the left is seen a coil (L_1) and a parallel capacitor (C). The properties of this combination were discussed in the last section. We saw there that it may give rise to electrical oscillations and that it can be maintained in a continuous oscillatory state if it receives correctly timed boosts from without. The function of the triode valve in this circuit is precisely to furnish these boosts, and it does so *via* the coil L_2 which is coupled to L_1 (§2.3).

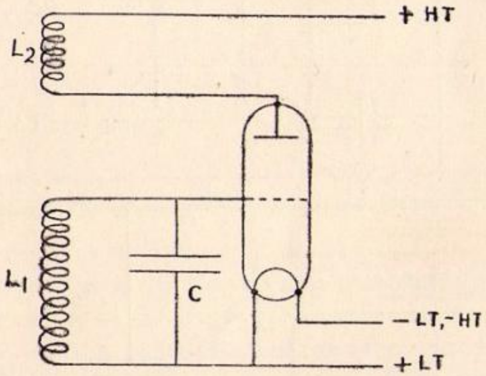


Fig. 2.26. *A valve oscillator.*

The process is as follows. Suppose that a steady anode current flows through the valve and that some small chance fluctuation in this current occurs (as is always bound to happen owing to the state of agitation of the atoms and electrons in the valve); this will cause a correspondingly small fluctuation in the magnetic field of L_2. Since L_1 lies within this field, this will generate a small current in L_2 and hence a small charge on the capacitor. This sets the capacitor and coil circuit oscillating (§2.6). Normally these oscillations would at once die down, but owing to the valve the very opposite occurs; for the oscillations cause an oscillating voltage on the grid of the valve and this in turn causes (magnified) fluctuations in the anode current; these are transmitted back to L_1 by the coil. Owing to this *feedback*, then, we get a progressive growth of the oscillations instead of a decline. The circuit of Fig. 2.26 may thus act as a spontaneous generator of electric oscillations whose frequency is approximately equal to the natural frequency of the L_1-C combination. If an aerial is connected to one side of L_1 and an earth to the other, the circuit acts as a *transmitter*, for it sets up oscillating voltages between the aerial and earth and this results in oscillations of the electrical field surrounding the aerial, i.e. in the radiation of electromagnetic waves.

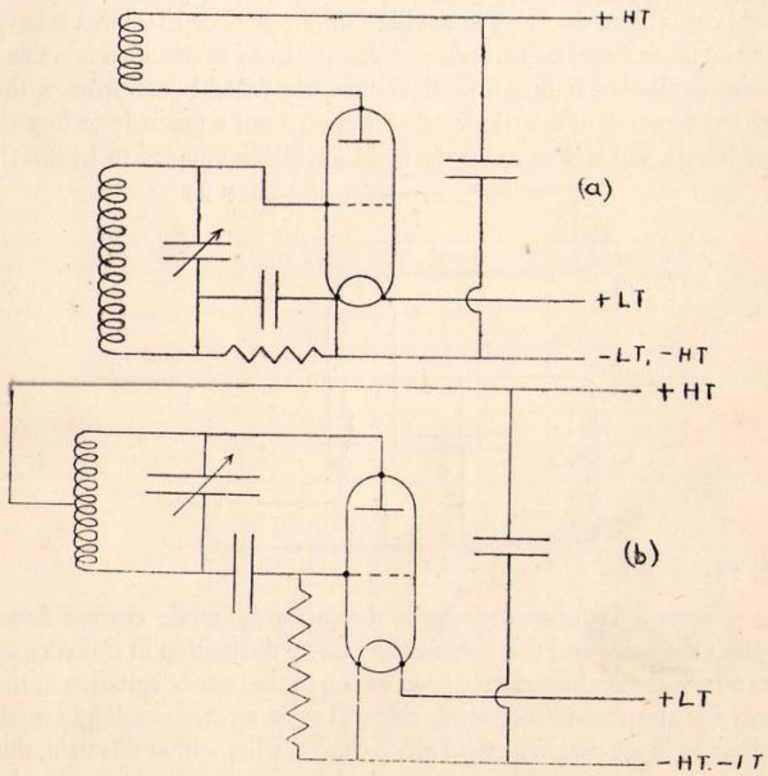


Fig. 2.27 (a) *and* (b) *Simple valve oscillators.*

Owing to certain secondary complications which may interfere with the events just described, the circuit of Fig. 2.26 should be supplemented by a resistor and two capacitors as shown in Fig. 2.27 (a). The figure also shows two alternative simple oscillator circuits. Variable capacitors are used to regulate the frequency of the oscillator.

Since the grid and the plate in a valve are in close proximity they have a certain capacitance which may be undesirable. This capacitance may be reduced by inserting a second grid—the 'screen grid'—between the original grid and the anode, which is kept positively charged. This gives us a valve with four electrodes, or *tetrode*.

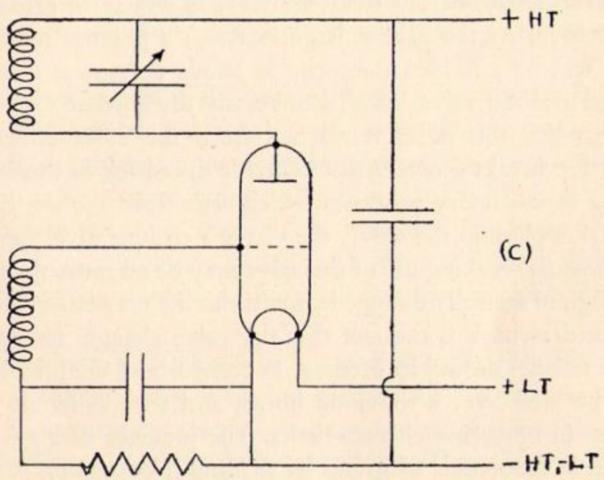


Fig. 2.27 (c) *Simple valve oscillator.*

If an electrode of a valve, e.g. the anode, is bombarded by high-speed electrons, as is bound to be the case in valves with a high anode voltage, this will result in electrons being knocked from the electrode. These are called secondary electrons, and the phenomenon is known as *secondary emission*. This spurious effect may be suppressed by inserting a third grid between the anode and the screen grid, and by connecting this to the cathode. This gives us a valve with three grids and five electrodes altogether. This is known as a *pentode* (Fig. 2.28 a). The principal results of suppressing secondary emission are an increase in the amplification action of the valve, increase in power output and decrease in the distortion of amplified signals. An alternative method for suppressing secondary electrons is used in the *beam power tetrode* (Fig. 2.28 b). Instead of the suppressor grid these valves have a pair of extra plates which give to the electron stream the form of a focussed beam acting as its own suppressor.

All the valves discussed above contain a vacuum, and as such are known as *hard valves.* As the result of certain war time discoveries, however, a certain type of miniature triode became popular for R/C work, in which was left a trace of a special gas. If the gas atoms in these *soft valves* are bombarded by sufficiently fast electrons they will accept the electrons temporarily and thus become electrically charged. This process is known as *ionisation* of the gas. The charged atoms ('*ions*') are attracted by the anode and migrate towards it, thus acting as carriers for the electron stream. The result is a valve in which the grid control is not progressive. As the grid voltage increases a point is reached at which there will be a sudden steep rise in anode current as the gas becomes ionised and the valve 'fires'. Conversely the current will drop precipitately when this point is reached from the other direction and the ionisation breaks down. A considerable drawback of these valves is that owing to secondary processes which arise from the ion bombardment that takes place in the valve, they have a comparatively short life only. The normal working life of the valve may be no more than 10–20 hours, although in specially designed circuits this life may be extended. Another serious drawback is the fact that the valve changes its main operating characteristics during its lifetime. In comparison, the life of a hard valve may be well over a thousand hours, and they suffer no comparative change in operating characteristics. The presence of a gas in a valve is shown in theoretical diagrams by shading (Fig. 2.28 c).

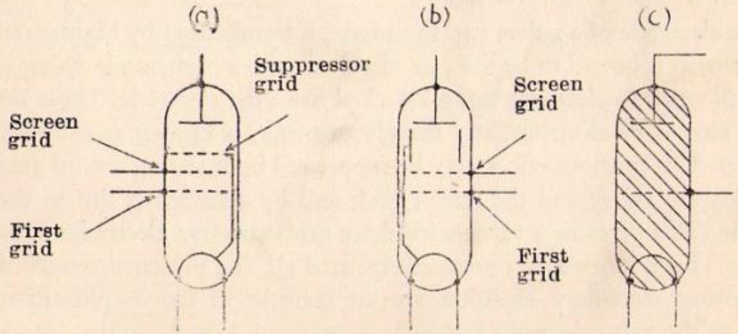


Fig. 2.28. *Pentode, Beam Power Tetrode, and Gas-filled Triode.*

The fragile part of any valve is the *filament.* This may break through mechanical shock or burn out like a torchlight bulb if too high a voltage is applied to it. To test whether the filament of a valve is intact, connect in series with it a 1½ volt battery and either a pair of headphones or a milliammeter which can read up to 100 mA. If the valve is all right a loud click should be heard in the phones when contact is made and the milliammeter should read something like 50 or 100 mA, depending on the type of valve used.

The filament of a valve has a special coating from which the electrons are emitted. If a valve is overheated by having too high a voltage applied to the filament, part of this coating will be destroyed. After a period of overloading, therefore, the filament may still appear to be all right, but in fact the valve will show a defective emission and a deficient anode current.

Most of the valves used in R/C work require a low tension battery of 1½ volts for the filament, and from 45 volts upwards high tension for the anode charge. In wiring a transmitter or receiver great care must therefore be taken to see that no faulty connection is made which might send the high tension electricity through the filament. The amateur should make it a strict practice always to test the voltages at the terminals of the valve base before he inserts a valve for the first time (or after alterations in the wiring).

Some valves have a filament which is tapped at the centre; this gives the radio constructor a choice of two voltages for the filament. For the two halves of the filament may be connected either in series (Fig. 2.29 a) or in parallel (Fig. 2.29 b). In the latter case the correct filament voltage is half that of the first case.

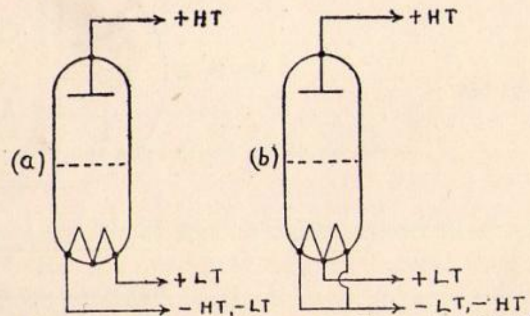


Fig. 2.29. *Valve with tapped filament, shown* (a) *wired for 3 volts L.T., and* (b) *for 1½ volts L.T.*

Within each of the categories of valves mentioned above there exist many different types, differing in such quantities as L.T. voltage, strength of anode current, sensitiveness of grid control, filament current consumption, etc. They also differ in the arrangement of their connections on the base.

The transmitting and receiving circuits used in this book have been selected and designed in such a manner that only two types of hard valve are employed. They are the 3S4 (or 1S4) and the 3Q4; both are pentodes.

Fig. 2.30 (a) shows the base connections for the 1S4 (as seen from underneath). Pin 6 is connected inside the valve to pin 2, so that a connection to the anode may be made either to pin 2 or pin 6, whichever is

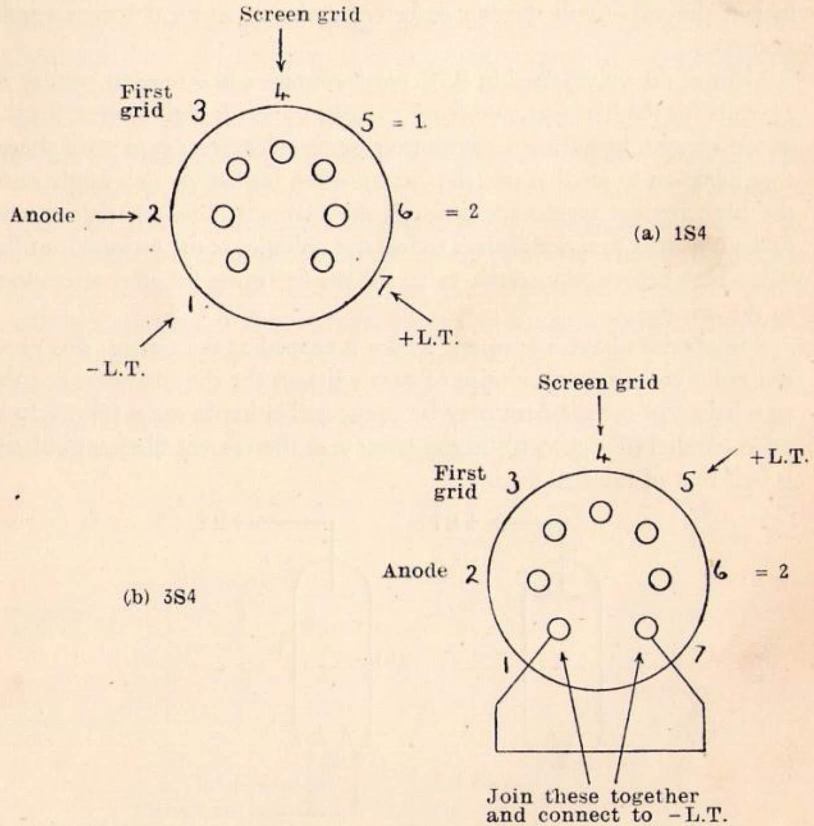


Fig. 2.30 *Base connections for the 1S4 and 3S4 (seen from below and enlarged)*

more convenient. Similarly, pin 5 is connected inside the valve to pin 1. A 1½ volt dry-cell is used for the low tension, and this, therefore, is connected to pin 1 (or 5) and pin 7.

The 3S4 and 3Q4 valves have a tapped filament which enables them to be used either with 1½ or 3 volt L.T.

Fig. 2.30 (b) shows the base connections for the 3S4 and 3Q4. Pin 5 is here connected to the centre tap of the filament, so that if a 1½ volt cell is used for the L.T. supply is must be connected to 1 and 5, and pin 1 must be joined to pin 7, whereas if 3 volts L.T. are used the L.T. connections are made to pin 1 and 7.

The gas-filled triode used in one of the receivers has the type number Hivac XFG1. Instead of the usual pins, it has four lead-out wires. These can either be soldered straight on to their respective connections in the receiver, or else cut short and inserted into a suitable miniature linear base. The valve has a red spot on one side and the lead-out wires are numbered from this spot outwards (Fig. 2.31).

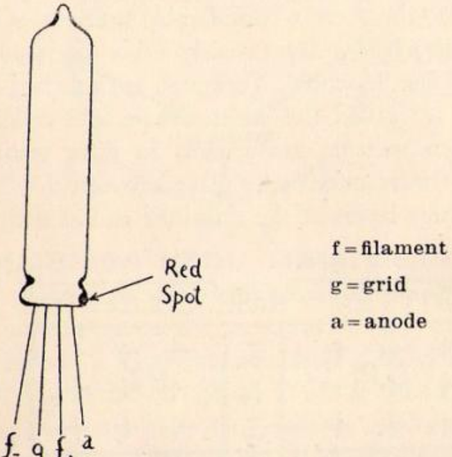


Fig. 2.31. *The XFG1 gas-filled triode (natural size)*

2.8. Transistors

In a growing number of applications transistors have come to take over the work that was previously done by valves. They have many advantages: they are smaller, work on lower voltages and as they have no filament they require no L.T. battery. But although their action is in some sense analogous to that of a valve, they cannot simply be substituted for a valve in any given circuit. They are not well suited to replace the valve in the radio control receivers which are under discussion in this book, but they are widely used for adding one or two amplifier stages to those receivers in order to give a more powerful receiver action. Various types of transistors are on the market. We shall confine ourselves to the type that is most widely used in these particular applications. This is the P.N.P. junction transistor.

A transistor of this type consists of a single piece of crystal that is made up of three layers. These are marked P_1, N and P_2 in Fig. 2.32. The layers P_1 and P_2 are made of a germanium alloy in which at any time a large number of molecules are short of electrons. The absence of a required electron in such a molecule may be considered as a positive 'hole'. The molecule having a 'hole' may rob a nearby molecule of an electron and leave this molecule therefore with a 'hole'. Thus the holes may migrate through the material. The central layer N is made of a different germanium alloy in which there is usually a surplus of electrons, so that at any time there are a considerable number of free electrons drifting about. This negative layer is only a few thousandths of an inch thick and is called the 'junction'. Terminals are attached to each of the three layers and are called the emitter, base and collector terminals respectively. When voltages are applied to these terminals a fairly complicated set of interactions take place between the 'holes' and the electrons in the three layers of the transistor and at their border lines.

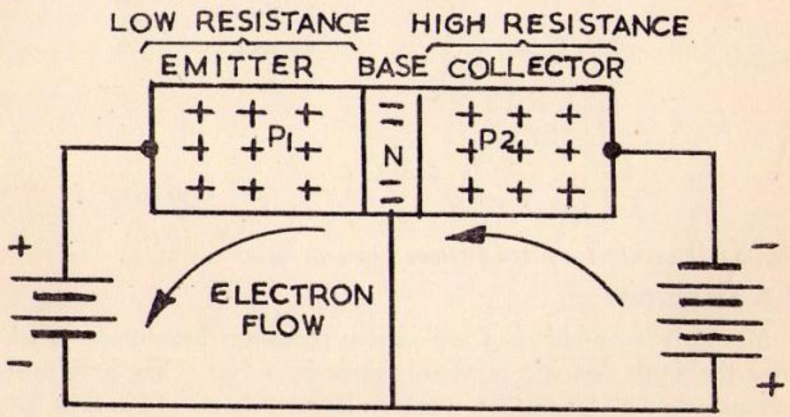


Fig. 2.32.

The effect of these interactions, and resulting migrations of electrons and 'holes', is that if the transistor is wired up in a circuit of the general type shown in Fig. 2.32, the stream of electrons flowing anti-clockwise in the left half of the circuit has a powerful influence over the stream of electrons that will flow anti-clockwise in the right half of the circuit. Amplifying action is obtained because the current in the left half (i.e. between base and emitter) influences current at a higher power level in the right hand half (i.e. between collector and base).

The difference, broadly speaking, between a valve and a transistor is therefore, that whereas in a valve a powerful current (the plate current) is controlled by small variations in a voltage (the grid voltage), in a transistor a powerful current (the collector current) is controlled by small variations in a less powerful current (the emitter current).

The symbol for the transistor is given in Fig. 2.33.

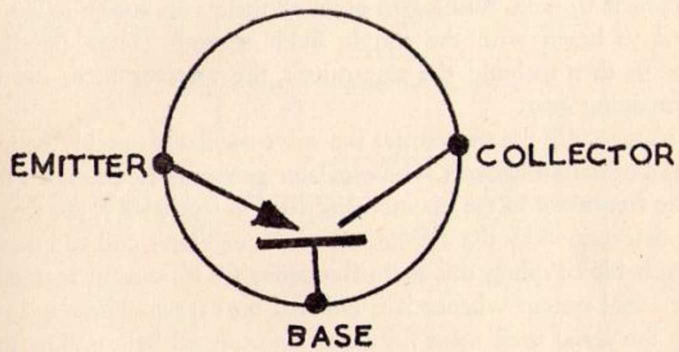


Fig. 2.33.

The reader should note that whereas in the above highly simplified account of transistor action the transistor would appear to be a symmetrical unit in which it would not matter if the collector and emitter connection were interchanged, this is in fact not the case. The transistor, for instance, offers a much greater resistance to electrons moving from the collector to the base than from the base to the emitter. This difference in impedance is primarily responsible for the amplifier action of the transistor. And it should be stressed that the transistor may be damaged if the voltages between the emitter and collector are accidentally interchanged.

CHAPTER 3

THE TRANSMITTER

3.1. The Theoretical Circuit

Although in a logical order of treatment the transmitter must come first, it is not necessarily the first unit that the beginner should build. Newcomers to radio wishing to build all their own equipment are well advised to begin with the simple field strength meter described in chapter 7; then to build the transmitter, the receiver next, and finally the remaining gear.

Fundamentally the transmitter is a valve oscillator suitably coupled to an aerial of definite length. The oscillator generates electrical waves of a definite frequency in the manner described in section 2.7, the frequency being determined by the dimensions of the oscillator coil and capacitor. By a suitable coupling this radio frequency ('RF') output is transferred to the aerial system whence it is radiated into space. The requirements which the aerial itself must fulfil will be outlined below. Transmitters differ widely in design and complexity. Only one basic design will be given a detailed discussion in this book. This circuit has been selected for its simplicity, stability and efficiency. It is very suitable for the beginner and yet has a performance adequate for advanced work.

The oscillator is a *push-pull negative resistance oscillator*. (Fig. 3.1). This consists of a symmetrical combination of two oscillators of the type shown in Fig. 2.27 (b). The functions of the two valves supplement one another in the manner which the name suggests: while the one pulls the swinging pendulum, so to speak, the other one pushes it. L.T. is 1½ volts.

The valves shown are 1S4's; but 3S4's can of course be used instead (cf. §2.7). The tuning coil is tapped at the centre and here connected to the high tension supply (120-150 volts). The aerial is coupled to the tuning circuit by a coil of two turns wound round the tuning coil. The

tuning capacitor C1 is used to adjust the frequency of the transmitter. This frequency, it will be recalled, must lie between 26.96 and 27.28 Mcps (§1.1). C4 permits the radio frequencies to bypass the batteries. RFC is a choke designed to keep the radio frequencies out of the leads

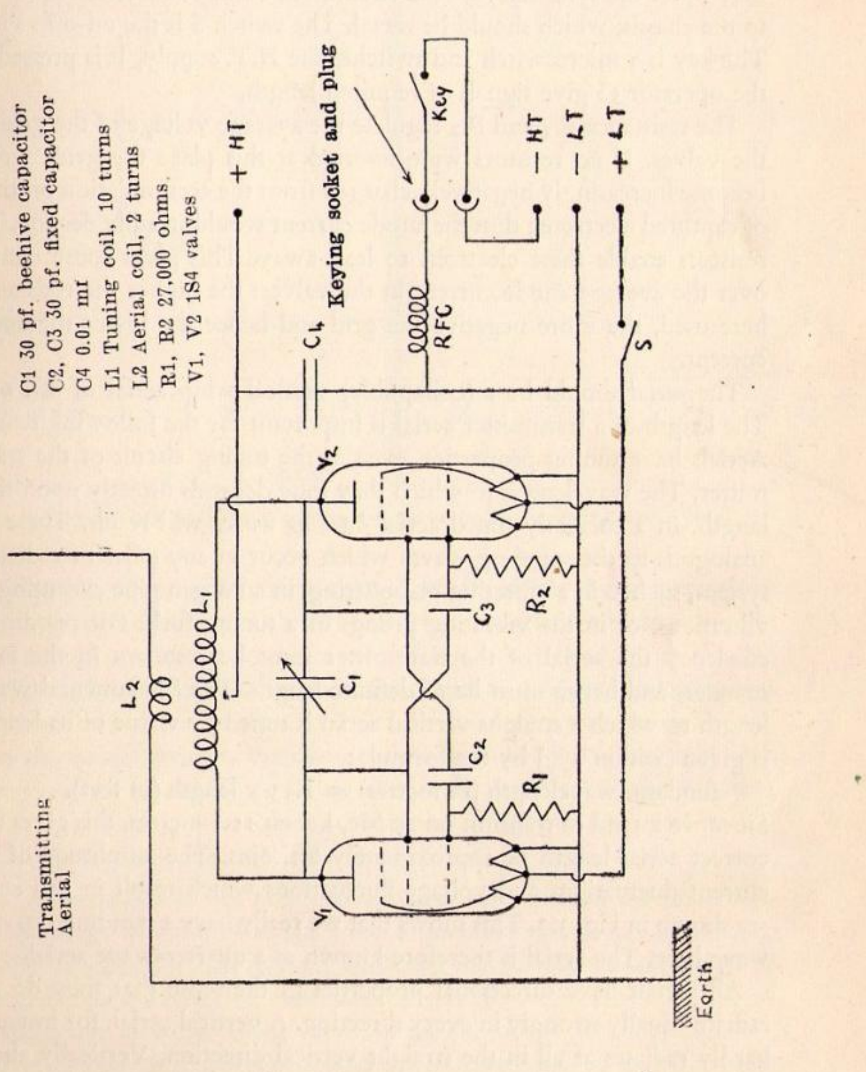


Fig. 3.1. *Theoretical diagram of Transmitter I.*

of the key, and thus to prevent radiation from these leads. The circuit of the oscillator being symmetrical, it is important that its components should be arranged and wired symmetrically on the chassis; failing this, the stray capacitances which exist between components and the chassis may upset the symmetry of the circuit. All earth connections are made to the chassis, which should be metal. The switch S is the on-off switch. The key is a microswitch and switches the H.T. supply. It is pressed by the operator to give signals of required length.

The resistance R_1 and R_2 regulate the average voltage of the grids of the valves. If no resistors were inserted at this place the grids would become increasingly negatively charged from the accumulation on them of captured electrons; thus the anode current would steadily decline. The resistors enable these electrons to leak away. This gives some control over the average anode current in the valves: the higher the resistances here used, the more negative the grid and hence the lower the anode current.

The *aerial* should be a (collapsible) vertical whip aerial of 8ft. 6ins. The length of a transmitter aerial is important for the following reason. Aerials have tuning properties, even as the tuning circuit of the transmitter. The wavelength to which they tune depends directly upon their length. In a correctly tuned aerial *standing waves* will result. These are analogous to the standing waves which occur in any efficient radiating system, such as in a vibrating piano string, in an organ pipe executing air vibrations, or in the vibrating prongs of a tuning fork. For maximum efficiency the aerial of the transmitter must be resonant in the same manner, and hence must be of definite length. The fundamental wavelength to which a straight vertical aerial is tuned by virtue of its length, is given (within 4%) by the formula:

fundam. wavelength (in metres) = 1.33 x length (in feet).

Since we intend to transmit on 27 Mc, i.e. on 11.1 metres, this gives us a correct aerial length of approximately 8ft. 6ins. The amplitude of the current fluctuations and voltage fluctuations which result in this aerial are shown in Fig. 3.2. This shows that we really have a standing quarter-wave here. The aerial is therefore known as a quarter-wave aerial.

All aerials have directional properties in the sense that they do not radiate equally strongly in every direction. A vertical aerial, for instance, hardly radiates at all in the straight vertical direction. Vertically above the aerial, therefore, there is a narrow 'silent' region in which the transmitter is comparatively ineffective. The angle of maximum radiation is about 10 degrees from the horizontal.

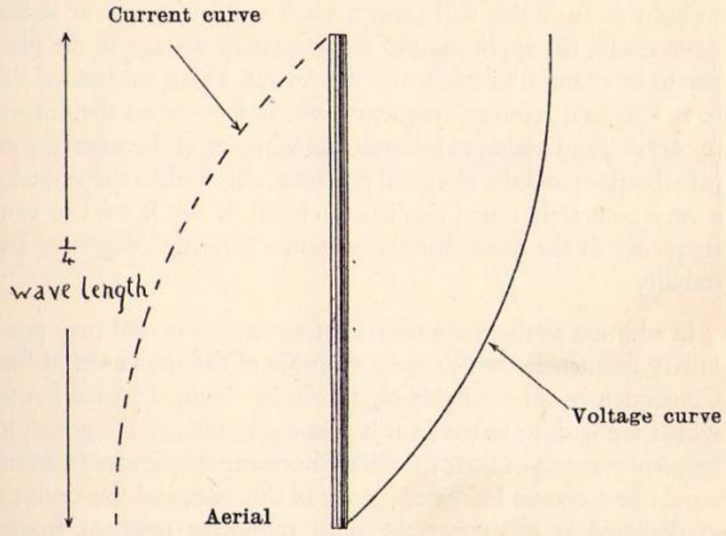


Fig. 3.2. *Currents and Voltage fluctuations in a quarter-wave aerial.*

Before passing to the constructional details of the above transmitter a few words must be said about alternative theoretical circuits.

A simple alternative to the circuit of Fig. 3.1 is obtained if a single *double-triode valve* is used instead of V_1 and V_2. A double triode is a valve containing two triodes, built into the same vacuum tube. For the rest, the circuit remains the same, although R_1 and R_2 may require a lower value (15,000 Ω) to bring the anode currents to the requisite value (see above). A sutiable valve is the American 3A5 or Mullard DCC 90.

This arrangement has not been adopted here because the price of a double triode is about twice the price of the other valves, so that nothing would be gained in this respect, while we should lose the advantage of using the same valves for the transmitter as for the receiver. And if an accident should occur to the valve we should suffer twice the loss.

The stability of the frequency of a transmitter can be improved if a suitably cut and ground *crystal* is included in the circuit. The special crystals made for this purpose (usually thin slices of quartz crystals) have a number of interesting properties which are known as 'piezo-electrical' effects. If the crystal is inserted between two metal plates and subjected to light pressure this will cause a small voltage to appear at the plates. Conversely, the application of an alternating voltage to the plates gives rise to mechanical vibrations in the crystal. These mechanical vibrations have a natural resonant frequency which depends on the dimensions of the crystal, and owing to interrelation which exists between the mechanical vibrations and the electrical potential, this enables the crystal to act as a very accurately tuned oscillatory circuit. If this is used to control the frequency of the transmitter we obtain a very high degree of frequency stability.

In addition to the main resonant frequency a crystal may possess subsidiary frequencies which are a multiple of the fundamental frequency. Consequently, if no suitable crystal can be obtained for the frequency on which we wish to transmit, it is possible to use crystals which have our frequency as one of their subsidiary resonant frequencies (although there would be a certain loss of efficiency in this case, and the circuit must be so designed as to extract the right subsidiary resonant frequency or 'harmonic' from the crystal).

Fig. 3.3 gives the circuit of a Xtal controlled transmitter. While frequency stability is, of course, to be aimed for, the modeller need not feel that the use of a crystal is imperative. The stability of the ordinary push-pull oscillator is quite adequate, provided the modeller takes the trouble to tune it very carefully at the beginning, to guard its tuning circuits against mechanical interference and from time to time to check its frequency against a wavemeter or the crystal-controlled transmitter of a friend.

Modellers who wish to experiment with systems using audio-modulated carrier waves, will find in Fig. 3.4 the additions which they must make to the circuit of Fig. 3.1. A third 3S4 valve is here introduced to act as oscillator for the audio-frequency. These low-frequency oscillations are then applied to the anode voltage of the push-pull oscillator, and thus come to be superimposed on the high-frequency oscillations generated by the latter. The result is a modulated carrier wave of the type discussed in §1.2.

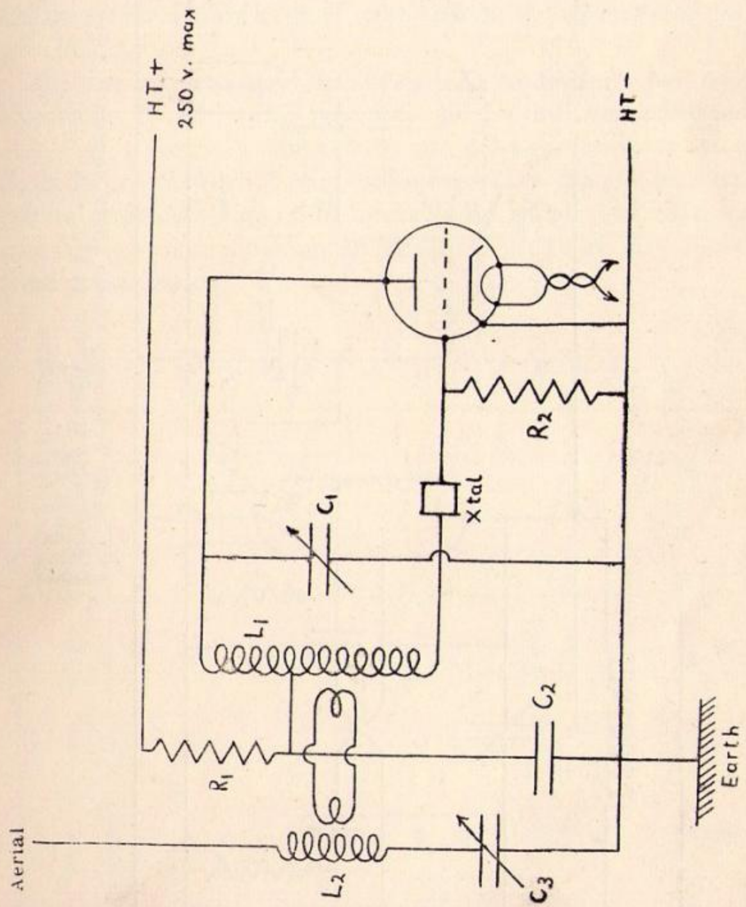


Fig. 3.3. *Simple Crystal Controlled Transmitter.*

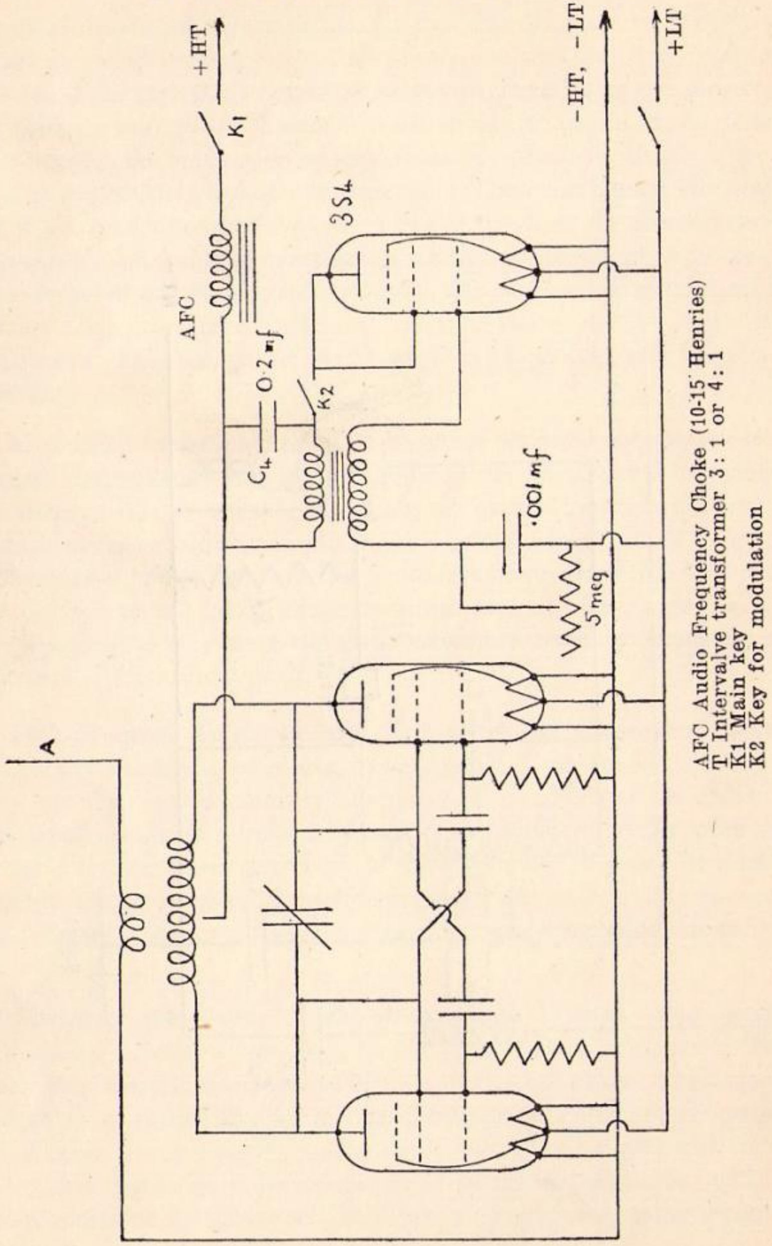


Fig. 3.4. *Transmitter for modulated signals.*

3.2. Construction of Transmitter I

The theoretical circuit of this transmitter is that of Fig. 3.1. The construction is really simple and, provided he has had a little preliminary practice in building the simple field strength meter or test meters of chapter 7, any modeller of average talents can undertake it, even if he has no previous knowledge of radio. But he should first read the hints give in §§7.1 and 7.2.

The first step is to make the chassis. This consists of a sheet of strong aluminium, or other metal, measuring 7ins. by 5ins., cut, drilled and bent as in Figs. 3.5 and 3.6. The holes A and B are for the valve holders; C holds the on-off switch; F is for the keying socket; D and E are fitted with rubber grummets (Fig. 3.6 b) to enable the battery and aerial leads to pass through without chafing the metal. The grummets may be obtained from radio dealers.

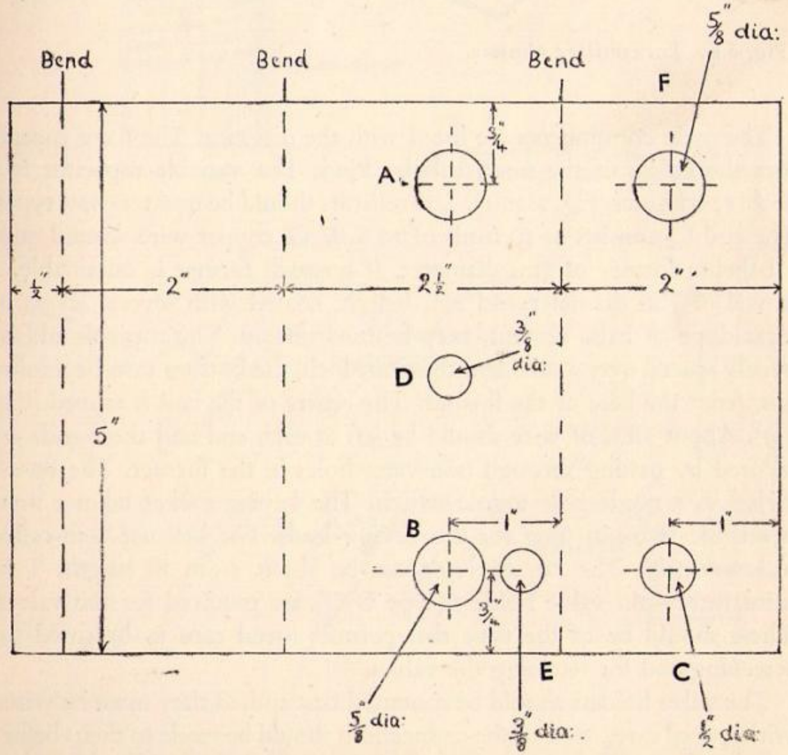


Fig. 3.5. *Plate for transmitter chassis.*

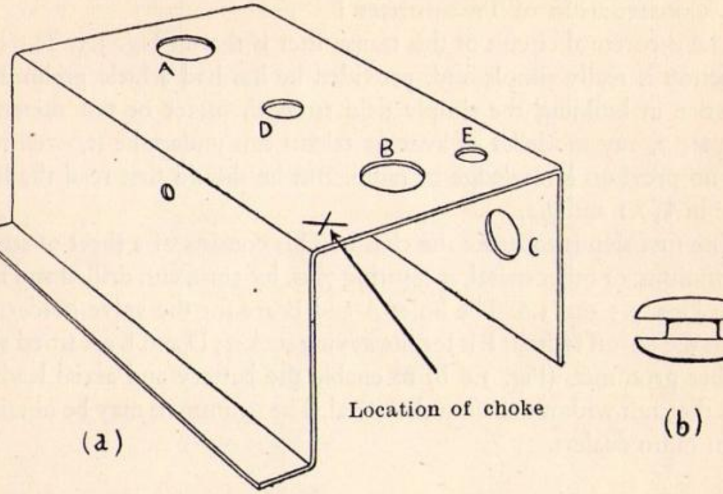


Fig. 3.6. *Transmitter chassis.*

The main components are listed with the diagram. The fixed capacitors should be of the small tubular kind. The variable capacitor is a beehive trimmer (Fig. 2.20 c). The resistors should be quarter-watt types. The coil L_1 consists of 10 turns of 20 S.W.G. copper wire wound onto a bakelite former of ¾in. diameter. If no such former is obtainable, a dowel of ¾in. diameter and 2in. length, coated with several layers of clear dope or balsa cement, may be used instead. The turns should be evenly spaced over a total length of one inch, the bottom turn beginning ¾in. from the base of the former. The centre of the coil is tapped (Fig. 3.7). About 2ins. of wire should be left at each end and these ends are secured by passing through transverse holes in the former. The on-off switch is a single-pole toggle-switch. The keying socket takes a non-reversible two-pin plug for the keying leads. For key use a so-called 'microswitch'. The keying leads can be about 5-6ft. in length. Two miniature 7-pin valve holders (type B7G) are required for the valves. These should be of the type that permits metal cans to be fitted for screening and for retaining the valves.

The valve holders should be mounted first and, as they must be wired with special care, some of the connections should be made to them before any other components are mounted. These are shown in Fig. 3.8.

The connections should be made with tinned copper wire of 20 or 22 S.W.G. and should be insulated by suitable lengths of sleeving. Newcomers to radio should first read the notes on wiring and soldering in chapter 8. Care must be taken that no solder runs into the holes for the valve pins and that no loose bits of solder become lodged inside the holders. The wiring shown is for a 3S4 valve. If a 1S4 is used instead, the link between tag 1 and tag 7 must be omitted. The wires from tag 7 are

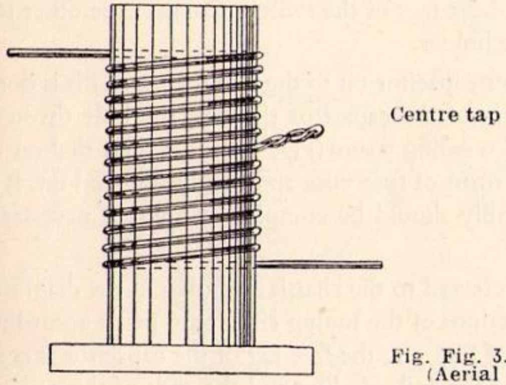


Fig. Fig. 3.7. The tuning coil
(Aerial link coil not shown)

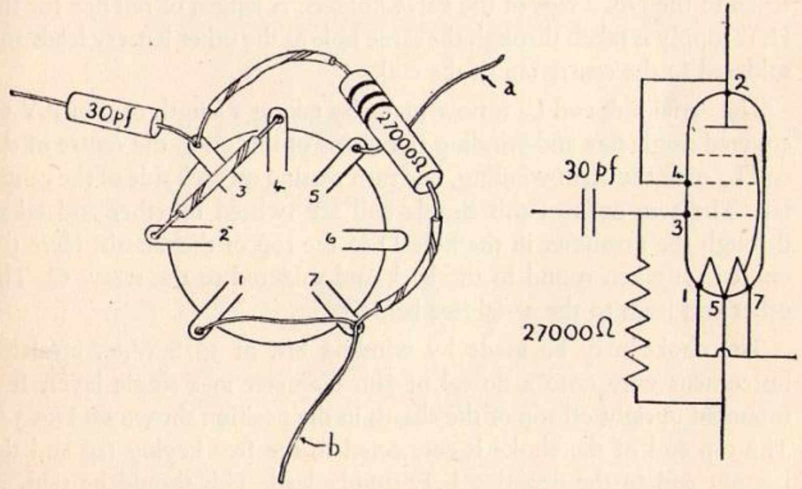


Fig. 3.8. *Connections to valve base prior to mounting other components. (Seen from underneath.)*

taken to a screw Q in the top centre of the rear panel of the chassis. The wire *a* is used to join the No. 5 tags of the two valve holders.

Next mount the keying socket. Pass the negative H.T. battery lead (black P.V.C. covered single flex, 15ins. in length) through the grummet of hole E and solder to one of the tags of the keying socket. Pass a similar length of flex (for negative L.T. supply) through the same hole and connect to tag 7 of the near valve holder. (Fig. 3.9.) Mount the on-off switch; pass the positive L.T. lead (as above, but black) through the same grummet and connect to one of the tags of the switch. Connect the other tag to tag 5 of the near valve holder.

Next mount the beehive capacitor on to the coil former. This is done by passing the bottom pin of the capacitor through the hole through which the end of the coil winding passes (Fig. 3.9). It is then tied on to this wire end with a few turns of fuse wire and firmly soldered on. It is important that this assembly should be completely rigid; if necessary, use cement.

The coil is now to be screwed to the chassis as shown in the diagram, and the remaining connections of the tuning circuit are made according to the theoretical circuit of Fig. 3.1; the free tag of the capacitor is connected to the other end of the coil winding and the ends of the coil are taken to the No. 2 tags of the valve holders. A length of red flex for the H.T. supply is taken through the same hole as the other battery leads and soldered to the centre tap of the coil.

The aerial link coil L_2 is now made by taking a length of thin P.V.C. covered single flex and winding two turns of this on to the centre of the coil L_1 over the main winding, one turn passing on each side of the centre tap. The two ends of this simple coil are twisted together and taken through the grmumet in the hole D to the top of the chassis. Here the one end is taken round to the back and soldered to the screw Q. The other end leads to the aerial (see below).

The choke may be made by winding 8ft. of 36 S.W.G. insulated instrument wire onto a dowel of ⅜in. diameter in a single layer. It is mounted upright on top of the chassis in the position shown on Fig. 3.6. The top end of the choke is connected to the free keying tag and the bottom end to the negative L.T. supply lead. This should be tied, as well as soldered, to the base of the choke so that the soldered joint will suffer no mechanical stress when this battery lead is handled.

The wiring is completed by fitting the capacitor C_4. It then only remains to fit the plugs to the battery leads and to make the keying leads. Single plugs are put onto the H.T. leads, a non-reversible two-pin plug onto the L.T. leads. The keying lead should be made of strong twin flex terminating in a non-reversible plug.

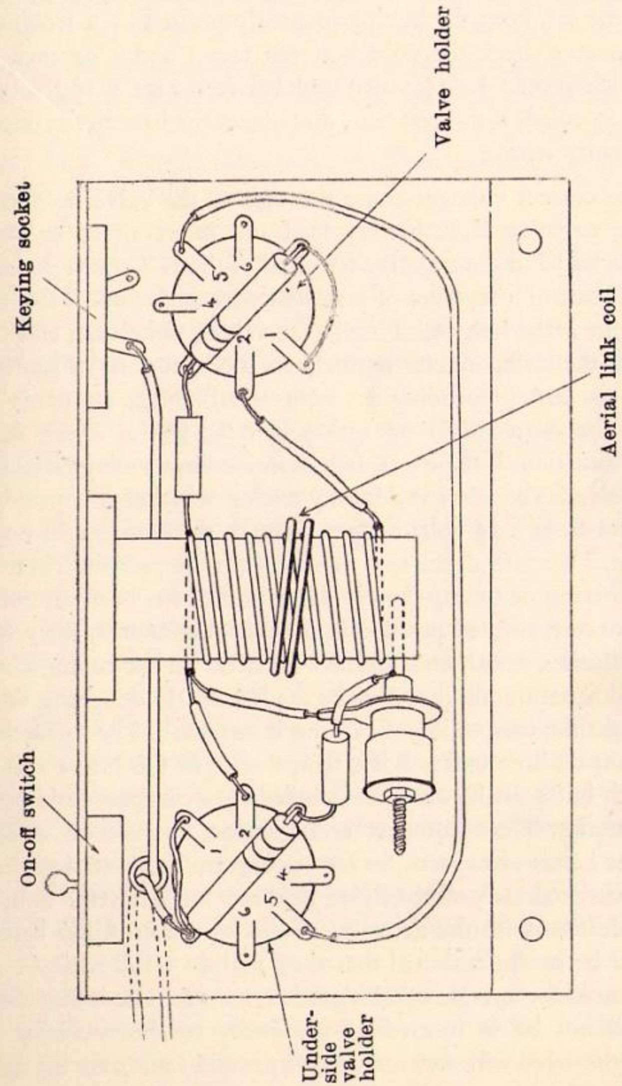


Fig. 3.9. *Transmitter I (from below) partly wired. Note the two turns of the aerial link coil around the centre of the tuning coil.*

3.3. Testing and Tuning the Transmitter

The transmitter may now be given its preliminary tests. The best L.T. battery is a 1½ volt box battery (Drydex H 1155 or equivalent). The H.T. battery should be a large 120 volt battery (Ever-Ready 'Winner' or equivalent). Connect up the batteries but do not yet plug in the valves. Switch on the set, keep the key permanently pressed by a weight, and with a voltmeter check the volts between tags 1 and 5 on each valve holder (which should be 1½ volts) and between tags 1 and 2 (which should be 120 volts). If this test fails, disconnect the batteries at once and search for faulty wiring.

When the correct voltages come through to the valve holders, disconnect the negative H.T. battery lead and insert a 100 mA meter between this lead and the negative terminal of the H.T. battery. Improvise an aerial out of a few feet of insulated wire and connect this to the free end of the aerial link coil. Plug in the valves, switch on, and satisfy yourself that the milliammeter registers an anode current of something between 15-40 mA (depending on your aerial). Next approach your aerial with the simple field strength meter (§7.5) and check for the presence of radiation. If these tests fail, examine your tuning circuits and check the valves. The latter is done by testing whether it is possible to pass a current from a 1½ volts battery through the filament; if not, the valve is dead. These are all the tests necessary for the present. There is no point in trimming or tuning the oscillator until it has been mounted in its permanent case, since its position in the case or container, the proximity of the batteries, aerial, etc., all have an effect on the tuning circuits. The case and aerial should therefore be made next. In designing the case one must resist the temptation of making it too small. The oscillator is a neat and compact little unit and it is tempting to fit this into a neat little box in which but a small corner is occupied by a compact little pack of deaf-aid batteries. These compact arrangements are seldom successful except in the hands of experts. So far as concerns the batteries, there is so much to check already on the flying field that it is a mistake to burden oneself in addition with the necessity of checking transmitter batteries. They should be so dimensioned that they will do a full season's work without the need for a single check. Another point to note is that the batteries should not be in immediate proximity to the oscillator unit. The aerial is mounted with two screws on a paxolin panel onto the narrow side of the case, close to the oscillator unit and in such a position that the aerial lead can reach it without passing the battery leads. It measures 8ft. 6ins. and can be made from a collapsible aluminium dinghy mast. If a sectional aerial is used, particular care must be taken to see that the sections make really good electrical contact. Near the bottom of the case a terminal is mounted for the earth connections. This is connected internally to the chassis of the oscillator and externally (when the transmitter is in use) with a crocodile clip to a pair of scissors or large screwdriver which has been pushed into the ground, or—better still—to a metal plate which has been screwed to the bottom of the transmitter box and on which the transmitter stands when in operation so that the plate is in close contact with the ground.

When all this has been assembled the time has come for the very important task of tuning the transmitter to the correct frequency of 27 Mc. This requires either the assistance of a dealer or amateur who has a wavemeter (or an accurately calibrated signal generator), or the help of a friend who has a correctly tuned transmitter and receiver. In the latter case the correct transmitter is set up at least fifty yards away and the receiver carefully tuned to it. Without disturbing any part of the receiving layout, our transmitter is then set up (with full aerial and earth) close to the receiver, and its variable capacitor is altered until, when keyed, it produces the maximum response in the receiver. This is only the first rough adjustment.

The next stage is to trim the transmitter for maximum radiation. This is tested with the field strength meter. To obtain the best trim, experiments may be made with different earths, no earth or a counterpoise (consisting of a short length of wire lying along the ground); slight adjustment may be made to the aerial length or the spacing of the two turns of the aerial link coil. At this stage attention should also be paid to the anode current. If this is too low it can be raised by reducing the valves of R_1 and R_2, e.g. by connecting resistors of something like 20 K or 50 K in parallel with the R_1 and R_2. The total anode current of the two valves should lie between 20 and 25 mA at 120 volt H.T. On no account must it be allowed to exceed a value at which the transmitter would generate more power than the G.P.O. regulations permit. Another point to check now is whether transmission is markedly affected if the operator's hand approaches or touches the keying leads. If this is the case the choke is insufficient and a second choke of similar construction must be inserted into the other keying lead. The field strength meter enables one to obtain a rough comparison between the strength of radiation of our own transmitter and that of a friend.

After these adjustments, the oscillator must once more be tuned to the correct frequency. The tuning procedure outlined above is repeated. But this time a final accurate adjustment must be made at which the transmitter to be tuned is set up at a distance of about fifty yards from the receiver. When the correct frequency has been attained the turns of the aerial link coil are secured in their position with balsa cement or Denfix and the variable capacitor is sealed with a drop of molten wax. This tuning should be carried out with the transmitter and batteries in their final position in the case.

3.4. Transmitter II

This transmitter is the simple crystal controlled oscillator of Fig. 3.3. It was designed by Mr Howard Boys, by whose kind permission I quote the following from Bulletin No. 6 of the I.R.C.M.S.[1]

'Some time ago, the Quartz Crystal Co. Ltd., Kingston Road, New Malden, Surrey, introduced a type of crystal unit known as Type FO for operation at series resonance. This allows a simple single-valve transmitter to be made with an input on the anode of about 1 watt. Such a transmitter has been constructed and gives very good results.

'The circuit did not oscillate as expected from the leaflet sent with the crystal, so here are the component values given in the leaflet, followed by notes of the changes made.

R1 10,000 ohms C_1 50 pf
R2 3,900 ohms C_2 500 pf
L_1 14 turns, 20 swg enamelled copper wire, on ½in. dia. former at 16 t.p.i., tapped at 4th turn.

With a stable 150 volt supply, the resistance R_1 can be reduced to 1,000 ohms.'

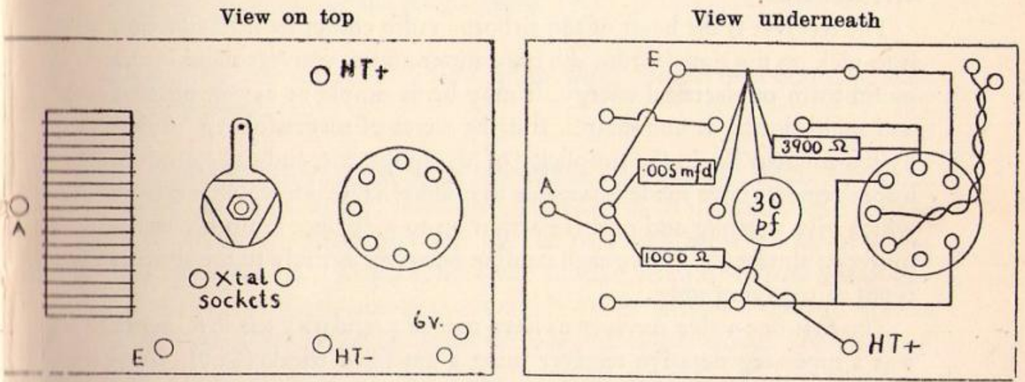
'First tests were made using a cheap motor generator to supply H.T. and this gave 125 volts at 9 mA, so 1,000 ohms was used for R1. It was not found possible to obtain oscillation until the tap was moved up to the 7th turn (centre). Using a different motor generator giving 250 volts at 11 mA and a 10,000 ohm resistor gave similar results. After playing around with tuning condensers, a 20 pf ceramic trimmer was used with a

1. International Radio Controlled Models Society.

45 pf fixed condenser in parallel. The tank coil was coupled to the aerial with a link of one turn around L_1 and 2 turns round L_2, with a plug and socket joint between to allow plug-in interchangeability of different transmitters. L_2 has 3 turns, 18 swg on a ¾in. former, and C_3 has a ceramic trimmer of 8-115 pf.'

The ground range of the transmitter as tested with a hard-valve receiver was found to be about half a mile. The same range was obtained when 120 volt H.T. was used and a radio frequency choke instead of a resistor in the H.T. lead.

The layout recommended by Mr Boys is shown in Fig. 3.11.



g. 3.11. *Layout of Transmitter II.*

CHAPTER 4

THE RECEIVER

4.1. General

The receiver is the heart of the airborne radio equipment. Its function is to pick up the signals from the transmitter and to convert them into a useful form of electrical energy. It may be as simple or as complicated and sophisticated as one desires. But the secret of successful R/C flying by the amateur lies in the simplicity of his equipment, and since modern improvements have made it possible to build reliable one-valve receivers which give a strong and positive action up to a distance from the transmitter of almost a mile, we shall confine ourselves entirely to the simpler types of receiving units.

The first one-valve receiver to have gained popularity for R/C work was a super-regenerative receiver using a gas-filled triode (§2.7). Constructional details for this receiver will be given in §4.4.

But the popularity of these receivers is rapidly being eclipsed by that of the modern hard-valve receiver. The gas-filled triodes have a very short life only, a matter of a few hours, whereas the life of a hard valve is a thousand hours or more. The hard-valve receivers, moreover, have a far greater stability throughout their lifetime and also give a response to signals which is at least twice as powerful as that of a soft-valve receiver, although the supporters of soft-valve receivers claim that the latter have a higher sensitivity at extreme ranges.

Constructional details for a hard-valve receiver will be found in §4.3 This receiver type is known as a super-regenerative self-quenching receiver. The circuit employed is the well-known 'Franklin' circuit. For correct operation this circuit depends very much on the selection of the correct component values. The first receiver design which exploited these potentialities to the full advantage for radio-control work was the

American Goode receiver. In this country the circuit was popularised by the commercial 'Ivy' receiver, designed by Mr H. Ives and embodying new forms of sensitivity control, also by the excellent little E.C.C. receiver.

In designing a simple receiver for radio-control work the goal is always the same: to bring about a set of conditions in which the arrival of a signal at the receiver will entail changes in the anode current of the valve large enough to operate a sensitive relay (§2.4). This relay can then be used for switching on or off the electrical energies which are required for decoding the signals and actuating the controls of the aircraft.

How this set of conditions is brought about in hard-valve receivers forms the subject of the next section.

4.2. The Nature of the Self-quenching Super-regenerative Receiver

In form a *super-regenerative* receiver is a simple oscillating circuit, a valve oscillator in fact, which is adjusted in such a manner that it does not oscillate continuously but instead produces short bursts of intermittent oscillation which follow one another at a rate of something like 20,000 to 50,000 bursts per second. In other words, 20,000 to 50,000 times per second it breaks into and falls out of oscillation. The graph of these oscillations therefore looks something like Fig. 4.1. The frequency of the bursts is known as the 'quench' frequency. Such an oscillator can act as a receiver if it is so tuned and adjusted that the arrival of a radio signal at its aerial from a transmitter significantly interferes with its own basic cycle of operations. It is suitable for radio control if this interference somehow entails large changes in the anode current.

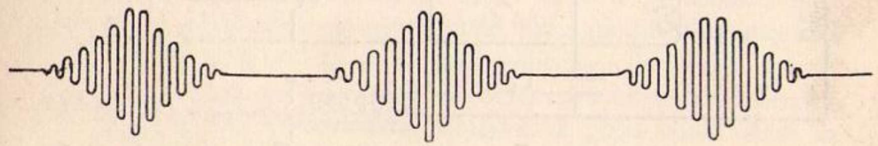


Fig. 4.1. *The super-regenerative oscillations of a self-quenching receiver.*

In some super-regenerative receivers the oscillations are rendered intermittent by impressing the oscillations of a second valve oscillator—the 'quench oscillator'—on to the circuit of the first oscillator. In others, however, the oscillating valve acts as its own quench oscillator, the grid of the valve being coupled in such a way that, by charging the grid, the fundamental oscillations give rise to their own intermittent suppression. These are known as *self-quenching* receivers, and the Franklin receiver is one of this type. Here the quench frequency (i.e. the frequency of the intermittent suppressions) is controlled by two 'quench' coils which are in series with the basic tuning coils of the oscillator. The coils have a high inductance and one of them has a capacitor in parallel with which it

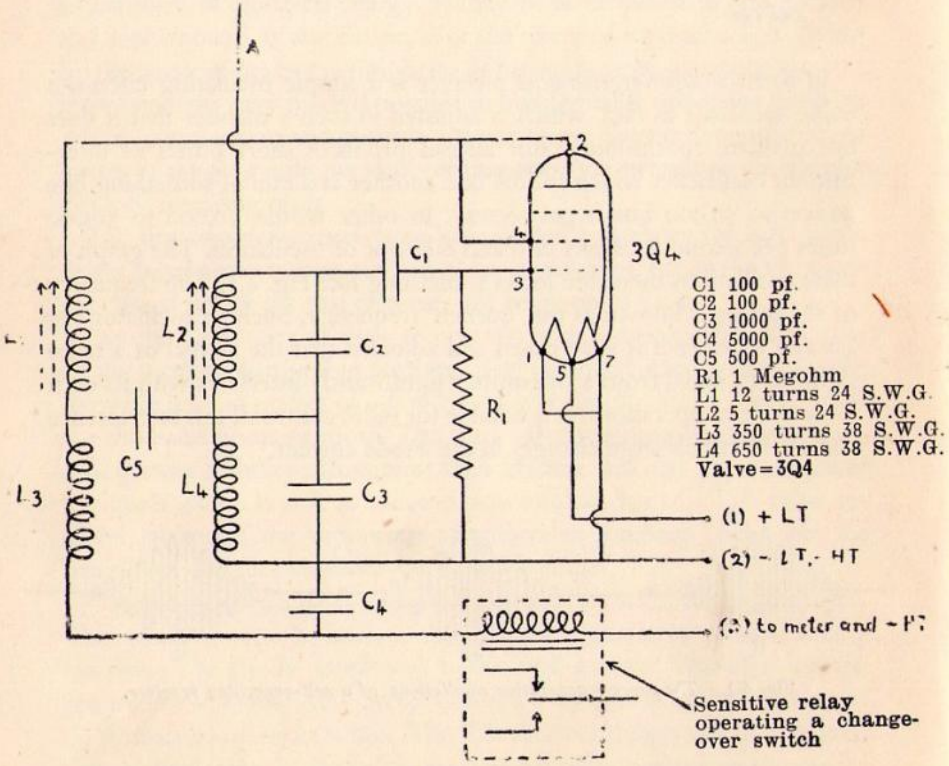


Fig. 4.2. *Circuit of Receiver I.*

forms a tuned circuit whose natural frequency controls the quench frequency of the receiver.

A simple form of the Franklin circuit used by the author is shown in Fig. 4.2, the correct component values having been determined by experiment. L_1 and L_2 are the main oscillator coils. L_3 and L_4 are the quench coils. The valve is a 3S4 or 3Q4 (§2.7).

The properties of this circuit which render it so eminently suitable for radio control are (a) that there is a drop of between 2 and 3 mA in the anode current of the valve when the receiver changes from a non-oscillating R.F. state into a state of self-quenched R.F. oscillation; and (b) that the quench of the receiver can be increased to a point at which the receiver will not oscillate at R.F. unless its oscillations are started and continuously boosted by an incoming signal of the same fundamental frequency. So we have here a receiving circuit in which even a weak incoming signal may at once bring about a drop of 2-3 mA in the anode current. To make this receiver do what we want for our radio control it remains merely to insert a sensitive relay (§2.4) into the anode circuit which is so adjusted that it pulls in at the higher value of the anode current and drops out at the lower value. This relay can then be made to switch on the heavier currents required for operating the actual flying controls of the model.

4.3. Receiver I

4.3.1. Construction

This receiver was designed by the author to meet the demand for a hard-valve receiver which is easy to build, has a good performance and requires no components that are difficult to obtain on the market. In fact, it requires fewer components than any other hard-valve design known to the author. The sensitive relay should have 3,000-10,000 ohms. In mounting the relay of his choice, the modeller should bear in mind that it should be adjustable from the same side as the tuning coil (L_2), since these are the two controls that may require last-minute adjustments before the model is launched. The receiver is tuned with the dust iron core ('slug') of L_2; the sensitivity is controlled by the core of L_1. Both these coils are wound on the popular 'Aladdin' formers. The size chosen has a diameter of $\frac{3}{8}$in.; its length is cut down to $\frac{7}{8}$in. and its base is reduced down to the small holes provided for fixing the ends of the coil winding (Fig. 4.3). The two formers are mounted on the baseboard in an inverted position by means of a short wooden plug on to which they fit tightly; they are glued down with carpenter's glue or Croid 'Universal' glue (do not use balsa cement or Durofix for this particular joint). L_2 has 12 turns of 24 S.W.G. enamelled copper wire, spaced evenly along the former (see Fig. 4.4 (b)) L_2 has 5 turns of the same wire, also spaced evenly, but wound in the opposite sense. The outer end of each winding is secured in what was the base of the former, the inner end is passed through a small hole in the baseboard. The finished coils are varnished to fix the winding.

The quench coils L_3 and L_4 are wound on to a *wooden* former which is made from discs of wood according to the dimensions shown in Fig. 4.3. *The dimensions and materials specified should be strictly adhered to.* The outer discs should be made of thin plywood; the others can be cut from balsa wood. The outer discs are provided with holes for the ends of the coil winding and for the terminals to which the connections and coil ends are soldered. These terminals are simply made by passing a short length of thin copper wire a couple of times through the hole and round the edge of the disc and twisting the ends together. When soldered this makes a firm tag. L_3 has 350 turns of 38 S.W.G. enamelled copper wire, and L_4 is given 650 turns of the same wire, wound in the same sense. When wiring the receiver note that the *outer* end of L_3 and the *inner* end of L_4 are the ones to be connected to the capacitor C_5. The quench coils are fixed to the baseboard with an iron bolt through their former (6 BA).

The actual receiving part of the set occupies a space of $1\frac{3}{4}$ins. by 2ins. on the baseboard, the remainder being occupied by the relay. The baseboard should therefore be cut $1\frac{3}{4}$ins. wide, but the length depends on the type of relay used. A suitable material is $\frac{1}{16}$in. paxolin. The valveholder is mounted $\frac{1}{2}$in. below the baseboard and is distanced by two short lengths of metal tubing. A hole $\frac{3}{4}$in. in diameter is cut for the valve.

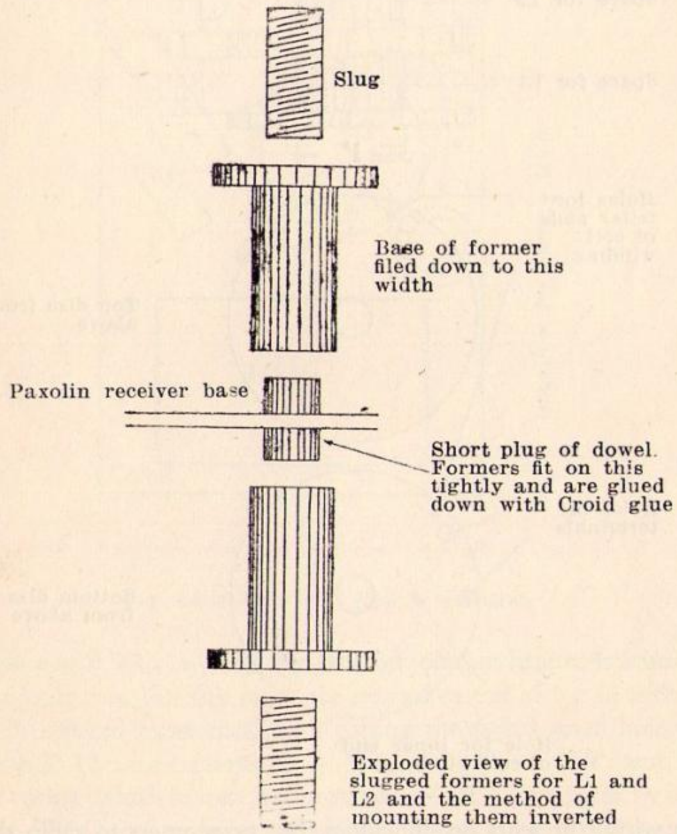
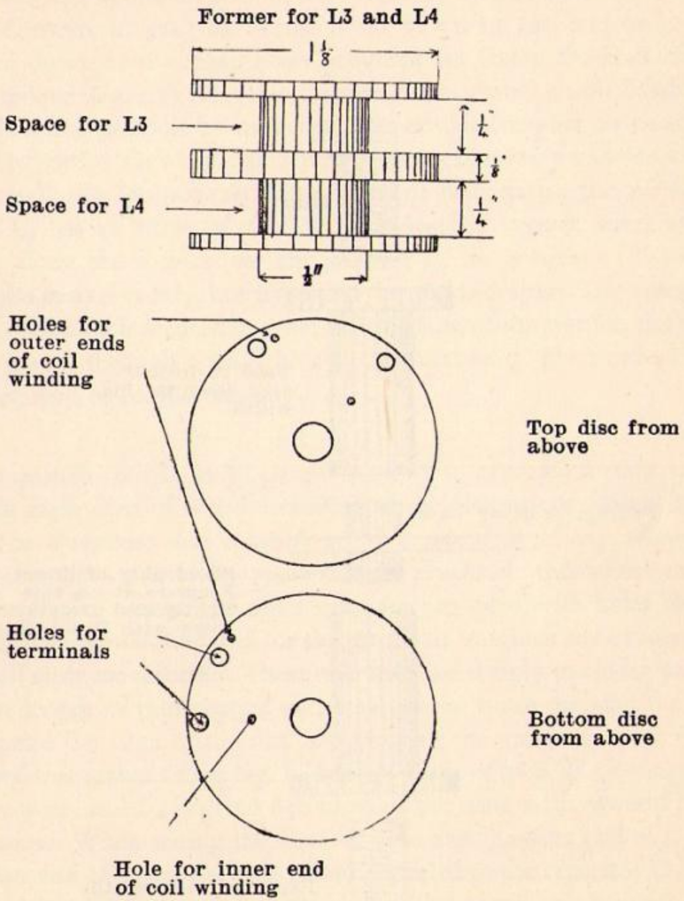


Fig. 4.3. *Details of coil former assembly.*

Fig. 4.3 (*cont.*)



The wiring presents no difficulties, but newcomers to radio should read §§7.1 and 7.2 first. 22 S.W.G. tinned connecting wire is used throughout and is insulated by suitably cut lengths of sleeving. All connections to the coils and the grid or anode of the valve should be as short as possible. The small tubular capacitors and the resistors are held in position by their connecting wires. The ends of L_1 and L_2 nearest to the baseboard go to L_3 and C_1 respectively. The sense in which L_3 and L_4 must be connected up has already been mentioned. The aerial consists

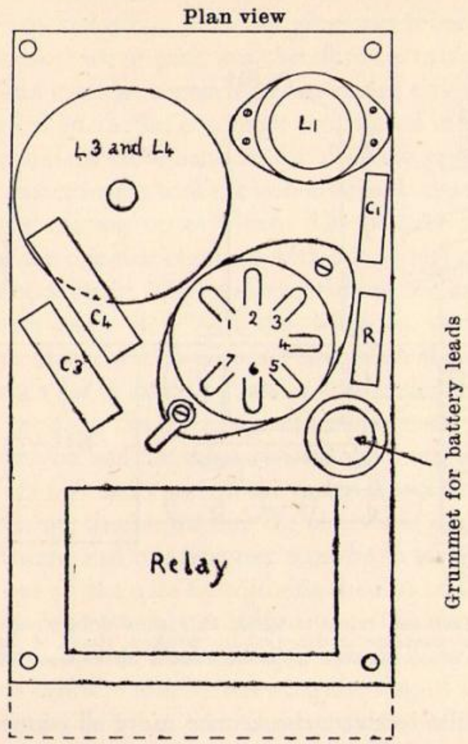
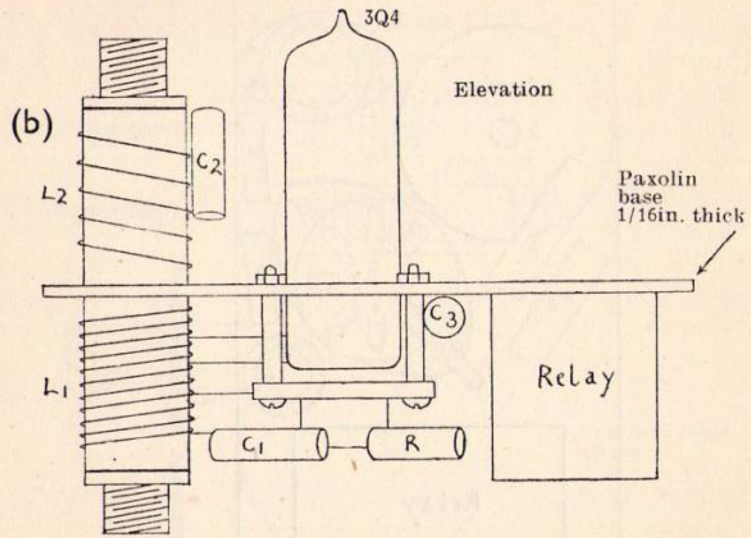


Fig. 4.4. a *Receiver I (approx. full size).*

of a piece of P.V.C. covered thin flex, 2ft. 6ins. in length. It is not sufficient simply to solder this on to the respective end of L_2: in addition it must be secured mechanically by passing through a small hole in the baseboard. The connections to + L.T., — L.T., — H.T. and to the meter socket (which in turn is connected to + H.T.) are made by lengths of thin P.V.C. covered flex which pass through the rubber grummet (Fig. 3.6b) and terminates in a five-pin plug. The length of these leads outside the receiver should be about 5ins. The remaining two pins of the plug are used for leads which come respectively from the centre contact of the switch on the sensitive relay and one of the outer contacts (this depending on the type of control system to be used: see Chapter 5). The exact manner in which the receiver is connected to the batteries, the on-off switch and the meter will be described below.

Fig. 4.4 (*cont.*)



If a Siemens relay is used, this should be mounted on top in the position indicated by broken lines. A longer baseboard must then be used (as shown by broken lines).

Before testing the receiver, check once more all connections, check whether they are mechanically sound so that they cannot break in the normal handling of the receiver; inspect the soldered joints and examine very carefully whether the solder has 'taken' in each case. Also examine the insulation.

4.3.2. Tuning and Adjusting

Before the receiver is tested and adjusted it is best to make a small provisional switchboard which holds the four-pin battery socket, the five-pin receiver socket, the meter socket and the on-off switch; also to make up a suitable battery pack (§6.2). The layout of this panel is immaterial; an example is shown in Fig. 4.5a. The on-off switch should be a two-pole switch; only one pole will be used at present, but the other pole may be needed later on for an escapement battery. The wiring diagram for this switch panel is shown in Fig. 4.5b. Since there is no need to connect up an escapement for these preliminary tests, two tags on the receiver socket and one on the battery socket are left open. The

receiver can be worked off 45 volts but gives much better results with 60 volts. A suitable battery pack can therefore be made up from two 30 volt hearing-aid batteries connected in series and a $1\frac{1}{2}$ volt dry cell for the L.T. supply (cf. §6.2). But it is more economical in the long run to keep a set of large-sized radio batteries for all bench tests.

The two-pin meter socket is of the non-reversible type and the meter is a milliammeter reading up to 5 mA. The positive terminal of the meter should be the one that connects with the + H.T.

The tests can now begin. The receiver, without the valve, is plugged in, also the battery and meter. With the switch on, the voltages at the valve holder are now checked with a volt-meter; there should be $1\frac{1}{2}$ volts between tag 1 (or 7) and tag 5, and a little under 60 volts between 1 and 2. If this test fails, check wiring; otherwise insert valve.

With the switch on and the valve inserted the meter may show anything between 1/2 mA and 3 mA. If the meter shows a current near the low end of this range this means that the receiver is in the state of self-quenched oscillation, and our first test must be to see whether we can bring it at will out of that state by adjusting the slug of L_1. Throughout this test keep the slug of L_2 about half-way in. The quench control (or 'sensitivity' control, as it is often called) is correct if we can reduce the anode current to below 1 mA by screwing the slug of L_1 right in, and raise it to above $2\frac{1}{2}$–3 mA (i.e. take the receiver out of the state of self-quenched oscillation) by unscrewing the slug. The upper limit of the anode current is largely governed by the grid resistor and the reader can adjust this to suit his requirements (or to adapt the receiver to different valve types) by altering the magnitude of this resistor.

If this test fails and the current remains constantly at the lower value the quench is too effective and the number of turns on L_1 must be diminished. It also helps to lengthen the aerial in that case.

If the anode current remains constantly at its higher value the quench is insufficient or the wiring is faulty. This can be decided by disconnecting the aerial. If the current now drops, this indicates that the quench was merely insufficient and a couple of turns must be added to L_1. If there is still no quench (i.e. the anode current remains high) with the aerial disconnected and the slug of L_1 right in, the wiring may be faulty. Try reversing the connections of either L_3 or L_4. If this still produces no result, restore the *status quo*, check the remainder of the wiring, try different positions of the slug of L_1 and, if necessary, add more turns to

L_1. Also check the voltage of the L.T. battery. Hard-valve receivers work badly on run-down L.T. cells.

When the sensitivity control works satisfactorily so that we can reduce the anode current to below 1 mA or raise it to its full value by turning the slug of L_1 in and out respectively, the time has come for bringing the transmitter into action and tuning the receiver to the right wavelength.

The transmitter is placed near the receiver, switched on and the key held down permanently, or shorted, so that there is a continuous signal. Check this with the field strength meter. Now turn the slug of L_1 right in until the anode current has dropped to a minimum. Then vary the setting of the slug of L_2 until you find a position at which there is a small dip (current drop) in the anode current when you approach this position from either side. By switching the transmitter, check that this dip is due to the reception of the signal. When this position has been found, slowly turn out the slug of L_1 until the current, with signal off, begins to rise. The dip now caused by a signal will increase correspondingly. Continue to adjust L_2 and slightly readjust L_1 until you get the greatest dip. This should be at least 2 mA.

The receiver is now tuned to the transmitter. The circuit is very stable so that, once tuned, only slight readjustments should be necessary before a flight. If with signal off the anode current seems unsteady the slug of L_1 must be turned out a little, i.e. there is a little too much quench. If a signal produces a hesitant current drop instead of an immediate one, this means that L_2 is not tuned with sufficient accuracy.

It remains to adjust the sensitive relay. This is done by varying the anode current and seeing at what value of the current the relay pulls in and when it drops out. The general procedure for adjusting a sensitive relay has already been dealt with (Chapter 2). The variation in the anode current may be produced by varying the slug of L_1, but since this involves a re-tuning of the receiver it is better to insert temporarily a potentiometer of 50,000 or 100,000 ohms in series with the meter, and to use this for varying the anode current. The relay should be so adjusted that it pulls in at least ½ mA before the current reaches its normal standing (signal off) value, and drops out about 1 mA above the value to which the current drops on receipt of a signal.

If for any reason the reader has used coils of different dimensions than those given in these instructions, he can find the correct number of turns for the tuning coil from the formula given in §2.3. All the same he may

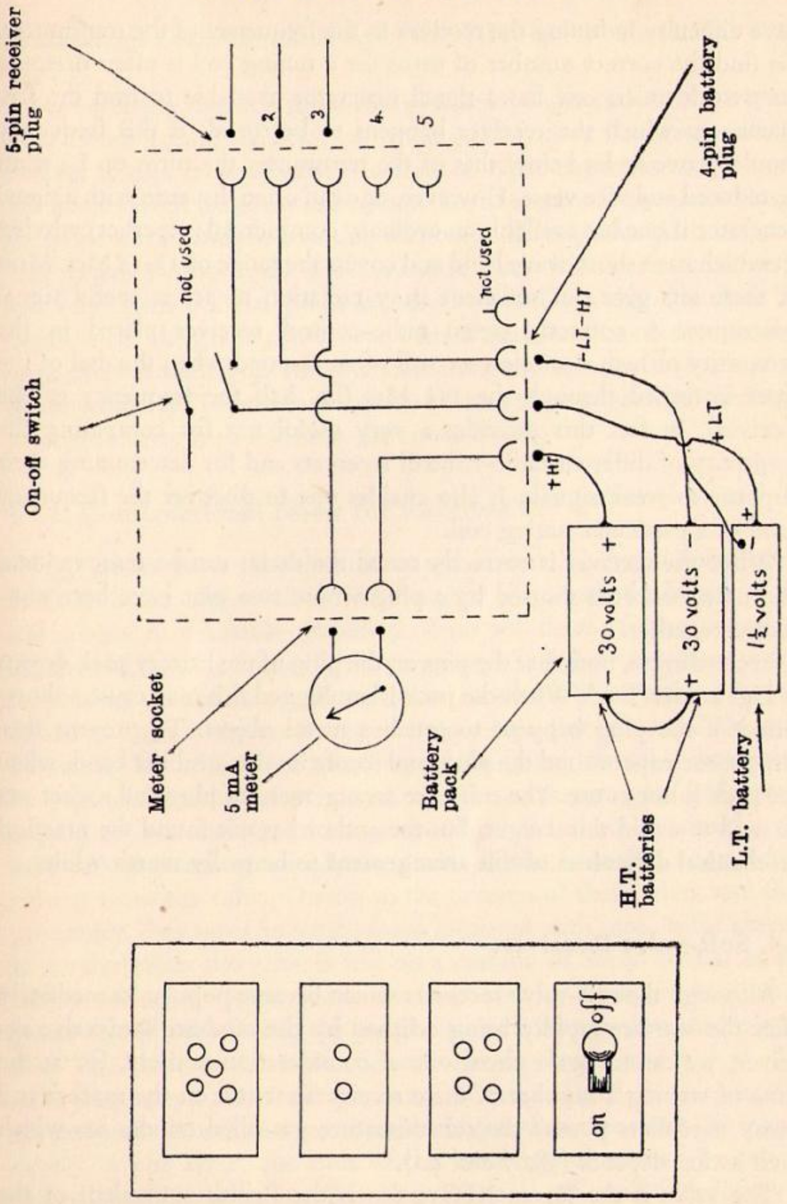


Fig. 4.5. *Layout and theoretical circuit of switch panel for preliminary bench tests.*

have difficulty in tuning the receiver to the frequency of the transmitter. To find the correct number of turns for a tuning coil is often tiresome guesswork unless one has a signal generator available to find the frequency to which the receiver happens to be tuned. If this frequency should prove to lie below that of the transmitter the turns on L_2 must be reduced and vice versa. However, one can often dispense with a signal generator if one has available an ordinary commercial (superhet) wireless set which has a short-wave band and covers the range of 13-14 Mcs. Most of these sets give out sufficient stray radiation to act as useful signal generators. A correctly tuned radio-control receiver placed in the proximity of such a wireless set will often respond when the dial of the latter is turned through the 13½ Mcs (i.e. half the frequency of the receiver). In fact this provides a very useful test for comparing the sensitivity of different radio-control receivers and for determining their response to weak signals. It also enables one to discover the frequency band of a particular tuning coil.

When the receiver is correctly tuned the meter can be removed and the meter socket is shorted by a plug whose two pins have been connected together.

In conclusion, note that the pins on the plug of the battery pack shown in Fig. 4.5 are 'live'. When the pack is unplugged this may cause a short-circuit if the plug happens to touch a metal object. To prevent this, wrap some paper round the plug, and secure it with a rubber band, when the pack is not in use. The converse arrangement of plug and socket can be used to avoid this danger, but the author has not found the practical mechanical difficulties of this arrangement to be really worth while.

4.4. Soft-valve Receivers

Although the soft-valve receivers which became popular immediately after the war are rapidly being eclipsed by the modern hard-valve receiver, we cannot leave them out of consideration entirely, for at the time of writing a number of these receivers are still on the market and many modellers possess the sub-miniature gas-filled triodes on which their action depends (§§2.7 and 4.1).

The valve is the Hivac XFG1; this is the British equivalent of the American RK 61.The very small size of this valve allows very compact receiver designs, although the gain is only slight in comparison with the

disadvantages inherent in the relative instability of the valve and its short life.

The receiving circuit is again that of a super-regenerative receiver, but there are no separate coils for controlling the quench frequency and the receiver is kept permanently in a state of super-regeneration. When a signal is received from the transmitter the strength of the oscillations in the receiver rises and the resulting increase in the negative grid charge or 'bias' causes a drop in the anode current. Since the anode current of a soft valve does not change progressively but drops sharply when the ionisation of the gas breaks down, a small signal can be made to have a large effect provided the standing anode current lies just above this point of discontinuity. To enable the anode current to be adjusted accordingly a potentiometer is provided in the anode circuit.

4.4.1. Constructional Notes for Receiver II

Fig. 4.8 shows a suitable circuit and layout. L_1 has 8 turns of 16 S.W.G. tinned copper wire. The diameter is ⅝in. and the length of the coil in 1¼in. Any suitable cylindrical object will do as a former for winding the coil, but the finished coil is removed from the former and is self-supporting. Its ends are soldered (over an adequate length) to the terminals of C_1, a compression-type trimmer capacitor of 100 pf. To make the tuning less critical the selectivity of the tuning circuit is diminished by a parallel resistor of 75,000 ohms. The miniature gas-filled triodes require no valveholders (although suitable holders are obtainable) and may be connected up simply by means of the four thin wires which emerge from the valve. Owing to the thinness of these wires, and their proximity, they must be handled and insulated with care. In the absence of a valveholder the valve is laid on a cushion of Sorbo rubber or soft rubber tubing and is secured to the baseboard by a loop of wire which passes through the board, the ends being twisted together on the other side. The order of the valve connections was shown in Fig. 2.31. The radio frequency choke RFC consists of 75 turns of 36 S.W.G. enamelled copper wire wound on a paxolin tube of ¼in. diameter and 1¼in. length, evenly in one layer; the ends of the winding are secured by passing through small holes in the tube. A length of dowel, well doped, may be used instead of the paxolin. The choke is glued to the baseboard with Croid glue. With fine sandpaper the enamel is scraped off the last five

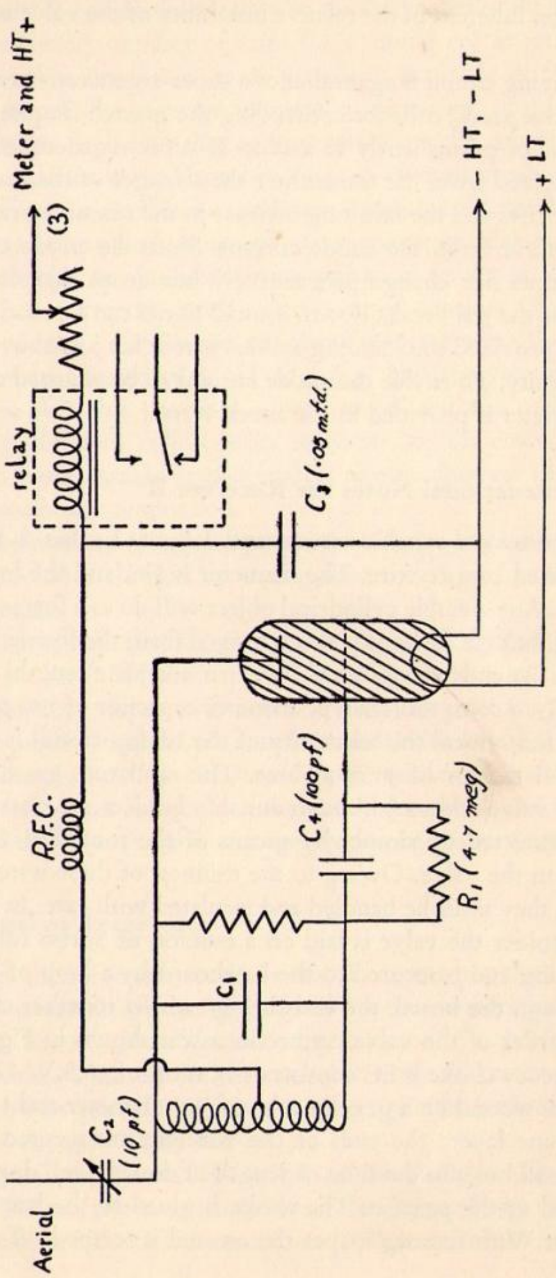


Fig. 4.8. (a) *Receiver II (soft-valve).*

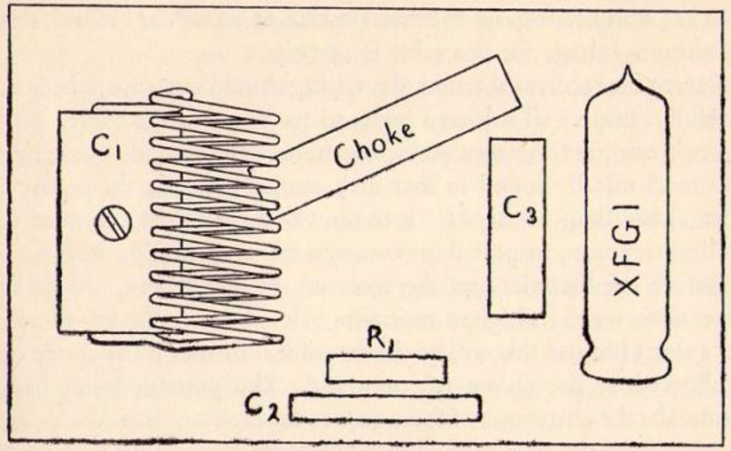


Fig. 4.6 (b) *Layout of Soft-valve Receiver (top view, natural size). R2 lies below the coil The relay is mounted underneath.*

turns at each end of the choke. Later, the connecting wires are soldered to these bared ends.

The sensitive relay should have the usual 3,000-10,000 ohms and lies in series with a miniature potentiometer of 5,000 ohms. It is more convenient to mount the latter on to the switch panel (Fig. 4.7) rather than to incorporate it with the receiver.

The layout on the baseboard is straightforward. A paxolin fibre base is used, 2ins. x 3½ins. As regards the wiring, selection of sensitive relay, etc., the same remarks apply as for Receiver I. As before, too, the battery leads and relay leads consist of P.V.C. covered flex and are taken out of the receiver in the form of a twisted cable, 5ins. in length, which terminates in a five-pin plug. The aerial is 2ft. 6ins. long and soldered on. The battery cable and aerial are secured mechanically by passing through suitable holes in the baseboard.

4.4.2. Tuning and Adjusting the Soft-valve Receiver

As with the previous receivers, a small switch panel is made for bench tests which contains a switch and the sockets for the meter plug, receiver plug and battery plug. In addition the panel now contains the potentiometer of 5,000 ohms. The circuit is shown in Fig. 4.7.

The battery pack now contains, in addition to the 1½ volt L.T. battery, two 22½ volt hearing-aid batteries (instead of 30 volt as before), since the maximum voltage for the valve is 45 volts.

Before the receiver is tested, the wiring should once more be inspected carefully. Inspect all soldered joints to see whether the solder has really 'taken', examine the insulation, examine whether the connections are also mechanically sound so that they cannot break in the course of the normal handling of the set. Since the valve cannot be removed for the preliminary tests, inspect these connections particularly carefully.

Before the batteries and the receiver are plugged in, always set the potentiometer to its highest resistance value, because the gas-filled triode has a short life and this will be shortened still further if the anode current is allowed to rise above 1.8 or 2 mA. The potentiometer has three terminals: the centre one of these goes to the moving arm; the other two connect with the ends of the resistance track. To use the potentiometer as a variable resistor the centre terminal and either one of the two end

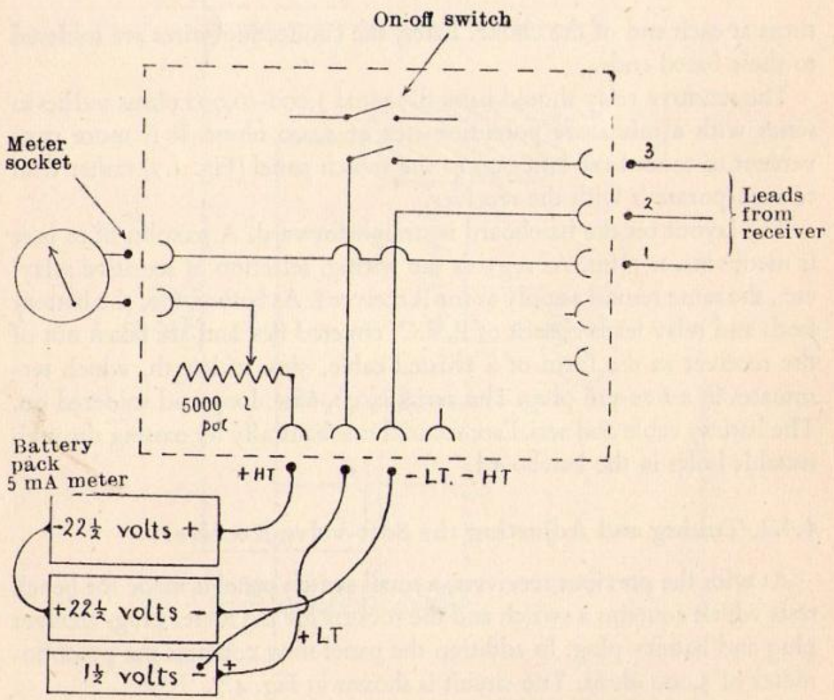


Fig. 4.7. *Switch panel for soft-valve receiver for bench tests.*

terminals is used. This variable resistor will have its highest resistance value if the moving arm is turned right over to the *unused* end terminal.

Mark the sense in which the knob of the potentiometer has to be turned to bring to its highest value with a large arrow on the switch panel; this is to remind you always to turn the potentiometer in this direction before you plug in the receiver and the batteries.

When everything has been plugged in and the receiver is switched on the meter should read something like 1 mA.

The receiver aerial should be thin insulated flex, about 2ft. 6ins. in length, which, in addition to having been soldered to the correct point of the circuit, is secured mechanically by passing through a small hole in the baseboard of the receiver. For the preliminary tests it can be left hanging down from the table. The transmitter should be placed close to the receiver for the first tests but be at least 50ft. away for the final adjustments. No more than a short length of aerial is required for the transmitter in these bench tests, but it should be noted that when this is replaced by the full aerial the receiver will require re-tuning.

With all units plugged in and in position, the tuning can begin:

(1) Using a narrow strip of paxolin as screwdriver, set C_2 about half-way. Do not yet switch on the transmitter.
(2) With the potentiometer carefully increase the anode current of the valve to 1.8 mA. A bright purple glow should be seen in the valve.
(3) Over a wide range of C_1 the set should now oscillate. This can be tested by touching the coil, for when the set oscillates this will cause a rise in anode current.
(4) Switch the transmitter on and, slowly giving intermittent signals, set C_1 until you find a position at which each transmitter signal causes a dip of the anode current to ½ mA or less. Adjust C_2 if necessary.
(5) If you cannot find the dip you must try coils of different diameter, or try a smaller capacitor for C_1. Read the notes made on this point in §4.3.2.
(6) When the receiver has been tuned and responds satisfactorily, adjust the sensitive relay. Switch the transmitter off and, slowly swinging the anode current with the potentiometer, adjust the relay until it pulls in at about 1.4 mA and drops out at about 1 mA or over. Remember, though, that the anode current must not be allowed to rise above 2 mA. If the current cannot be

made to drop low enough for adjusting the relay, connect temporarily a second potentiometer in series with the milliammeter.

(7) Remember that on the field the receiver should be given a final adjustment with the full transmitter aerial and earth rigged up and with the transmitter about 50ft. away.

(8) The receiving circuit is very sensitive to changes in H.T. voltage A drop of 5% in this voltage can reduce the anode current by 25%. Unfortunately all small H.T. batteries of the deaf-aid type will drop their voltage during the first few minutes of any period of operation. Even although this slightly reduces the range of the receiver, a gap of at least 0.3 mA. should therefore be allowed between the adjusted standing current of the valve and the safe 'pull in' current of the relay.

(9) As the valve advances in age the anode current declines and the action of the receiver tends to become uncertain (i.e. the anode current becomes unsteady, or may fail to rise after a signal). For a time the first defect can be offset by appropriate readjustments of the potentiometer setting. When the valve reaches an age at which it is no longer possible to raise the anode current to the correct value by this means, the current can be raised further by substituting a resistor of 50,000 ohms or even less for R_2. The second defect can be remedied for a time by a closer aerial coupling, or a longer aerial in conjunction with a reduced coupling, thereafter only by reducing the inductance of the coil, i.e. by reducing the number of its turns, at the same time increasing the capacitance of C_1.

Modellers who wish to make their set permanently adaptable to the ageing characteristics of their valves should therefore (a) mount a two-pin socket parallel to the coil and make R_2 a plug-in resistance; and (b) substitute a coil with an adjustable dust iron core for L. The number of turns of this coil should be so chosen that with a new valve the receiver can be tuned in with C_1 fairly wide open and with the dust iron 'slug' well inside the coil. All routine adjustments continue to be made with C_1, but as the valve shows signs of ageing, the slug is gradually turned further out and, accordingly, C_1 is turned further out.

When the valve has reached an age at which the anode current becomes either unstable or too low altogether, it is 'finished' for R/C work. According to Mr Honnest-Redlich it can then still be used for ordinary

broadcast reception. He has given a suitable circuit for a pocket receiver in *Model Aircraft*, August 1951.

4.5. Transistorised Receivers

The transistor has made it possible to add simple and light amplifier stages to radio control receivers and so to make their action more positive. A current change of 3-4 mA can be effected in the sensitive relay in response to transmitter signals and a much more reliable relay action results at lower HT voltages.

There are two basic types of amplifier stages that can be used here and these are shown in Figs. 4.8 and 4.9 in conjunction with our hard-valve receiver.

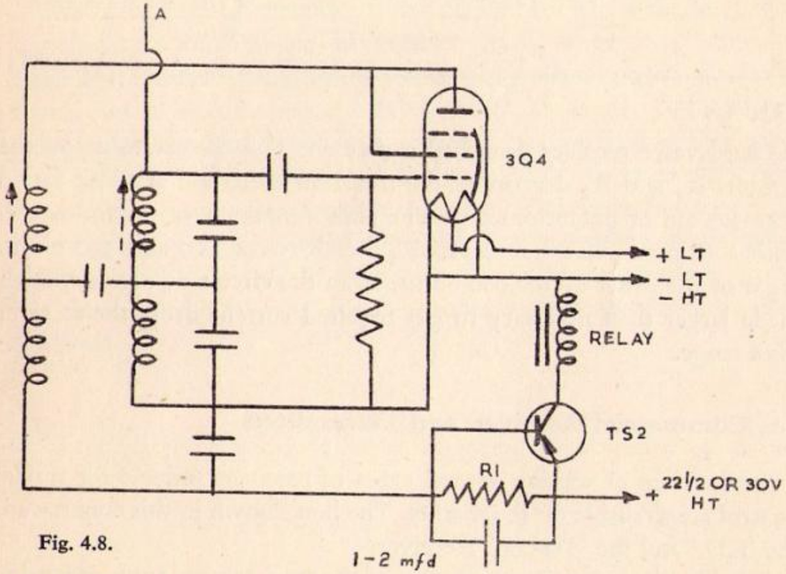


Fig. 4.8.

In the first the transistor is 'D.C. coupled'. In this case the transistor idling current is high and drops in response to transmitter signals. In the second the transistor is 'A.C. coupled' and here the transistor idling current is low and rises in response to transmitter signals. In the first case therefore the relay is normally 'in' and drops out in response to signals. In the second it is normally 'out' and pulls in in response to signals. The latter, therefore, is more economical from the point of view of battery consumption. But the former makes a more sensitive receiver.

The component values of the valve-stage are the same as those for

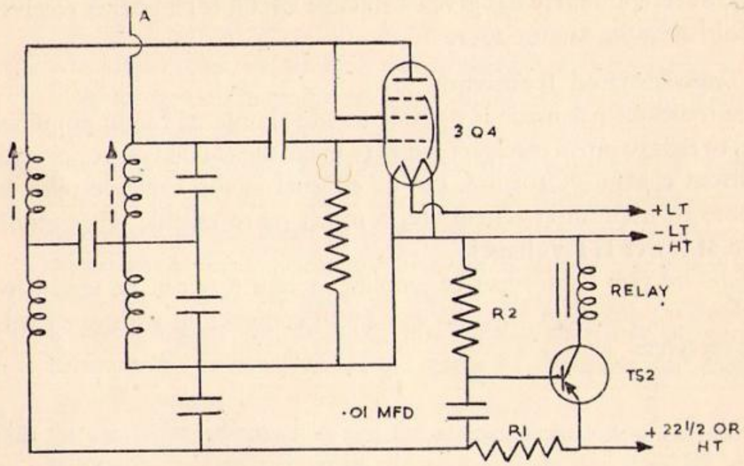


Fig. 4.9.

the hard-valve receiver described earlier on. The correct values of the resistors R_1 and R_2 depend on the transistor used, and are best found with the aid of potentiometers. The author attained very good results with a Brimar T.S.2 transistor. R_1 lies between 100 and 500 ohms. R_2 is of the order of 200,000 ohms. If, in the circuit of Fig. 4.8, R_1 is made larger than necessary to get required current drop, the receiver loses range.

4.6. Commercial Receivers and Transmitters

At the time of writing several types of receivers suitable for model control are available on the market. The best known in this country are the 'E.D.' and the 'Tri-ang' Receiver.

The 'E.D.' receiver is the smaller of the two. It employs a soft valve followed by a transistor stage. The relay is a single pole spring-biassed relay. Two 22½ volt batteries are required for the H.T. supply. It is particularly easy to tune and the soft valve in this circuit has a long life.

The 'Tri-ang' receiver employs a hard valve, also followed by a transistor stage. It is slightly larger as it uses a double-pole sensitive relay. The advantage of this is that it lends itself to more advanced circuit arrangements and can also give greater switching security. The relay is polarised. The receiver has a sensitivity control as well as a tuning control

so that troublesome interference from servo-motors can be eliminated. It operates on a single 30-volt H.T. battery.

All commercial receivers are supplied with clear instructions for connecting up, tuning and adjusting. All the same, it is advisable to read the relevant sections in this book.

Remember your battery voltages. None of these receivers work well on run-down L.T. batteries. But also remember that you may get a deceptive meter reading if you measure the voltage of your batteries when these are doing no work. The voltages should therefore be measured only under normal operating conditions.

The ageing characteristics of soft valves and the remedies that have to be applied were discussed in section 4.4.

The commercial transmitter most suitable for the newcomer is the crystal-controlled 'Tri-ang' transmitter. Owing to its crystal control it holds its frequency with absolute accuracy and when its aerial is removed it will emit a weak test signal on the correct frequency. This is of great value when checking whether the aircraft receiver is correctly tuned. In the absence of crystal control the removal of the transmitter aerial invariably induces an appreciable change in transmitter frequency. The above transmitter also incorporates a radiation indicator and a television interference filter circuit. It also has built-in electronic pulsing circuits but these are of little value for the simple control systems discussed in this book.

CHAPTER 5

CIRCUITS FOR COMPLETE CONTROL SYSTEMS

So far we have only dealt with the radio link; that is, with the transmitter and receiver. We must now turn to some of the systems which may be used for operating the controls on the model by means of the signals sent over this radio link. In theory there exists a very great variety of ways in which signals of different composition, duration, sequence, etc., can be made to release different operations in the control mechanism of the flying model. But the keynote of successful radio control of model aircraft is simplicity and reliability. Only the most simple and reliable systems have any practical value for the average modeller, and only these systems will therefore be given space in this chapter. And when I say reliable, I do mean *reliable*. It will not do to have a control component that works with 95% reliability. For if we have a chain of ten such components in our control system, the chance of a single successful command is reduced to 50%, and the chance of a sustained successful flight is almost nil, particularly if the normal hazards of model flying are taken into account.

The beginner is strongly advised to start only with simple rudder or aileron control, possibly coupled with an engine cut-out, but not to attempt anything more ambitious at first. Even the simplest system offers plenty of scope for technical hitches and mistakes. These should be mastered before anything more ambitious is attempted. They should also be noted in a log book to prevent their recurrence.

It is advisable to build up the complete control system on the bench first and to test it thoroughly before building the aircraft into which it is to be fitted. These operations should definitely include tests with the transmitter set up at a distance.

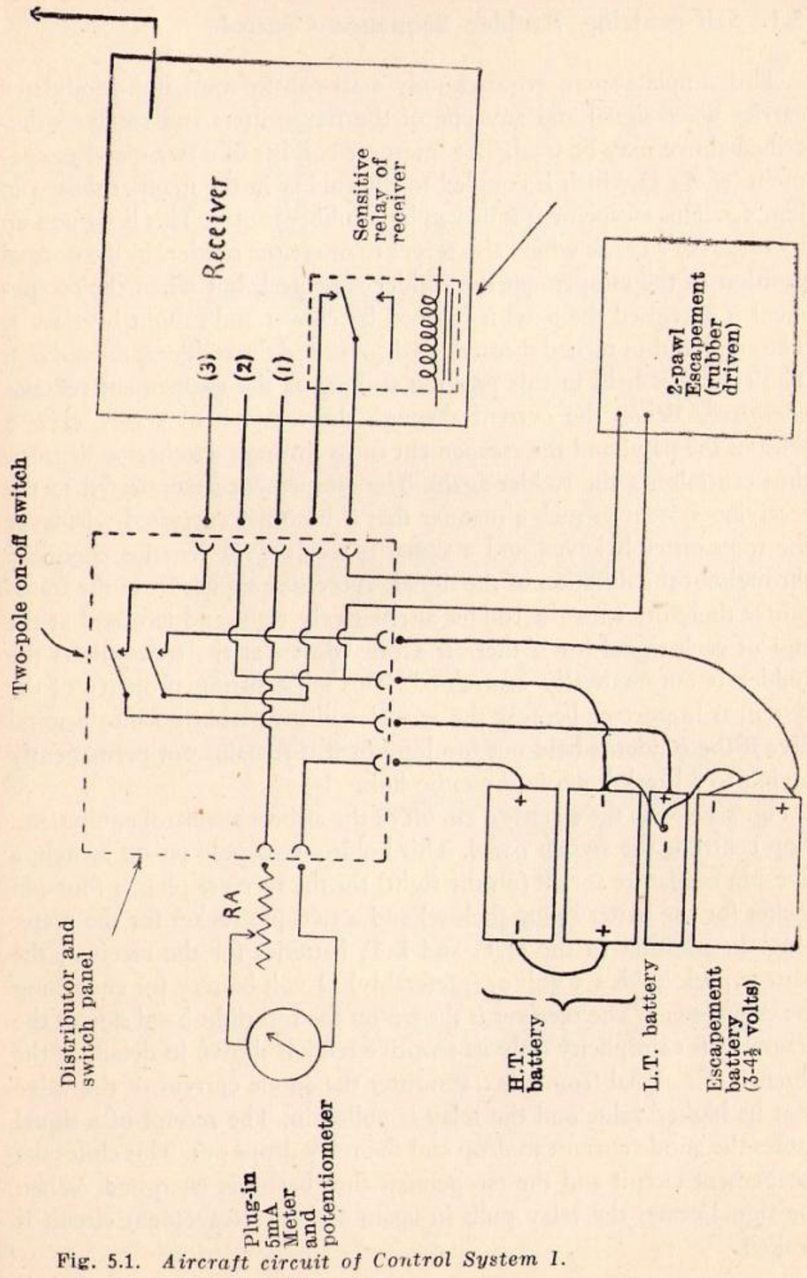


Fig. 5.1. *Aircraft circuit of Control System 1.*

5.1. Self-centring Rudder Sequence Control

This simple system requires only a straightforward non-modulated carrier wave signal and any one of the transmitters and receivers described above may be used. The intergear consists of a two-pawl escapement (cf. §2.3) which is coupled to the rubber in the manner shown in Fig. 5.2. This escapement is driven by a rubber motor. This is wound up by means of a crank which also serves to move the rudder. In the normal position of the escapement the rudder is neutral, but when the escapement is energised the pawl is released by claw 1 and caught by claw 2. The crank is thus turned through 90 degrees and the rudder is moved out. The rudder is held in this position so long as the escapement remains energised. When the current through the escapement ceases, claw 2 releases the pawl and the escapement turns through another 90 degrees, thus centralising the rudder again. The escapement is connected to the receiving system in such a manner that it becomes energised whenever the transmitter is keyed and a signal is received; it remains energised throughout the duration of the signal. Successive signals from the transmitter therefore turn the rudder alternatively right and left, and at the end of each signal (or if there is a breakdown at the transmitter) the rudder is automatically centralised. This self-centring property of the system is important because the model will invariably go into a spiral dive if the rudder is held out too long or if it remains out permanently owing to a breakdown in the radio link.

Fig. 5.1 shows the electrical circuit of the airborne control equipment. Top centre is the switch panel. This holds a two-pole on-off switch, a five-pin miniature socket (on the right) for the receiver plug, a four-pin socket for the battery plug (below) and a two-pin socket for the meter plug. In addition to the H.T. and L.T. batteries for the receiver, the battery pack holds a 3 volt or (preferably) 4½ volt battery for energising the escapement. The receiver is shown on the top right hand side of the diagram; for simplicity only its sensitive relay is shown in detail. In the absence of a signal from the transmitter the anode current of the valve is at its higher value and the relay is pulled in. The receipt of a signal causes the anode current to drop and the relay drops out. This closes the escapement circuit and the escapement thus becomes energised. When the signal ceases the relay pulls in again and the escapement circuit is broken.

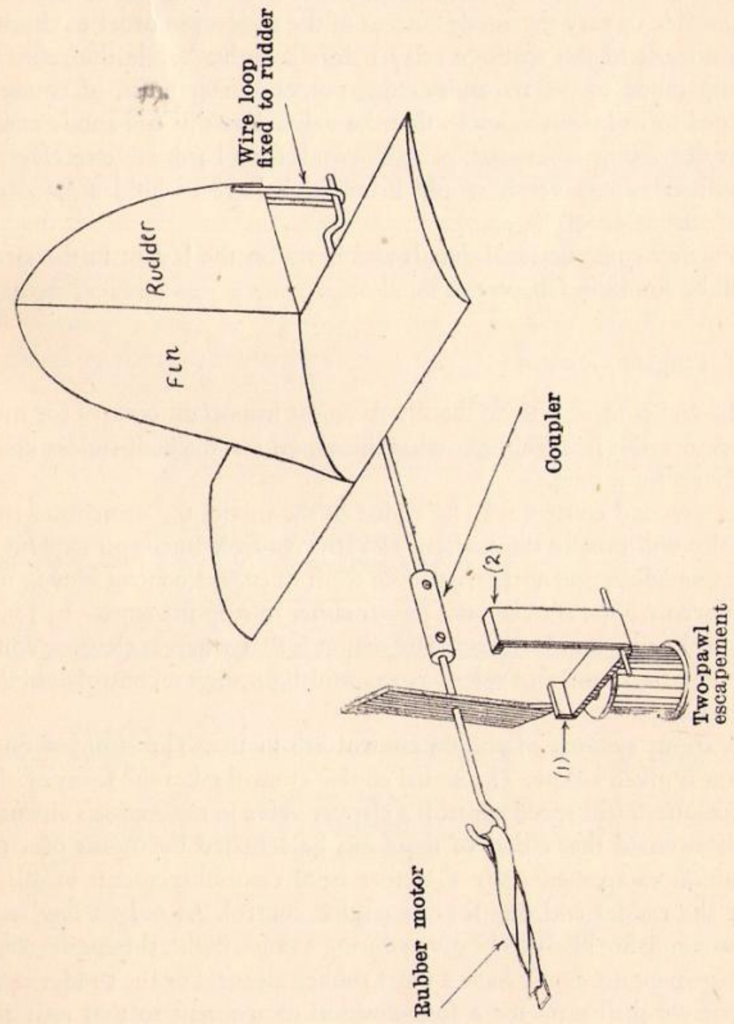


Fig. 5.2. *Self-neutralising Rudder Control.*

The milliammeter is plugged in only for tuning the receiver before the flight. During the flight is it replaced by a simple shorting plug. It is fitted in series with a potentiometer (RA) of 100,000 ohms. This makes it possible to vary the anode current of the receiver in order to check the adjustment of the sensitive relay before a flight. While the receiver is being tuned to the transmitter this potentiometer must, of course, be turned to its lowest value so that the valve draws its full anode current. The distributor and switch panel shown is for a hard-valve receiver. For a soft-valve receiver it would in addition have to hold a 5,000 ohm potentiometer (cf. Fig. 4.7).

Further constructional details and notes on the layout in the aircraft will be found in Chapter 6.

5.2. Engine Control

Lateral control is undoubtedly the most important control for model aircraft and it is astonishing what the expert can do with rudder control only on his model.

If a second control is to be added to the model the newcomer to the hobby will usually think about elevator control. But most experienced aeromodellers will agree that some form of engine control is even more important. That is to say, the power either to stop the engine by remote control or to vary its speed. The reason is that whereas elevator control increase the number of risk to a successful flight, engine control diminishes the risks.

Various systems of engine control are in use. The simplest one of them is given below. The actual engine control takes the form of either a cut-out or (for speed control) a clapper valve in the engine's air-intake. It is assumed that either of these can be actuated by means of a two-position escapement. We therefore need two escapements in all: one for the rudder and one for the engine control. As only a few engine commands are likely to be given during a single flight, the engine control escapement need only have a short rubber motor. For the rudder escapement we shall now use a four-position escapement so that only short signals are required to operate the rudder. And we want the engine control to come into operation when there is a long signal from the transmitter. This is easy to achieve if the receiver is fitted with a double-pole sensitive relay (such as the 'Tri-ang'). One set of these relay contacts

(the set A in Fig. 5.3) is then used to actuate the rudder escapement, using the battery V. The other set (set B, Fig. 5.3) is so connected that throughout the duration of a transmitter signal a condenser of 50 mfd is charged up from the receiver's H.T. battery and when the transmitter signal ceases this condenser is discharged through the engine control escapement. The short signals for rudder operation do not give the condenser enough time to charge up sufficiently, but if a signal of 2 or 3 seconds duration is given the condenser will become charged up sufficiently and at the end of the signal will send such a heavy discharge through the engine control escapement that this will pull in. Note that the condenser is an electrolytic one and that the correct polarity must therefore be observed. It should also be of a type that can operate safely at a working voltage of up to 50 or 60 volts. The charging time is regulated by the potentiometer P.

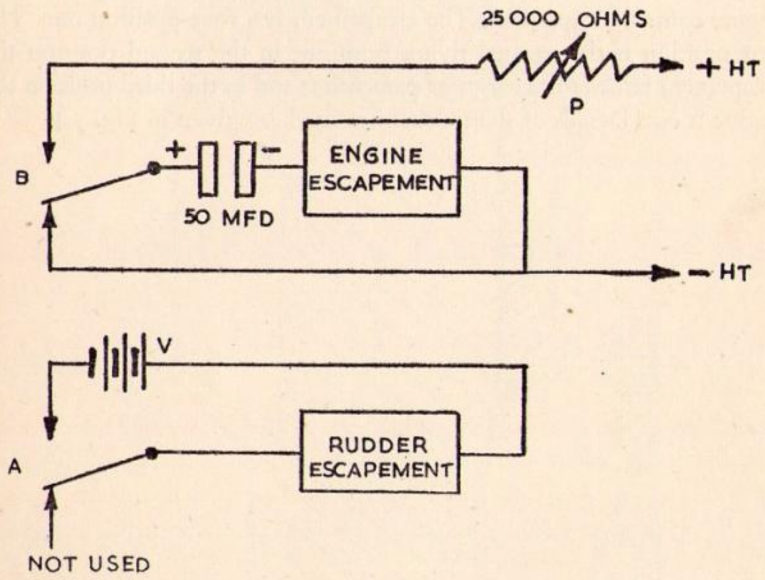


Fig. 5.3.

5.3. Aileron control

As, in this system, the rudder is no longer self-centring some modellers refer to use aileron control here instead of rudder control. Aileron control has two advantages over rudder control. The action of the ailerons is not affected by the slip-stream of the propellor and therefore does not lose effectiveness when the model changes from power flight to glide. And also the model is less likely to spin in if the escapement sticks when the model is turning. Details for escapement-operated ailerons are given in chapter 6.

5.4. Cargo Release by Remote Control

Facilities for releasing a cargo or a parachute from a flying model by radio control, add greatly to the enjoyment of the hobby. A model equipped with such facilities can be sent on a goal flight and can be given the task of dropping a message or a cargo over a predetermined goal.

In the method used by the author the cargo release is coupled to the engine control escapement. The escapement is a four-position one. The first position is the normal flying position; in the second position the escapement releases the cargo or parachute; and in the third position the engine is cut. Details of the mechanism used are given in Fig. 5.4.

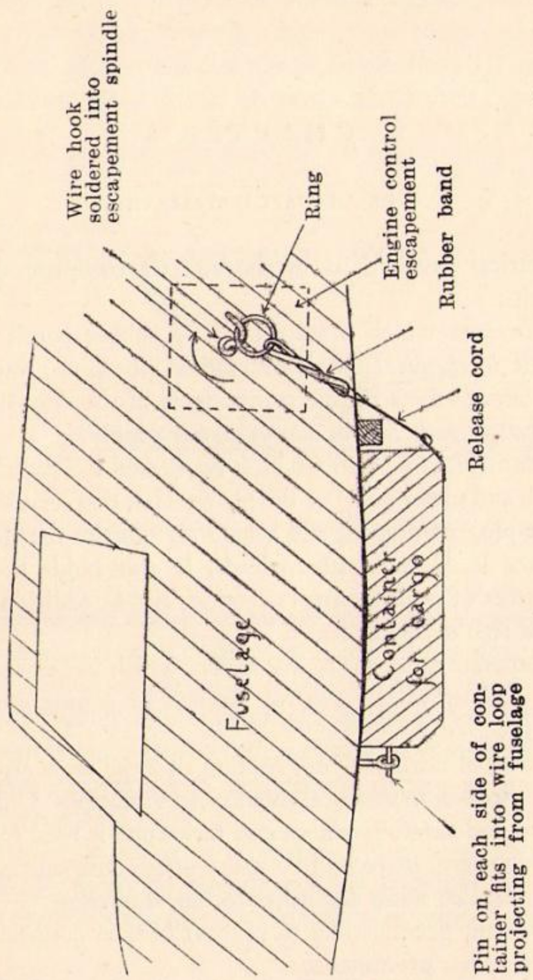


Fig. 5.4. *Mechanism for releasing a cargo.*

CHAPTER 6

THE AIRCRAFT INSTALLATIONS

The electrical installations in the aircraft comprise the following separate units.

(a) The *receiver*, which is suspended by rubber bands to protect it against mechanical shock or engine vibrations, and which also incorporates the sensitive components of the decoding system.

(b) The *battery pack*, which acts as power supply.

(c) The *distributor panel*, to which is connected the switch panel (with switch and meter plug) or the plug-socket that serves as switch and meter plug combined, and which also carries the sockets for the receiver leads and battery leads. It also holds the electrolytic capacitors of multi-control decoders, and in addition it may carry one or two escapements.

(d) The separate *escapements or actuators* which act as translating systems, and move the control surfaces or engine controls of the aircraft.

In the course of normal flying routine all these units are subjected to considerable stresses, mechanical shocks and vibrations. Unless therefore a very sound and carefully elaborated technique is used for assembling and mounting them, there will be many disappointments due to faulty connections, broken wires and other technical hitches.

Two important general rules to prevent broken connecting wires or leads must be given prominence:

Rule I: All wires and leads which may be twisted or bent in the course of normal flying routine, e.g. when the equipment is being handled or assembled, must be made of P.V.C. covered *flex* (e.g. battery leads, receiver leads, intergear connections, etc.).

Rule II: No flexible connection should be able to bend at the point where it is soldered on, or at any point at which its insulation has been removed (for otherwise it will invariably break at this point). To prevent movement at these points, the flex should be taken through a hole in the baseboard or chassis, or it should be tied down with carpet thread (Fig. 6.1). No miniature plugs should be used without their caps.

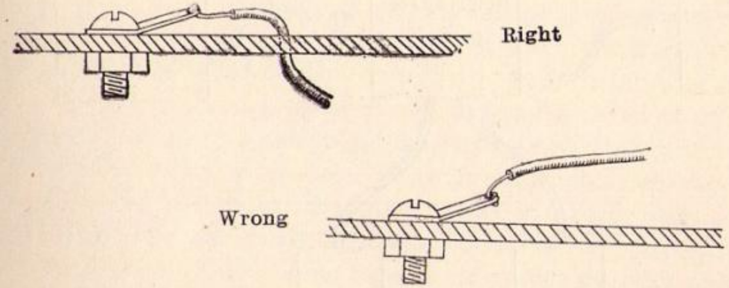


Fig. 6.1. *How to connect flex to prevent it from breaking at the joint.*

Experience has taught that these rules permit of *no exceptions*. It is a pity that the manufacturers of radio control equipment often ignore the second rule and fit their receivers simply with soldering tags to which the modeller is told to solder suitable lengths of flex by way of battery leads, etc. No provision is made by the designers to give those leads the additional mechanical support which they require if they are not to break eventually at the soldered joints.

Another general rule is that all the radio-control components should be easily removable from the aircraft and that it should be possible to assemble them quickly and easily on the bench for testing overhaul and cleaning.

From the electrical point of view, the central unit in the aircraft is the switch—or distributor panel. Both the battery pack and the receiver plug into this panel so that they can be easily removed or exchanged. The remaining units, such as escapements or actuators have permanent connections with it (Fig. 6.2).

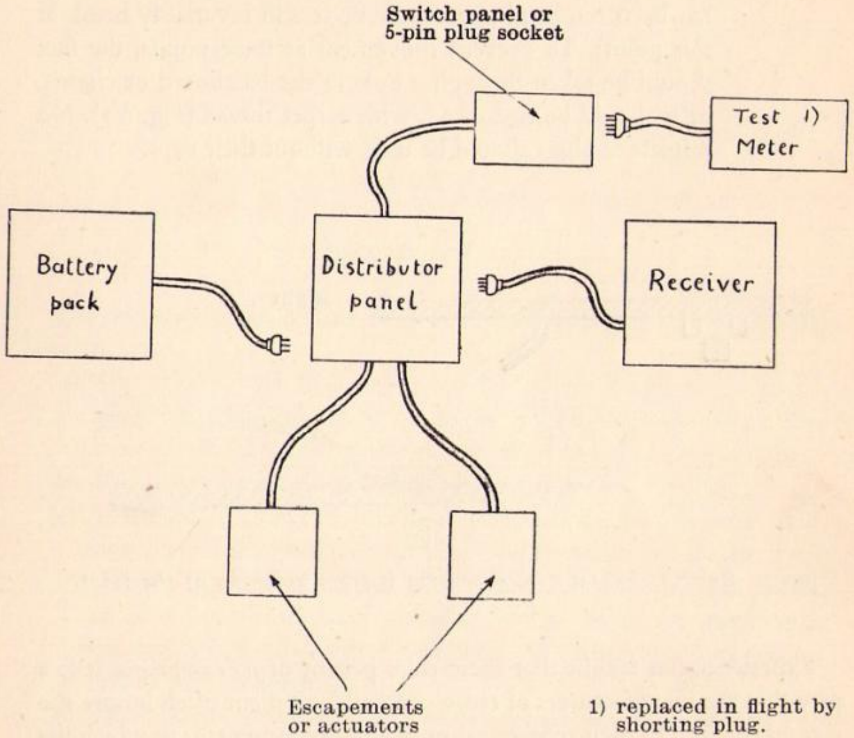


Fig. 6.2. *Block-diagram of the Aircraft Installation.*

6.1. The Receiver

The construction of the receiver has been dealt with in earlier chapters. We must now deal with its installation. The correct location for the receiver is near to the C.o.G. of the model (preferably a little behind this point). Here it is suspended by four diagonal loops of elastic tape from two pairs of wire hooks (16 S.W.G. piano-wire). Elastic tape is to be preferred to rubber bands since it has only a limited extension and will not break. This is very important in case of a nose dive or crash landing. The tape should be about ¼in. wide. Each loop is attached to a corner of the receiver by means of a small split ring (of the type used on key tags)

which passes through a hole in the chassis of the receiver. Each pair of hooks forms a single unit, made of one length of piano-wire, and is bound firmly to the chassis with carpet thread. Alternatively, the receiver may be held in a 'nest' of foam rubber.

The receiver should be positioned with the valve facing upwards or backwards so that the valve will not fly out of its holder in a crash landing. The tuning and adjusting screws should be readily accessible from outside the fuselage through suitable openings in the cabin sides or wing-root, so that the receiver can be tuned when in position.

The author does not believe in cabin doors for giving access to the receiver or for inserting the receiver. However wisely constructed, every cabin door weakens the fuselage at a vital point. It is much better to insert the receiver through the open top of the cabin before putting the wings on. If necessary a small hatch may be inserted into the wing for inspecting the receiver from above. This need not weaken the wing-root.

Another difficulty about cabin doors is that of making really strong hinges which will not deteriorate in use. Also, unless they have a really good fit, doors are apt to admit exhaust fumes into the cabin and this will oil up our electrical contacts. Doors of any descriptions, therefore, are best avoided altogether.

The *aerial* consists of P.V.C. covered flex, 2ft. 6ins. in length, which is fixed and soldered to the receiver. It passes through a small hole in the side of the cabin and is attached with a rubber band to a hook at the top of the fin or near the wing-tip. The best position is found by experiment. One should be on the look out for directional effects. On models which are painted with aluminium or metallic dope, the wing-tip position may give better result, and the aerial should be kept well clear of the doped surfaces.

6.2. The Battery Pack

The battery connections are always a bit of a headache. Yet they must be 100% reliable and must withstand bumps, shocks and vibrations without giving trouble. There are so many things to be checked before a flight, that we cannot afford the additional burden of having to check whether the batteries are making proper contact with their clips, or whether they are about to slip out of their holders.

Admittedly, if the batteries are simply held by clips on a battery tray, or if the battery leads are simply clipped to the battery terminals, the exchange is greatly facilitated. But the author knows of no such system which is really fool-proof and 100% safe. The system which he uses himself and which he can safely recommend to his readers is to make up a pack of the required batteries and to solder the battery leads to the terminals. The pack is made up simply by binding the required batteries together with Sellotape or insulating tape; the leads are then soldered to the terminals and are firmly fixed to the pack by another layer of tape so that they will not bend at the soldered joints and will not break at these points.

Two such packs are made so that one can be held in reserve. Admittedly this method is more cumbersome, but it is a very safe method. It is well worth while to spend an extra ten minutes in the workshop the night before, if this will save two minutes on the flying field or if it diminishes the risk of a breakdown at the crucial moment.

The only acceptable alternative is to use batteries which are fitted with plug sockets, and to face the additional expenditure which this involves.

Before soldering the leads to the battery terminals the latter should be given a thin coat of solder to make sure that the connections will be sound. But the soldering iron should not be applied to the terminals of the hearing-aid batteries for longer than necessary since extensive heat damages these batteries.

The correct position of the battery pack in the aircraft is well forward, preferably up against the engine bulkhead so that there is a strong member to take the stress of this very heavy weight in a rough landing. The effect of a battery pack flying through the length of the cabin in a crash is devastating.

Once again, the author deprecates the idea of having a separate door or hatch to give access to the batteries (see above).

In the standard arrangement which he uses for his own models the battery pack lies between the distributor panel and the engine bulkhead. The panel slides up and down between two pairs of balsa guides and can be pulled out through the open cabin top. This then gives access to the battery pack through the open cabin top. The sliding panel holds one pair of the hooks for the receiver so that the receiver comes up through the open cabin top when the panel is pulled up (Fig. 6.3).

The best working voltage for hard-valve receivers is 60 volt. This is made up of two hearing-aid batteries of 30 volt each. If these have to

supply the receiver only, two Ever-Ready B 123 (or equivalent) batteries may be used.

6.3. The Distributor Panel

It was stipulated above that the whole radio gear in the aircraft must be easily removable. A general layout which serves this purpose well, was shown in Fig. 6.3. The key position in this layout is occupied by the sliding distributor panel. This acts as distributor for the power supply from the battery pack; it has sockets for both the receiver and the battery plugs, and carries the front hooks for the receiver suspension. Unfortunately we cannot also make it carry the on-off switch and the plug socket for the milliammeter, for these must be accessible from outside the cabin when the wings are on. These must therefore be mounted as a separate unit.

The author generally prefers a shorting plug to a switch: it is cheaper, lighter and less likely to be switched on accidentally. Standard toggle switches are very reliable, but the author has had very disappointing experiences with some of the small sliding switches which have been recommended for radio control work. On his latest model the only switch extension to the distributor panel consists of a five-way socket which is fixed by two screws on the side of the cabin, facing outwards, and is easily removable. For tuning and adjusting a five-pin plug is inserted into this socket two of whose pins are connected to the milliammeter. The other three pins are shorted and make the connection to the L.T.—and escapement batteries (thus acting as switch for the receiver and intergear). Before a flight this plug is replaced by another one on which the meter pins, too, are shorted (cf. Fig. 6.3).

An additional advantage of this method is that it enables us to check very quickly either the L.T. consumption of the receiver or the current consumption of the intergear; for we simply have to insert the test prods of the test meter into the respective holes of the five-way socket.

The guides for the sliding distributor panel are made of ¼in. by ¼in. balsa strip and are cemented on to the longerons. Enough room must be left at the top of the cabin to enable the component on the front side of the panel to slide out through the open cabin top. It is often more convenient to have the sliding distributor panel at a slant.

The sockets for the receiver- and battery-plugs should be mounted near the top of the sliding panel so as to be readily accessible from above.

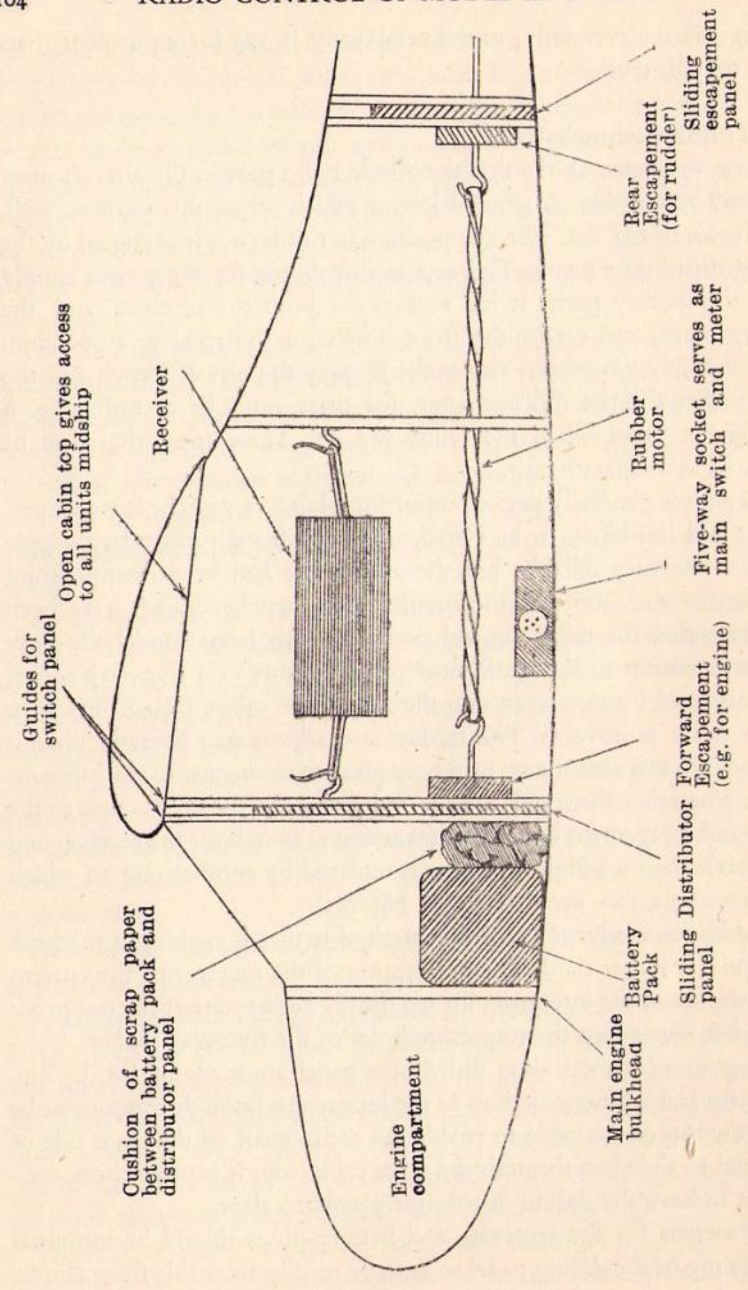


Fig. 6.3. *General Layout of the Radio Installations.*

Plywood may be used for the panel, but it is better to use paxolin, even although this is slightly heavier.

6.4. The Escapement

The engine control and elevator escapements are best mounted on the main distributor panel so that they are easily removed for inspection and overhaul. The rudder escapement is mounted on a separate sliding panel which lies behind the receiver. The exact position of this panel can be left undetermined until the last moment, that is to say until the entire aircraft has been covered and doped, and all other gear has been installed. The position of this unit can then be used to bring the C.o.G. of the model roughly to the desired point. When the best position has been found the top or bottom of the fuselage is cut away at that point and replaced by a trapdoor, and the balsa guides for the escapement panel are glued into position.

The connecting rod between the escapement and the rudder is 14 S.W.G. piano-wire. At the rear end it passes through a short length of wide tubing and terminates in a crank which engages the rudder loop. This loop is made of slightly thinner wire and should be almost ⅜in. wide so that the crank has plenty of play and the rudder can freely centre itself when the crank is in the neutral position. The loop has the shape shown in Fig. 6.4 and is bound to the rudder at two places with several turns of fuse wire. These turns are afterwards fused into a solid ring by the application of a soldering iron and a little solder.

If the connecting rod is long and has too much whip, an additional bearing must be inserted at some intermediate point. This, too, should have plenty of play.

The rubber motor used for driving an escapement should consist of a single loop of strip rubber whose length when unwound, exceeds the distance between its attachments by about one fifth. ⅛in. strip should be used for escapements which are entirely battery operated, but $\frac{3}{16}$in. or even ¼in. strip can be used for escapements which are pulled in by the discharge of an electrolytic capacitor.

The area of the rudder should not be greater than about one fifth of the area of the fin. The rudder movement should be 10 to 15 degrees in either direction. These figures are merely a rough guide, since their correct value varies from case to case.

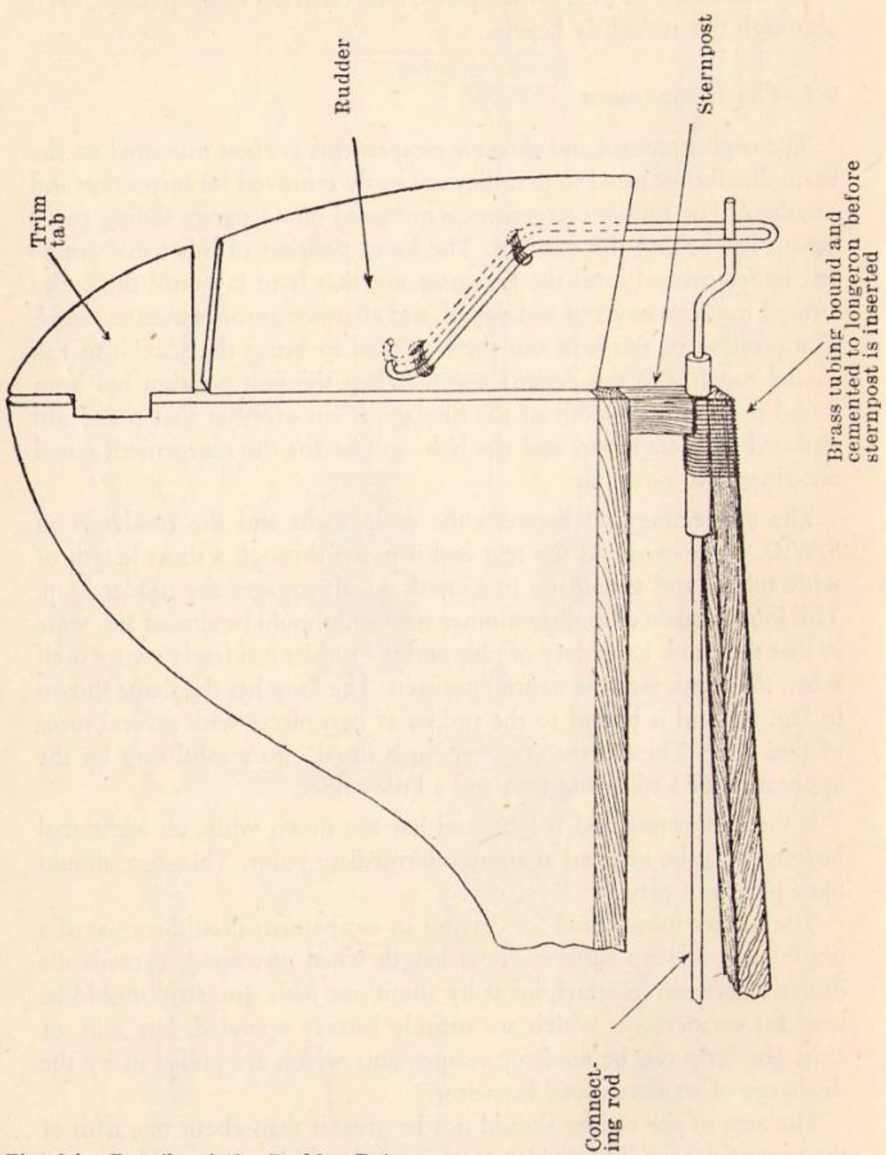


Fig. 6.4. *Details of the Rudder Drive.*

The best position for an escapement which is to operate the *ailerons* is in the wing root. Details are given in Fig. 6.5. The rubber motor passes through the open cabin top and is attached to the bottom of the fuselage. The escapement spindle carries a crank and this engages a wire loop which is pivoted at its root and is attached to two arms. From these arms two cables run to the horns at the end of the aileron shafts. The aileron shafts are made of 14 S.W.G. piano-wire and run external to the wing, just behind the trailing edge. The bearings for these shafts (which should have plenty of play) are bent from aluminium strip. The ailerons are bound to the aileron shafts by rings of fuse wire which are made rigid by the application of a soldering iron. At these points the shafts should be tinned first.

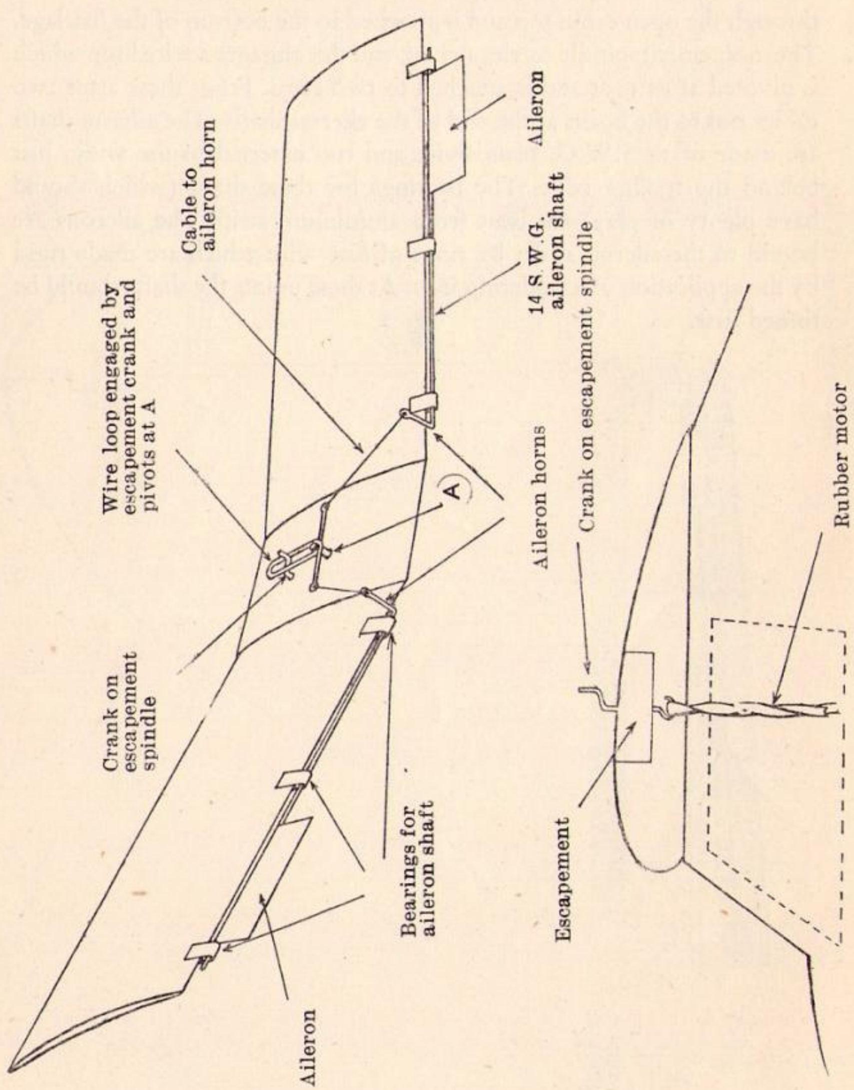


Fig. 6.5 *Details of escapement-operated ailerons.*

CHAPTER 7

HINTS AND PRACTICAL INSTRUCTIONS

7.1. Soldering

The best tool for soldering electrical connections is undoubtedly a small soldering pencil. This operates from a 6 volt or 12 volt transformer or from a car battery. It has therefore the advantage that it can be used on the field. But even apart from this it is an asset on account of its small size, easy manipulation and quick heating. However, it will not do for some of the larger mechanical jobs, such as those involved in building up an undercarriage. This requires a heavier iron with a larger 'bit' and a greater heat reserve.

The most common mistake the beginner is apt to make is that he fails to get the solder really to fuse with the two surfaces which have to be joined. And unless the solder really does combine with these surfaces the joint is, of course, quite useless. In fact, it is worse than useless, for it may give the appearance for a time of really holding the surfaces together —and then suddenly at a critical moment they part company or break the electrical contact. This is called a 'dry' joint.

Fig. 7.1 shows how to distinguish between a case in which the solder has 'taken', i.e. has combined with the surface of the metal, and a case in which it has not. In the first case (on the left) the solder has run along the surface of the metal; it has drawn itself out and spread along it. In the second case (on the right) the solder has not run along the surface; it has remained in convex blobs and has not taken to the metal.

If the solder does not 'take' this means that the surface of the metal was dirty or greasy, or that an oxide formed, or that the heat was insufficient. If two surfaces are to be soldered together they should therefore be sanded first or treated with a wire brush. This should be done even if they look clean, for they may still have a thin film of grease on them.

To prevent the formation of an oxide, flux must be applied to the surface of the metal before it is soldered. A vigorous movement of the soldering iron also helps in this respect.

The correct method for soldering two metal surfaces together is to give each a thin coating of solder first, making quite sure that the solder has 'taken'. This is known as 'tinning'. The two surfaces are then put together and the two coats of solder are welded together by applying the hot iron.

The soldering tags and terminals of standard radio components, and the standard radio connecting wire, already have a coating of tin so that they can be joined together straight away. Comparatively little flux is required for these electrical connections so that it is sufficient to use 'cored solder' (which is hollow and contains small quantities of resin or flux). But these terminals and tags are often covered with a thin layer of wax or grease and may have to be scraped a bit with the soldering iron before the solder will 'take'.

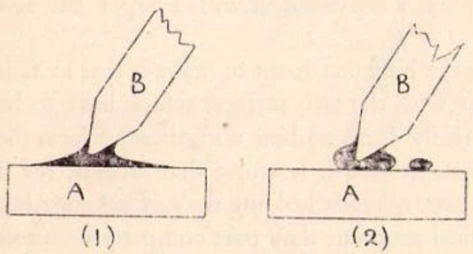


Fig. 7.1. (1) *The solder has 'taken'.*
(2) *The solder has not 'taken'.*

Solder will not combine with a metal surface unless the latter has reached the right temperature. If we have to deal with a large piece of metal or one which is a particularly good conductor of heat, such as brass or copper, this point may never be reached unless we have a large soldering iron capable of storing a sufficient quantity of heat.

The beginner often fails to bring his metal surfaces to the required temperature by overlooking one or two elementary precautions. In the first place, the heat of the iron must have some means of getting across to the metal to be soldered. Merely holding the bit of the soldering iron against that part may be no good at all, because the thin layer of oxide which forms over the bit is a bad conductor of heat and also because the area of contact may be too small, so that the heat disperses as quickly as it enters. The bit, therefore, should be kept well tinned and when it is held against the part to be soldered a bridge of solder should be built up at once at that point so that the heat can flow freely across.

Secondly, one should guard against avoidable loss of heat. For instance, in certain cases one should not hold the part to be soldered in a vice or pliers without interposing two pieces of cardboard or other form of heat insulation.

Remember that solder has very little mechanical strength. It should never be used as the sole means of joining two members which are subject to mechanical stresses. If there is mechanical stress and screws cannot be used, e.g. when joining to U/C struts, give each part a coating of solder, bind them together with closely wound fuse wire, or tinned copper wire of a thicker gauge, and then apply the soldering iron once more to fuse the assembly into a rigid whole.

Finally, a word of warning: a single 'dry' joint can spoil the transmission or the reception of your signals!

7.2. Wiring a Circuit

In wiring up a radio circuit the beginner should learn straight away to go by the theoretical circuit and should not have to rely on plans which show him the actual layout of the connecting wires.

The main thing to remember is that the circuit diagram leaves us a certain freedom of choice in the layout of the connecting wires, and we must exercise this choice wisely. Take, for instance, the circuit of Fig. 7.2 and let A, B, C and D denote the soldering tag of the coil, the variable capacitor, the resistor and the valve filament respectively. Now the theoretical diagram leaves us entirely free as to the order in which we are going to join these four soldering tags. You may connect A with B, B with C, C with D; or A with D, B with D, C with D; or any other combination. Which of these are you to choose? The general rule is that you should try to make your connections as short as possible, and that you should try in particular to make the connections of tuning circuits and grid circuits as short as possible. Also, take your connections to their destination along the shortest route.

Battery leads inevitably have to have a certain length. To prevent undue radiation from these leads, twist each 'minus' lead together with the corresponding 'plus' lead. Also twist together the connecting wires going out to remote escapements or actuators.

The two most important rules to be observed in wiring up the radio equipment have already been given at the beginning of Chapter 6. Thin and yet strong P.V.C. covered single-stranded flex for these flexible connections is obtainable from most radio dealers.

The plastic insulation of flex is easily removed with the hot soldering iron. To diminish the risk of short circuits, take care not to remove more insulation than necessary for making the joint.

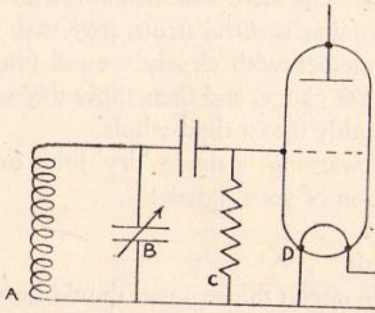


Fig. 7.2.

For rigid connections use tinned copper wire of 20-22 S.W.G. and insulate this by suitably cut lengths of the special sleeving which radio dealers sell for this purpose.

Remember that solder serves primarily to ensure electrical continuity. It has very little mechanical strength. It is a mistake, therefore, simply to lay a connecting wire against a soldering tag and then to solder it on. The wire should be secured mechanically first, e.g. by hooking it firmly round the tag or by passing it through the small hole in the tag. Similarly, if two wires are to be soldered together they should be twisted together first.

For very delicate wires, e.g. the lead-out wires of coils, bicycle valve tubing is a better sleeving than the commercial radio sleeving.

To make quite sure that no connection is being overlooked when you are wiring up a circuit from a theoretical diagram, draw out the diagram

in *ink* and cross off with a *pencil* each connection as soon as you have completed it.

To solder the connections to miniature plugs requires a special technique. Proceed as follows: Take the cap of the plug and hold the plug in a vice, pins horizontal. Remove about ⅜in. of insulation from the flex and push the bare end through the respective pin of the plug and the wire itself protrudes from the front end of the pin. Now apply the hot iron to this protruding end of the wire and feed it with solder. The solder will then gradually run along the wire end and run into the pin of the plug. Hold on for a few seconds so that the pin has time to heat up. Then remove the iron, let the solder cool and cut off the protruding wire. (cf. Fig. 7.3.)

Don't forget to push the wire through the cap before you solder it to the plug!

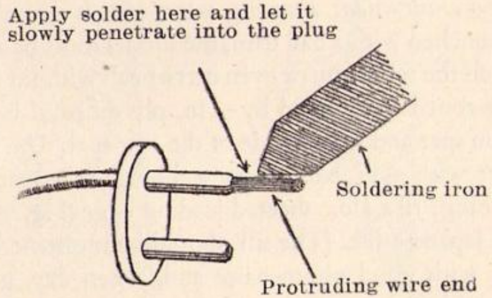


Fig. 7.3. *How to solder a miniature plug.*

7.3. Airframe Design and Construction

The general principles of model aircraft design fall outside the scope of this book, but all the same there are a *few* points which may save the reader much disappointment.

As in all R/C equipment, the keynote must be simplicity, reliability and strength. Only by keeping everything as simple and as straightforward as possible can the chances of failure be sufficiently minimised to give real satisfaction.

A simple, strong and stable high-wing cabin layout is the best choice. The model should be fast flying to give good penetration against adverse winds, and yet slow climbing. The combination is that of a really powerful engine and a fairly high wing loading.

The model should be designed to have a long life and to give reliable service so that the modeller can concentrate on his radio equipment. It must be able to take without damage the knocks of bad landings, cartwheels and minor crashes.

All this is perfectly possible if a number of points are kept in mind.

(a) Choose your model neither too large nor too small: not too large for simple balsa construction, nor too small to absorb the stresses due to the heavy payload in a crash landing.

In the author's personal experience it is a mistake to go much below 5ft. wingspan or above 6ft. Chord should be 15-16% of wingspan; wingloading about 15ozs per sq. ft. wing area; tailplane area about 27%-30% of wing area; fin, 10% of wing area. Dihedral: 10 degrees.

(b) *Wing construction:* a strong wing-root is desirable. If caught in a gust, or launched with a bad trim, the model must be able to touch down violently on the wing-tip, or even cartwheel, without sustaining damage. The wing-root is reinforced by $\frac{1}{16}$in. ply dihedral braces on both sides of the main spar and on one side of the rear spar. The two main spars are $\frac{1}{4}$in. square with $\frac{1}{16}$in. balsa sheet webbing; rear spars $\frac{3}{16}$in. square also with webbing; ribs $\frac{1}{8}$in.; sheeted leading edge (Fig. 7.4a). The covering should be Japanese silk. (The silk should be moistened with a damp rag, pasted on with good photo-paste and, when dry, given two coats of extra strong dope.)

(c) *Wing mounting:* it is important that the wing should be able to sheer off in a crash landing without causing damage to the fuselage. At the same time it must be possible to locate the wing accurately on the fuselage. The author's models have a one-piece wing held on top of the cabin by rubber bands and located by means of a small locating block which is pinned to the wing platform by two matchsticks. In a crash the matchsticks shear off and the wing can shift freely without causing damage (Fig. 7.4b). A choice of three locating blocks is available, giving three alternative wing positions.

(d) *Fuselage:* design the position of your spars, spacers, longerons, etc. in such a manner that they will absorb not so much the stresses of normal landings as those of abnormal landings (cf. Fig. 7.6). The nose of the fuselage suffers the heaviest blows and very special consideration, there-

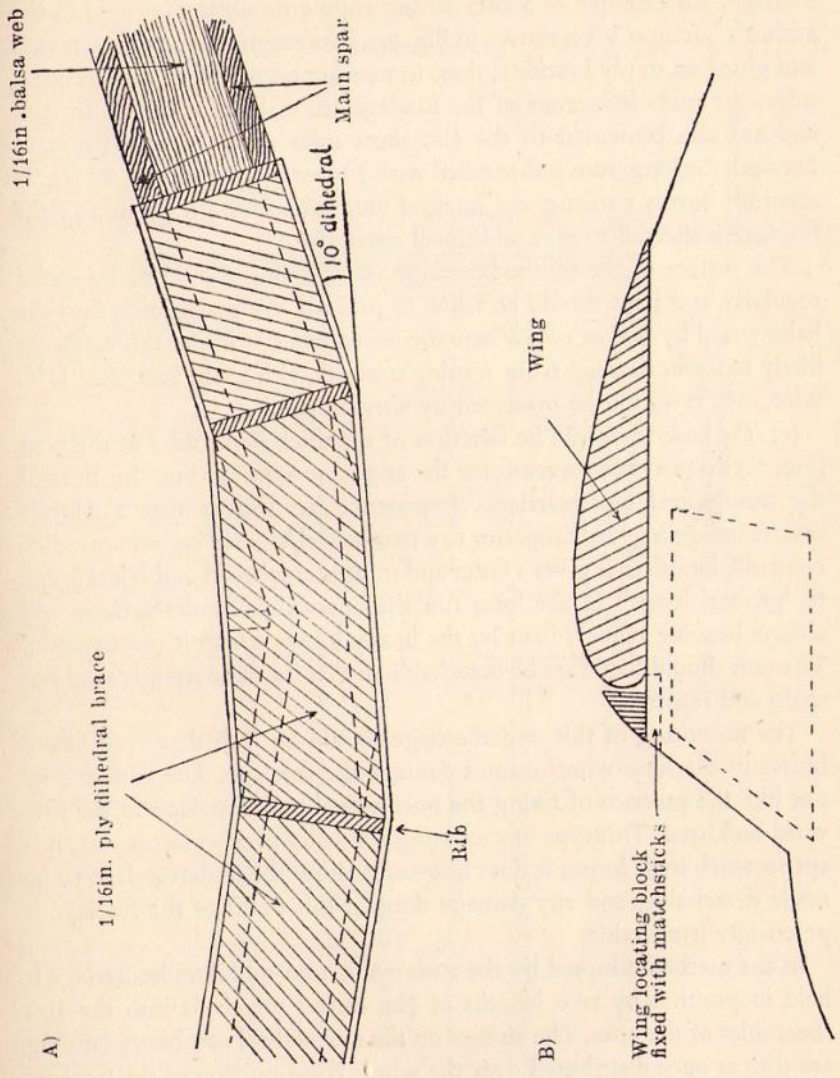


Fig. 7.4 *Details of wing root and wing locating.*

fore, must be given to the mounting of the engine unit and of the undercarriage. An example of a very strong engine mounting (as used in the author's 'Dragon V') is shown in Fig. 7.5. The engine bearers are screwed and glued on to ply brackets; these in turn are cemented to the ½in. sheet sides; the main longerons of the fuselage are of balsa strip ½in. by ¼in. and are also cemented to the ½in. sheet sides of the nose. The space between the longerons is then filled with ¼in. scrap balsa sheet. The whole assembly forms a strong and integral unit. The forward portion of the fuselage is sheeted to give additional strength.

The surface of the finished fuselage and cowling should be inspected regularly and steps should be taken to prevent any penetration into the balsa wood by fuel or oil. Where the protective coating of this surface is likely to suffer damage from routine contacts with tools, fuel cans, U/C wire, etc., it should be protected by a nylon patch.

(e) *The undercarriage.* The function of the thick (½in.) sides of the nose (Fig. 7.5) is not only to reinforce the engine mounting, but also to hold the nose-wheel undercarriage. Experience has shown that a tricycle undercarriage is greatly superior to a two-wheel/tailskid layout for radio-controlled models. It gives a faster and straighter take-off and is less prone to 'ground loops'. In the long run the nose-wheel undercarriage will always become slightly bent by the heavy blows which it must sustain. The unit should therefore be detachable so that it can be straightened out again and repaired.

The mounting of this undercarriage should be such that even heavy blows to the nose-wheel cannot damage the fuselage. The author does not like the practice of fixing the nose-wheel undercarriage to the forward bulkhead. This type of mounting is usually pretty inaccessible; it is apt to work itself loose; it does not easily allow the undercarriage to be made detachable, and any damage done at this point of the fuselage is practically irreparable.

In the method adopted by the author the nose-wheel undercarriage is held in position by two lengths of ⅜in. dowel which fit into the ½in. sheet sides of the nose. The stresses on the nose-wheel of a heavy landing are thus at once distributed over the whole front portion of the fuselage by two large balsa sheets of ½in. thickness. This is a very strong arrangement, almost impossible to damage. The nose-wheel undercarriage is removed simply by pulling out the two dowels (Fig. 7.8). The holes for the dowels must, of course, be fuel-proofed.

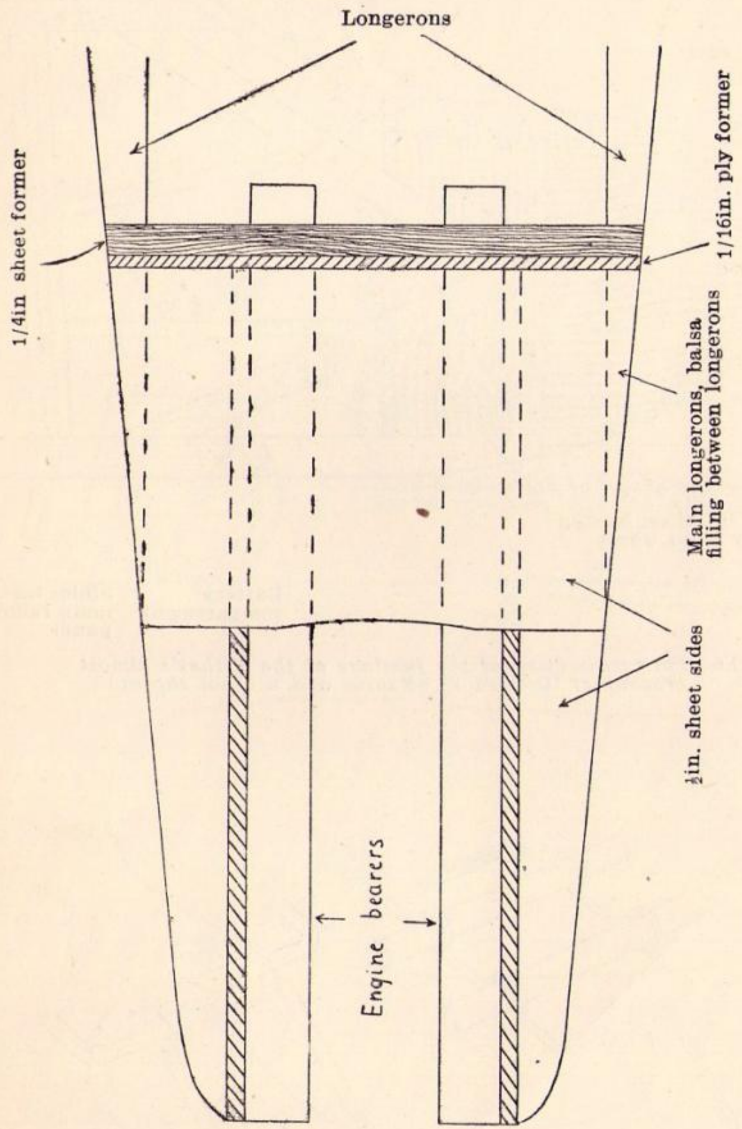


Fig. 7.5. *Plan view of the engine mounting in the author's 'Dragon V'*

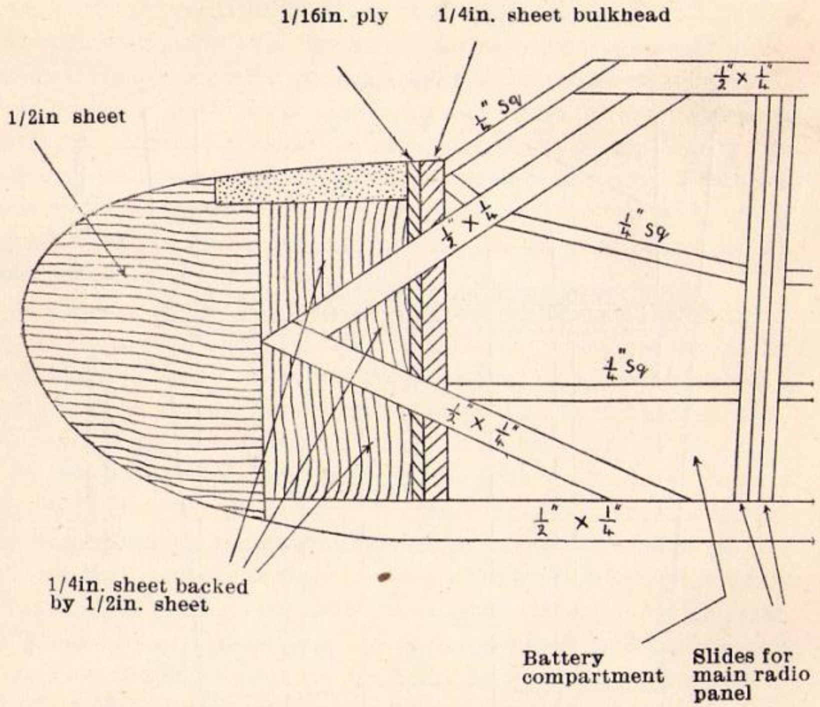


Fig. 7.6. *Forward section of the fuselage of the author's almost crashproof 'Dragon V'. (Engine and u/c not shown.)*

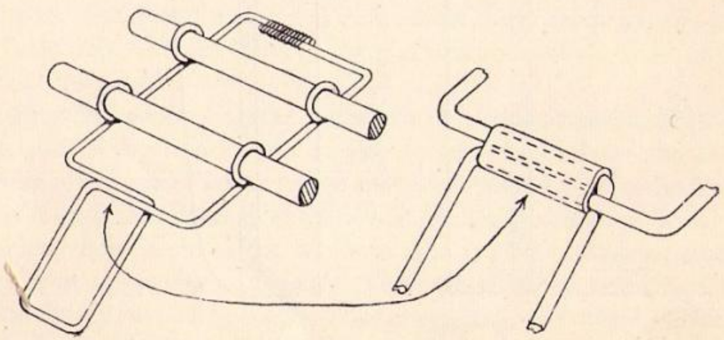


Fig. 7.7. *Torsion Bars.*

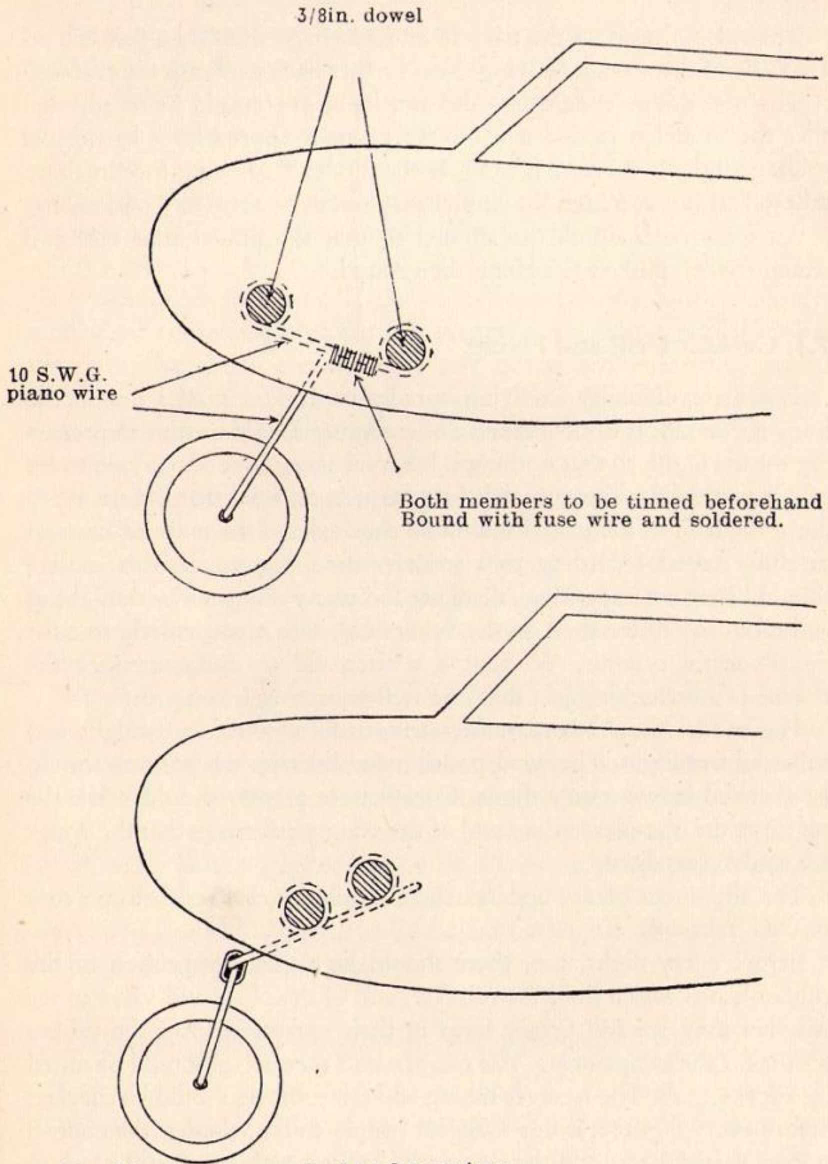


Fig. 7.8. *Strong nosewheel undercarriages.*

Torsion bars may be used in this system for springing the nose-wheel (Fig. 7.7).

The main wheels of the tricycle undercarriage should be just behind the C.G. of the model. Moving them further back prolongs the take-off.

The nose-wheel should be solid and its height should be so adjusted that the model is nose-down on the ground, approaching its normal gliding angle. If the nose is too low the model may zoom too much on take-off; if it is too high the model may bounce excessively on landing.

All the wheels should be aligned so that the model runs true and straight when pushed fast along the ground.

7.4. Cockpit Drill and Flying

The main difficulty in flying a radio-controlled model lies in the human element. It is the difficulty of accepting a rigid routine in preparing for the flight, so that nothing is left to chance. That is to say, in order to get successful radio-controlled flights it is essential that before every flight the trim of the model should be checked and the radio equipment carefully tested according to a strict routine. Moreover, this routine should be set out in writing: there are too many things to be thought of and too many distractions on the flying field. This is particularly true for multi-control systems. Without a written aid to one's memory the chance of overlooking just that one switch or plug is too great.

The model should be carefully trimmed for a stable, straight and balanced free flight. The wing position and the trim tab position should be checked before every flight. Conspicuous arrows should mark the centre of the one-piece wings and of the wing platform so that the wings are easily centralised.

The alignment of the undercarriage should be checked before every R.O.G. take-off.

Before every flight, too, there should be a quick inspection of the rubber bands which hold the receiver, and of the plugs and valve to see whether they are still firmly fixed in their sockets; also of the rubber motor for the escapements. The escapements themselves should be tested by a few signals. The receiver tuning and relay setting should be checked before every flight; it is not sufficient simply to try whether the control system works, because if the receiver is badly tuned it may still work in the neighbourhood of the transmitter, although it would break down

at a greater distance. For accurate tuning the model should be at least 30 yards from the transmitter.

The engine should be allowed to warm up before it is given its final adjustment and the model sent off. During that time a few transmitter signals should be given to test the controls once more, but this time subject to the influence of engine vibrations.

The exact routine of testing and checking before a flight differs according to the type of model and control system used, but even in the simplest models and systems there is plenty to check.

It is a mistake to feel that an elaborate checking routine before a flight is a confession of weakness. The necessity for following such a routine is simply the consequence of the fact that the small flying model cannot afford the weight of the elaborate test meters and instrument panels which are built into full-scale aircraft. There is nothing, therefore, absurd about it; and if the routine is carried out according to a fixed and printed schedule, it requires but little time.

To assist in the checking the author makes liberal use of 'decals', i.e. of small labels with instructions. These are cemented on to the control box, transmitter, or model as required. 'Switch off', 'Rudder travel: ½ inch', 'Set rudder for left turn', 'Check air-feed before starting', etc. All these little things help. Every decal is covered with a thin sheet of celluloid for protection.

When the electrical equipment has been checked and the model is trimmed as for free flight, the time has come for the first short test flights. Make these flights very short ones, either by using your radio-controlled cut-out, or by employing an ordinary timer, or by using merely a short length of neoprene tubing as fuel tank. During these first short test flights try no more than a quarter turn *to the left* by radio control. Make the necessary adjustments to flight trim, rudder travel, etc. Then, when everything is satisfactory, gradually extend the length of your flights and the range of your manoeuvres.

7.5. A simple Field Strength and Wave Meter

The purpose of this instrument is to check the radiation of our transmitter and to compare the relative strength of different transmitters. It is also a means for finding the optimum aerial length, aerial coil coupling, etc. To obtain a reliable comparison between two meter readings the two readings should be taken under identical circumstances so far as concerns the distance of the meter from the aerial, the position along it,

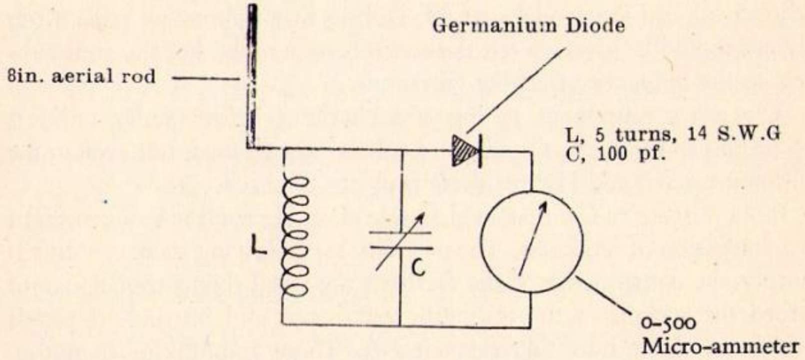


Fig. 7.9. *Circuit of simple Field Strength Meter.*

the relative position of adjacent structures, batteries, earth, etc.

The circuit is that of a simple Xtal receiver coupled to a microammeter (Fig. 7.9). The Xtal unit is a Germanium Diode. The coil has five turns of 14 S.W.G. enamelled copper wire, 1¼ins. in diameter. It is self-supporting and has a length of 1 inch. The aerial is an upright metal rod, 8ins. in length, mounted beside the coil.

The whole unit is built up on a small sheet of paxolin.

Comparatively cheap microammeters with a scale of 0–500 micro-amps are obtainable on the surplus market. These are very suitable for this instrument.

The variable capacitor C has 100 pf and is used to tune the field strength meter until the optimum meter reading is obtained. If the wave meter is to be used for accurate frequency checks of the type required by the G.P.O. regulations, the capacitor C should be replaced by a trimmer capacitor which is shunted by a small air-spaced variable capacitor of (say) 10 pf. The trimmer is set to the correct value and then sealed. The air-spaced capacitor is fitted with a dial and calibrated to show the correct frequency band. The coil in this case must be wound onto, and bonded to, a former; and the whole unit should be placed in a metal case. The aerial rod is mounted on stand-off insulators.