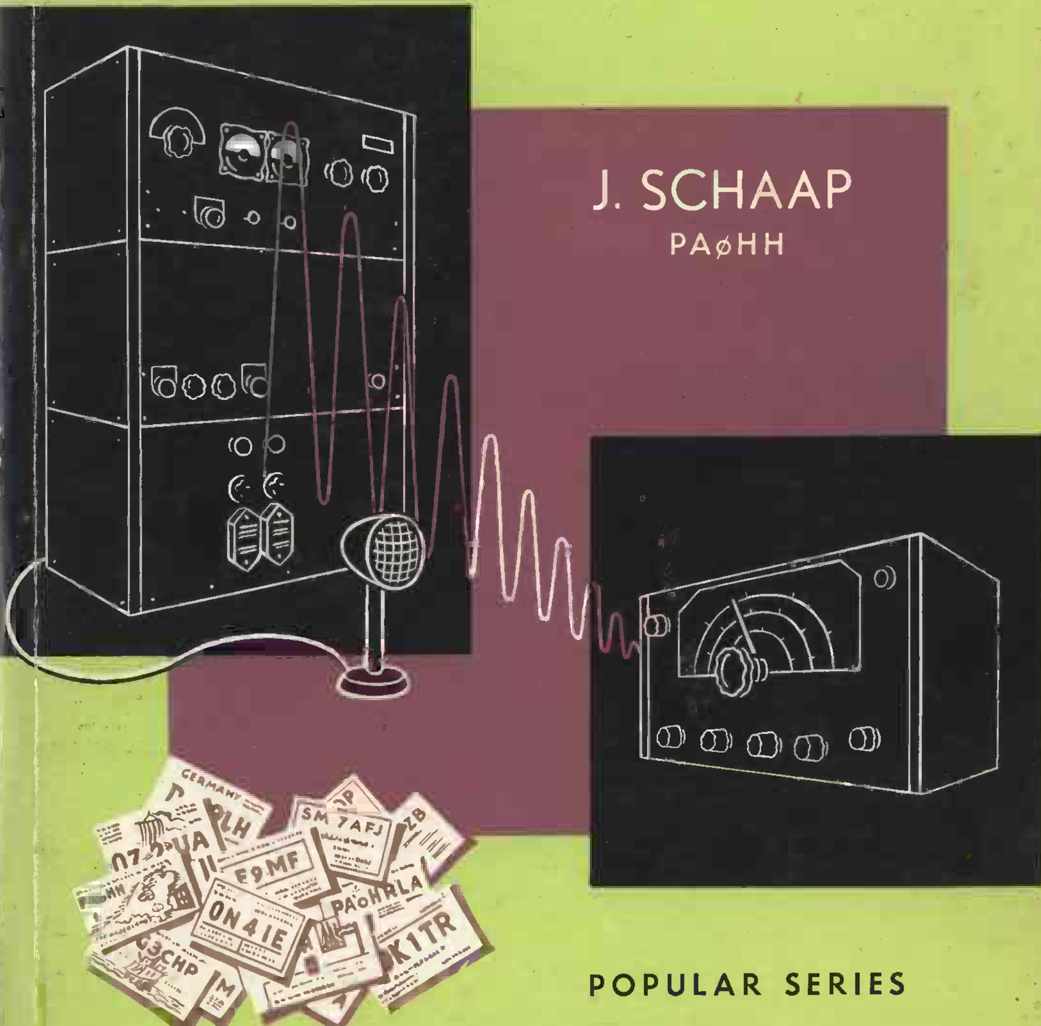
SHORT WAVE AMATEUR RADIO



J. SCHAAP
PAØHH

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PREFACE

This book is intended primarily as a guide for those radio amateurs who wish to specialize in short wave transmissions. It tells the beginner what these amateur transmissions entail and what he has to know to be able to practise this hobby successfully.

It should be emphasized, however, that this book is not to be considered as a training course for the radio amateur, as there already exist many facilities for acquiring the theoretical knowledge required to pass the examination for a transmitting licence. The national amateur radio organisations have teaching and correspondence courses for this purpose and these in themselves already exceed the scope of this book.

Neither is it claimed that this book is an extensive practical manual. For that purpose such books as the Handbook published annually by the A.R.R.L. (American Radio Relay League) and consisting of about 500 pages of text, circuit diagrams and photographs, give a much greater variety of subjects of interest to the radio amateur. The experienced amateur will nearly always find something which fits in with his own plans and ideas. The newcomer to amateur radio, however, often finds it very difficult to make a good choice from such a handbook, for he may lack the experience required to convert, for instance, the published circuits using unfamiliar American valves and components into similar circuits which can use valves and other components readily available in other parts of the world.

The author's aim has been to present the newcomer with a concise reference book which will introduce him to amateur radio; he has not attempted to give a complete treatment of the subject.

U.H.F. work has therefore been deliberately omitted, because in the view of the author this requires special knowledge which can only be acquired after extensive practical experience with the more commonly short waves. The same applies to mobile equipment, single sideband modulation, etc.

The applications of transistors have also been omitted, although some amateurs are already using them in various circuits, such as microphone amplifiers. More general application of transistors is not likely to occur until a sufficient number of suitable types are available at a reasonable price. Only then can a practical circuit design technique develop and its inclusion in a manual of this kind be justified. However we would advise every serious amateur to keep in step with all the latest developments in short wave amateur radio by means of the periodicals published by the various national associations.

As far as the contents of this book are concerned, the first chapter gives the history of radio and in particular of amateur radio and describes current activities in this sphere.

This is followed by several chapters dealing with circuits and components and the design of receivers, transmitters, measuring equipment etc.

Finally there are several chapters dealing with the more practical aspects of amateur radio work, such as station planning and building, procedure, receiver and transmitter circuits and several appendices containing practical data useful to the amateur.

If short wave amateur radio has been presented in such a way that the reader becomes an enthusiastic amateur himself, the object of this book will have been achieved.

J. SCHAAP

September 1963

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CHAPTER 1

WHAT IS AMATEUR RADIO?

At the start of this book which, as already explained, is intended as a manual for those radio amateurs who wish to work with short waves, we would like to explain what amateur radio really implies, why it is so fascinating and why it gives so much pleasure and relaxation to those practising it.

Amateur radio being as old as radio technique itself, we begin by giving a short summary of the history of the development of radio.

After the German physicist Heinrich Hertz confirmed the theories of Thomson and Maxwell by means of his brilliant experiments during 1880-1887 and the Italian engineer Guglielmo Marconi, on his father's estate, carried out in 1895 the first practical experiments on transmitting Morse signals without the aid of connecting wires, and succeeded in bridging a distance of about $1^1/_2$ miles, "radio" suddenly became the object of intense public interest. It occurred to Marconi that the distance between transmitter and receiver might be greatly increased by using an aerial. In 1897 the first Marconi station was set up on the Isle of Wight, contacting with the coast of the mainland across a distance of about 16 miles. In 1899 Marconi achieved communication between England and France by bridging the English Channel and in 1901 the first signals were transmitted across the Atlantic Ocean when the station at Poldhu (Cornwall, England) was heard across a distance of about 1750 miles in Newfoundland.

All these communications were achieved with "spark" transmitters. However, the way to the appearance of the thermionic valve had already been opened when in 1883 the world-famous inventor Thomas Alva Edison made certain observations, later to be known as the "Edison-effect", on an incandescent lamp. Fleming studied the first diode in 1904 and in 1907 De Forest constructed his triode with which Meissner built the first oscillator in 1913. These inventions revolutionised the radio techniques then in existence.

The first radio amateurs appeared about 1910. At that time they had to build their own receivers based on the very scarce information available, using them to listen to news and weather forecasts broadcast by a number of official stations for press and official services (e.g. the Eiffel tower in Paris on a wavelength of 2500 metres). The enthusiasm with which the pioneers discovered new and ever better circuits for improving the reception fascinated the younger generation and led finally to the formation of a group of radio amateurs. The first amateur organisation, the A.R.R.L. (American Radio Relay League) was founded in 1914. At this time, however, amateur radio was forbidden in most European countries for security reasons, because of the outbreak of World War I. Nevertheless, forbidden fruit is sweet, and not all amateur activities could be stopped.

The real development of amateur radio began after the amateurs had been relegated to wavelengths below about 300 metres designated as "short waves" and at that time considered to be unsuitable for communication over very great distances. American amateurs then discovered the possibility of bridging greater distances on these "short waves". As early as 1919, the A.R.R.L. organised the first transatlantic tests on wavelengths below 200 metres. The first American amateur radio stations were heard in Europe during the winter of 1921/22 and afterwards European stations were also heard in America. Thus, two-way communication across the Atlantic Ocean seemed to be possible. Yet, we had to wait until the 27th November, 1923 before Fred Schnell (1 MO) in America and Leon Deloy (8 AB) in France established communication on about 110 metres. A distance of 3100 miles had been bridged and we stood on the threshold of a change in radio technique resulting from the rapidly growing interest in short waves. It was not long before communication between America and other European countries was established; so, on 8 December of that year, 1 MO communicated with the English station 2 KF and then, on 12 December, with the Englishman 2 SH. On 16 December the Canadian station 1 BQ worked with the Englishman 2 OD and during the night from 26 to 27 December the station PCII at Leyden, Holland, worked for several hours with the American station 2 AGB at Summit, N.J.

The initial transatlantic contact was followed by an ever increasing

number of DX (= long distance) - contacts. In October, 1924 communication was established between Britain and New Zealand, thus practically spanning the whole globe.

The great successes achieved by radio amateurs on the short waves aroused an intensive commercial interest in this range of wavelengths, so that amateurs soon found themselves threatened on their own hunting ground. They resorted to ever shorter wavelengths and very quickly established that wavelengths below 6—7 metres were useless for DX purposes. (It was not discovered until much later that long distance communication is possible on these wavelengths under certain conditions). To promote the interests of radio amateurs in the international sphere, the I.A.R.U. (International Amateur Radio Union) was founded in Paris in 1925. The International Radio Conference held in Washington in 1927 allocated officially recognized bands to amateurs. Although they were greatly reduced in subsequent years, they still represent the most important part of the amateur working space to-day in spite of the ever increasing importance of the newly allocated bands in the ultra short waves.

To give an idea of the manner in which a transmitting amateur practises his hobby, let us visit a so-called "ham shack". We greet the amateur with the customary "old man" and on hearing the purpose of our visit, he immediately invites us to follow him into his sanctum. When we enter his shack, our attention is at once drawn to a number of pieces of equipment studded with knobs, metres, switches, wires, etc. There we see a large metal rack in which the equipment is housed. Such racks have the advantage of having standard dimensions and greatly simplify the changing over or the conversion of equipment. The top panel, the one with the meters and knobs, is probably the actual transmitter which produces and amplifies the r.f. signal. We see a calibrated dial by means of which the operating frequency is adjusted. The meters indicate the currents to the valves and serve at the same time to check the transmitter setting. At the side we see a separate panel for coupling the transmitter to the aerial. Yes, the aerial with associated matching is indeed a very important piece of equipment on which much depends. A low-power transmitter combined with a good aerial and correctly matched is much better than a high-power transmitter with something that serves as an aerial, but is completely unsuitable for this purpose. Below the transmitting panel we see the modulator. How do we know this? By the cable which connects it to the microphone there on the table. The modulator amplifies the vibrations of the microphone and passes them to the transmitter. The lower panels on the rack contain the supply units and switches. The supply unit converts the mains voltage into the type and value of voltage required for the transmitter and the modulator. The switching panel contains the switches needed to put the equipment into operation and also the necessary fuses in case a short-circuit should develop in the equipment.

Yes, that equipment on the table is the receiver. We can recognise it immediately from the large dial and the S-meter for reading the strength of incoming signals. In addition to the microphone, a transmitting key is mounted on the table; for communication may be achieved in two ways: telephony (i.e. transmission of speech by way of the microphone or of music by way of the microphone, record player or tape recorder) and telegraphy (transmission of messages in the form of morse signals).

We do not employ telephony only. This would, of course, be by far the simplest way, because we can speak to each other without difficulty and recognize each other's voices. However, this method of transmission requires a much more complicated installation than that for telegraphy, apart from the fact that with a transmitter of given power, telegraphy permits of much greater distances being covered than telephony. Besides, it is fascinating to pick out one certain signal from among many and to follow and read it. In this case, too, it is possible to recognize a station by its tone or by the manner of keying before its call sign is received.

Each transmitter has a call sign which is repeated several times during each transmitting period. It consists of one or more letters indicating the country of origin of the transmitter, followed by a figure which sometimes indicates a certain district in that country and by a group of two or three letters identifying the station itself.

Of course it is not all that easy to learn the Morse code properly. And yet this is absolutely essential in order to obtain a licence. The examination which will have to be passed to this effect is not so very difficult, but a certain amount of skill and knowledge is required before you can be "let loose" in the ether with good results.

We look further round the shack. There are many QSL-cards on the wall. These cards are exchanged after a QSO has been made, in order to

confirm the communication and the conditions under which it took place. We see cards from many countries and it is very interesting to learn the achievements of this station from them.

We notice several meters on the shelf over there. That meter, for instance, is the wavemeter to check the wavelength (or frequency) of the transmitter and is also suitable for monitoring the modulation quality. The other one is the grid-dip oscillator by means of which many valuable measurements can be carried out. Also, there is a universal meter suitable for measuring a great variety of currents and voltages. Good measuring equipment is really an essential for the experimentally-minded amateur.

We leave the shack with a "good-bye, old man" and on our way home we are already beginning to make plans for building our own transmitter. But don't forget, a licence is required first!

It is better to begin by making or buying a good receiver, constructing the necessary measuring equipment and studying at the same time for the examination. Only then can a start be made with the transmitter. The following chapters will be devoted to what is involved in all this.

CHAPTER 2

COMPONENTS USED IN AMATEUR RADIO EQUIPMENT

Before describing actual receiver circuits, it is desirable to examine the components which are used in an amateur receiver.

Valves

Although all the components are important for the satisfactory operation of a receiver it may be said that valves constitute, in fact, the heart of any receiver.

As there are many books in which radio valves and the circuits in which they are employed are described in detail (e.g. Philips Technical Library) we do not intend to enter further into this subject here and will assume that the newcomer to amateur radio is already quite familiar with this subject.

Resistors

To ensure that valves carry out their appropriate function in receiver circuits, their electrodes should be supplied with the specified voltages and currents. For this purpose a supply section is incorporated in the receiver, and should be capable of supplying all the different voltages and currents to the valves. The exact voltages are usually obtained by means of *resistors* which are inserted in the d.c. circuits. They are distinguished as *fixed resistors,* i.e. those the resistance of which lies within a given tolerance of the value marked on them, and *variable resistors,* mostly in the form of potentiometers, in which a tap can slide along the constant resistance, so that the value between one end of the potentiometer and the tapping is adjustable. Both the fixed and variable resistors may

consist of carbon powder or may be wirewound. The latter, being able to dissipate more energy, are usually suitable for higher wattages. As is generally known, the resistance is expressed in ohms.

Coils and transformers

In its most general form, the coil consists of copper wire wound on a former. The resistance to alternating currents of such a coil is frequently found to be much higher than the ohmic (= direct current) resistance of the copper wire, and depends on the inductance expressed in henrys and the frequency of the alternating current.

Thus: $Z_L = 2\pi fL$, where Z_L = impedance of the coil
f = frequency
L = inductance in henrys.

For example, the d.c. (= direct current) resistance of a coil of several tens of turns on a former of 1 cm diameter, wound with 0.5 mm wire is approx. 0.05 ohms. For an alternating current of a frequency of 50 c/s (mains supply), the impedance is virtually the same as the d.c. resistance, but at a frequency of 10 megacycles per second (= ten million c/s = 10 Mc/s) the impedance will be found to have increased to approx. 150 Ω (Ω is the symbol for ohms), so that this alternating current will experience an apparent resistance of 150 Ω. According to Ohm's Law, the a.c. (= alternating current) voltage across this coil will then be 150 x the current.

The dissipation (i.e. the "d.c. losses") is determined solely by the d.c. resistance (here, 0.05 Ω) and thus remains low.

In addition to the d.c. losses, there are losses due to the magnetic field which forms in and around the coil. The quality of the coil is expressed by the quality factor Q which is the ratio of the a.c. resistance (impedance) of the coil, to its total lossresistance.

$$Q = \frac{2\pi fL}{r} = \frac{Z}{r} \quad \text{where } r = \text{resistance in ohms}$$

The inductance L may be increased by increasing the number of turns and/or the diameter of the former, since L is proportional to the diameter and the square of the number of turns.

$L = F \times n^2 \times D$ where F = the form factor
n = number of turns
D = diameter of the coil.

Another possibility is to provide the coil with an iron core in which it is much easier to set up a magnetic field than with an air core. The number of times by which this is effected more easily is known as the relative permeability. The inductance of the coil, which depends on the magnetic fields, also increases accordingly. For a given inductance fewer turns would therefore be required if an iron core were used instead of an air core, so that there would be fewer losses in the coil. Losses would occur in the iron, however, so that it is purely a question of construction and available material which solution is preferred in a given case. A solid iron core is unsuitable for this purpose and even for low frequencies the core consists of iron laminations which are insulated from each other, in order to reduce the losses due to eddy currents in the core. Eddy current losses in iron increase rapidly with the frequency of the alternating current. For this reason we use powdered iron mixed with a binder of insulating material and pressed into cores, for radio frequency work. The individual iron particles are insulated from each other by the binder, thus ensuring that the losses due to eddy currents are reduced to a minimum. The latest types of coils use ferrites, e.g. Ferroxcube, whereby the core consists of iron oxide processed by a special method to obtain a magnetic material of a very high resistivity. The eddy currents are then suppressed in a highly efficient manner, whilst the permeability can be increased to a very high level.

The iron core in a coil is often used to vary the inductance. The core is then fitted inside the former and is usually provided with a thread to enable it to be moved in and out of the former. The inductance is varied by passing a greater or smaller portion of the magnetic field in the coil through the core. For the above-mentioned reasons, however, the quality of the coil then usually varies at the same time. It will be obvious that the inductance of coils with cores of high permeability (Ferroxcube) can be varied over a considerable range.

We assumed at the start that solid copper wire was used for winding the coils. This is generally true for coils intended for frequencies up to

200 kc/s. At frequencies in the range from 200 kc/s to about 3000 kc/s, the resistance increases considerably due to the "skin effect" which increases with the frequency. To prevent this from happening, coils to be used at these frequencies are wound with "Litz" wire which consists of a number of strands insulated from each other and braided in such a way that each strand passes alternately from the outside to the centre of the wire. This counteracts the skin effect. At frequencies above 3 Mc/s this method is usually no longer satisfactory, unless very expensive Litz wire is used. It is then better to wind the coils with fairly thick solid wire. This is quite within practical possibilities, because the inductances at these high frequencies are much lower and so far fewer turns are required. It should be mentioned however that the frequency range mentioned above is subject to various conditions, e.g. the quality requirements and the coil construction.

If two coils are placed in close proximity to each other, so that the magnetic field induced in one coil passes wholly or partly through the other, these coils are said to be coupled to each other. If an alternating current is passed through one coil, the resulting magnetic field wil induce a voltage in the second coil. The greater the part of the field traversing the second coil, the higher the voltage induced in this (tighter coupling). Thus we have been provided with a means of converting (transforming) a high a.c. voltage into a low one or a low a.c. voltage into a high one, depending on the degree of coupling and the number of turns of the first (primary) and second (secondary) coils. The combination of the two coils is known as a transformer. In the case of transformers for use in low frequency circuits, e.g. H.T. (= high tension) or loudspeaker transformers, the core consists of iron laminations, whereas for use in radio frequency circuits, the core consists of air or r.f. (= radio frequency, high frequency) iron.

Capacitors

In its simplest form, a capacitor consists of two metal plates separated by an insulating material. The current will be unable to pass through such a capacitor. Yet, the interruption in a circuit formed by a capacitor is different from an ordinary interruption. If we close the switch in

Fig. 1, no current will flow through the circuit, because this is broken at O and meter M will read zero. In Fig. 2, however, if switch S_1 is closed, meter M will deflect momentarily and return to zero. This shows that a current flowed for a brief moment in spite of the presence of capacitor C in the circuit and that a quantity of electricity passed to the capacitor and collected there. The capacitor is then said to be charged.

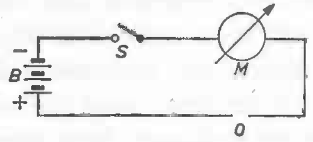


Fig. 1. If S is closed, no current flows, because the circuit is interrupted at O.

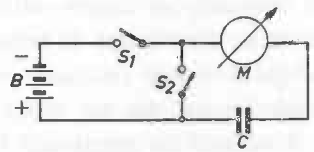


Fig. 2. If S_1 is closed, M deflects momentarily and then returns to zero. If S_1 is subsequently opened and S_2 closed, M deflects in the other direction.

This phenomenon was discovered by chance by professor Musschenbroek of Leyden in 1746 by means of the "Leyden jar" which soon grew to be very popular, many people wanting to have the "pleasure" of experiencing the shock accompanying the discharge. The experiment was also demonstrated at Versailles in the presence of Louis XIV and his Court, where a company of guards consisting of 240 soldiers was even made to form a chain, holding each other's hands. After the jar was charged it was given to the soldier at one end of the chain to hold in his free hand and the soldier on the other end was asked to touch the inner conductor of the jar. The electric shock was felt simultaneously by all of them.

Before long it was discovered that the capacitor, when charged, received a positive charge at the side connected to the positive pole of the battery and a negative charge at the other side. If switch S_2 in Fig. 2 is closed the circuit will be short-circuited via meter M which will be seen to deflect again, but this time in the opposite direction. This indicates that a current flows in the opposite direction, in which case the positive charge must have been neutralised by the negative one.

The capacitance of a capacitor consisting of two plates which are insulated from each other, is obtained from the following expression :

$$C = \frac{0.0884 \times O \times \varepsilon}{d} \text{ pF}$$

where O = effective area of one plate in cm^2
d = thickness of the insulating material in cm
ε = (Greek letter epsilon) relative permittivity of the material between the plates (= dielectric)
C = capacitance in pF (picofarad = 10^{-12} farads)

Various experiments revealed that two capacitors of equal dimensions, but with different dielectrics (of the same thickness) received different charges even if the applied voltage is the same. Since this is characteristic of the material, each material is denoted by a figure, the relative permittivity ε (or dielectric constant) which defines how much more charge the capacitor will hold than the same capacitor with air as dielectric. Consequently, it is seen that the relative permittivity of air : $\varepsilon = 1$.

In practice we encounter capacitors with air as the dielectric (variable capacitors and trimmers), mica capacitors, ceramic capacitors, paper capacitors and electrolytic capacitors. The dielectric of the last-named type may be aluminium oxide which is formed on a strip of aluminium by placing it in boric acid. The actual dielectric thus produced is very thin and permits of fairly small capacitors with very high capacitances to be made. The disadvantage of electrolytics is that they are polar, i.e. that they must always be under a direct voltage which must be applied in one sense only.

If the battery in Fig. 2 is replaced by an a.c. supply source the polarity of which changes continuously, the capacitor, when switch S_1 is closed, will be alternately charged, discharged, recharged (but this time in the reverse direction), discharged again, etc. The meter M reads a constant value in spite of this current alternating continuously. The charging and discharging of the capacitor and the alternating direction of the current in M obviously occur at the frequency of the alternating voltage supply. If for M we take an a.c. meter which reads the average current, the capacitor behaves in the same way as a resistor, but now for alternating current. As with the coil, this is known as the impedance of the capacitor.

$$Z_c = \frac{1}{2\pi f C} \quad \text{where } Z_c = \text{impedance}$$
$$f = \text{frequency}$$
$$C = \text{capacitance in farads.}$$

The tuned circuit

In radio and television receivers we often see a coil and a capacitor connected in parallel, the capacitor constituting the variable component in most cases. Such a circuit represents a very high resistance for a given frequency. If we connect an aerial to one end of the circuit and earth the other end, signals of the tuned frequency energised in the aerial will be present in the circuit as radio-frequency voltages. The resistance of the circuit will be less for the adjacent frequencies (smaller circuit impedance), hence signals of these frequencies energise the aerial proportionally less strongly. The more the frequencies differ from the tuning frequency, the lower the circuit impedance and the smaller the voltages across the circuit (see Fig. 3). The voltages energised in the aerial are channelled off to earth more readily because of the lower inpedance. For frequencies far removed from the tuning frequency the circuit behaves practically as a short-circuit. The more efficiently the voltages of the adjacent frequencies are attenuated, the better the "quality" of the circuit.

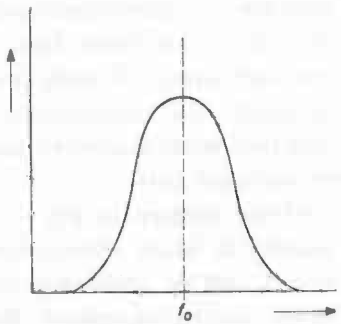


Fig. 3. The voltages across the tuning circuit are smaller according as the difference between the frequency and the tuning frequency f_o is greater.

If the circuit is to be tuned to another frequency in order to receive signals of that particular frequency, it is necessary to change the product of L and C, which determines the tuning frequency. For a given value of L and C, the tuning frequency or resonance frequency f_o is:

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

If the circuit is to be suitable for tuning to any frequency within a certain range some means must be provided for varying either the inductance L or the capacitance C of the circuit. This is normally accomplished by using a variable capacitor. The extent of this variation then determines the extent of the frequency range, whereas the inductance L of the coil determines the actual range to be covered.

Instead of "frequency", the term "wavelength" is often used. The relationship between frequency and wavelength is as follows:

$$\lambda = \frac{300{,}000{,}000}{f}$$

where λ = wavelength in metres
f = frequency in c/s

Band-pass filters

A frequently-used component is the band-pass filter. This consists of two circuits tuned to the same frequency and coupled to each other in such a way that voltages applied to the first circuit are partly transferred to the second one (see also under "coupled coils"). To what extent this takes place depends on the degree of coupling. Various methods of coupling are shown in Fig. 4. The most commonly used type of band-pass filter in the intermediate frequency amplifiers of receivers (see Chapter 3) consists of a high impedance inductive coupling (Fig. 4a). In this the coil of the second circuit is placed in the magnetic field of the first one, so that a voltage is excited in the second circuit of the same frequency as that in the first. Another type is low impedance inductive coupling (Fig. 4b.) where an extra coil is included in both circuits. If, as a result of the applied voltage, a current flows through the circuit (because

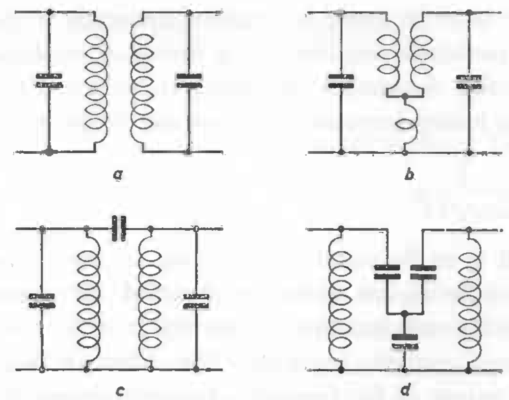


Fig. 4. Coupling methods with band-pass filters

a. inductive coupling
b. common inductance coupling
c. capacitive coupling
d. common capacitance coupling

the circuit is in tune), this current will also flow through the coupling coil, producing a voltage across it. This excites the second tuned circuit to produce a voltage of the same frequency across it. A third method is high-impedance capacitive coupling (Fig. 4c.), where the voltage is transferred via a small capacitor between the primary and secondary circuit. A fourth method is low-impedance capacitive coupling (Fig. 4d.) where the coupling coil in Fig. 4b. is replaced by a coupling capacitor which otherwise has the same function.

As already stated, band-pass filters are often employed in i.f. amplifiers where they are tuned to one fixed frequency. The advantage of band-pass filters is that they greatly improve the sharpness of tuning (selectivity) which is often inadequate in the case of individual circuits. The selectivity may be increased to a very high level by using several band-pass filters. What happens, in fact, is that a given adjacent frequency is attenuated by a certain factor by each circuit, so that the final result is determined by all these attenuation factors together.

Matters become more difficult if continuous band-pass filters have to be used for continuous tuning, because the coupling of all the above-mentioned systems is greatly dependent on the tuning frequency, so that during tuning the voltage transfer to the secondary circuit would vary.

Although some improvement is possible by adopting a combination of coupling methods, band-pass filters for continuous tuning are very difficult to apply in actual practice.

Microphones

The microphone is a very important instrument for the amateur who wishes to transmit on "phone". Many types of microphones have been developed, the following three types being amongst those most frequently used by amateurs.

a. *The Carbon Microphone*

This consists of a vibrating metal plate (diaphragm), usually circular and very thin, placed on a box made of an insulating material and filled with granules of carbon. A metal plate is fixed to the bottom of the box (back of the microphone). This plate forms one connection and the diaphragm the other connection of the microphone which is supplied with d.c. voltage. When the diaphragm is set in vibration by sound waves, the pressure on the carbon granules will vary; the resistance of the contacts between the carbon granules is varied and consequently the current through the microphone will vary in sympathy with the sound waves. If a transformer is included in the circuit, the a.c. voltage produced across the primary will be transferred to the secondary winding. The transformer ratio is usually 1 : 20 to 1 : 100 in the case where the secondary is connected to an audio valve. The voltage delivered by the secondary may amount to several volts. The direct current flowing through the primary should be 50 to 100 mA.

b. *The Crystal Microphone*

This type of microphone is very popular, because it requires no battery or transformer. The output is of the order of 10 mV, depending on the contraction and/or the fidelity required. A crystal of Rochelle salt is clamped in such a way that when vibrated by means of a diaphragm, piezo-electric voltages are produced between the two metallised outer faces of the crystal. These plates are provided with leads. The crystal microphone can be connected directly to the grid of an audio amplifier.

c. *The Dynamic Microphone*

In this type, a small coil is so attached to the diaphragm that it is able to move freely between the poles of a permanent magnet. Sound waves cause the diaphragm to vibrate, thus generating an a.c. voltage in the coil. In this case, too, the output greatly depends on the construction and the required fidelity. Robust models of this microphone are very popular for use with mobile equipment.

In addition to the components described in this chapter, a number of other components and materials used in practice will be discussed with the relevant circuits.

CHAPTER 3

AMATEUR RECEIVERS

3.1 Introduction

By amateur receivers we generally understand those receivers which are suitable for the reception of the amateur frequency bands. Although a great many different types are available commercially (usually British or American types), many amateurs prefer to build their receivers themselves. This is by no means always done for financial reasons, but because it is realized that more experience is gained with home-built receivers, apart from the fact that one can choose a circuit which is within the technical capabilities of the constructor. Moreover, the experienced amateur places a high value on a receiver which conforms to his own special requirements; many commercial receivers (more especially those which are within the financial reach of the average amateur) fall far below these requirements.

To give an idea of the requirements to which a conventional type of amateur receiver should generally conform, it is best to make a comparison with a good quality broadcast receiver. Starting with the audio-frequency section, we may safely assume that broadcast receivers are designed with a view to increasing the fidelity, both of speech and music, to the highest possible degree. To achieve this, the circuit is designed to be capable of undisturbed reproduction of all the frequencies within the audible range, i.e. from about 50 to 20,000 c/s and the output circuit is designed to supply the maximum undistorted power to the loudspeaker(s). With amateur receivers, however, which are intended mainly for the reception of speech and telegraphy signals, the frequency range to be taken into account extends only from, say, 400 to 3000 c/s for speech whilst a narrow band in the neighbourhood of 1000 c/s is to be preferred for telegraphy. The main purpose of an amateur receiver is to be able to understand speech and read morse signals, so that any slight distortion which does not affect the legibility is unimportant. Of the volume and tone controls found on broadcast receivers, the latter is often omitted, because in well-designed circuits the low tones are in any case suppressed. Furthermore, the output stage can usually be made much smaller (less energy required), because it is only required to actuate a small loudspeaker or headphones.

The differences in i.f. amplifiers are often even greater, the frequency range (i.e. frequencies on both sides of the carrier wave) to be amplified again being the determining factor. Whereas in broadcast receivers we encounter bandwidths of up to 10 to 15 kc/s as a compromise between the requirements for high fidelity and adequate selectivity, in amateur receivers the selectivity may be made much higher, because the bandwidth need not be greater than between 4 to 5 kc/s in the case of speech (telephony) and often even less in the case of telegraphy, where the carrier waves in the frequency spectrum may be spaced very close together and a high degree of selectivity is desirable. The choice of i.f. generally between 440 and 480 kc/s in broadcast receivers, is determined by entirely different factors in amateur receivers, where intermediate frequencies of 1.5 to 2 Mc/s are fairly common. For reasons to be explained later, the frequency is sometimes changed twice (first to a relatively high i.f. and then to a low i.f.) by connecting two i.f. amplifiers in cascade.

The radio-frequency section often consists of one or more r.f. amplifiers to improve the noise characteristics or the sensitivity and selectivity of the receiver. The tuning circuits need only be variable over the fairly narrow amateur bands which may therefore be spread out over the whole available dial (bandspreading). This simplifies the tuning procedure to a considerable extent.

Automatic gain control is in common use both in broadcast- and amateur receivers, although the methods adopted may vary widely. The "magic eye" type of tuning indicator frequently encountered in broadcast receivers is, in amateur receivers, usually replaced by a meter indicating the strength of the incoming signal (S-meter).

Amateur receivers sometimes include a number of additional features which may be very useful in amateur operation. The principal features will be described when discussing various circuit arrangements.

3.2 Receivers using a diode

The simplest form of receiver circuit is shown in Fig. 5. The parallel circuit L_1C_1 is tuned to the frequency of the station required. The arrow through C_1 indicates that this is a variable capacitor by means of which the circuit is tuned. The top end of the circuit is connected to the aerial and the bottom to earth. Thus, signals of the tuned frequency produce a voltage of this frequency across the circuit. The top end of the circuit is further connected to the anode of a diode, the cathode of which is connected to earth via capacitor C_2 and parallel resistor R.

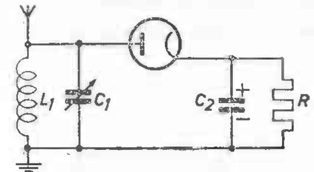


Fig. 5. Circuit diagram of a simple receiver. L_1 and C_1 form the tuning circuit. The detected voltages are produced across C_2 and R.

During the period that the top of the circuit is negative with respect to earth (during the negative half of the cycle), the anode is therefore negative with respect to the cathode and no current will pass through the diode. This is due to the fact that the electrons, although continuing to be emitted by the heated cathode, are now repulsed by the negative anode. When the top end of the circuit becomes positive with respect to earth however, as will occur during the positive half of the cycle, the electrons are attracted by the anode, so that current then flows through the diode. The electrons actually pass from the cathode to the anode, but the current, always being indicated in the opposite direction, is considered as flowing from the anode to the cathode. This current so charges the capacitor C_2 that the earth end is negative and the diode end positive. Without the resistor R, C_2 would be charged to the peak value of the a.c. voltage. The r.f. voltage with a peak value e is shown in Fig. 6*a*. By connecting R in parallel with capacitor C_2, however, this will be able to discharge across it. The rate at which this occurs depends, of course, on their values.

If the incoming signal is modulated with an a.f. tone, the amplitude of the r.f. signal will vary with the frequency of the audio signal (see Fig. 6*b*). The current through the diode, which flows only during the positive halves

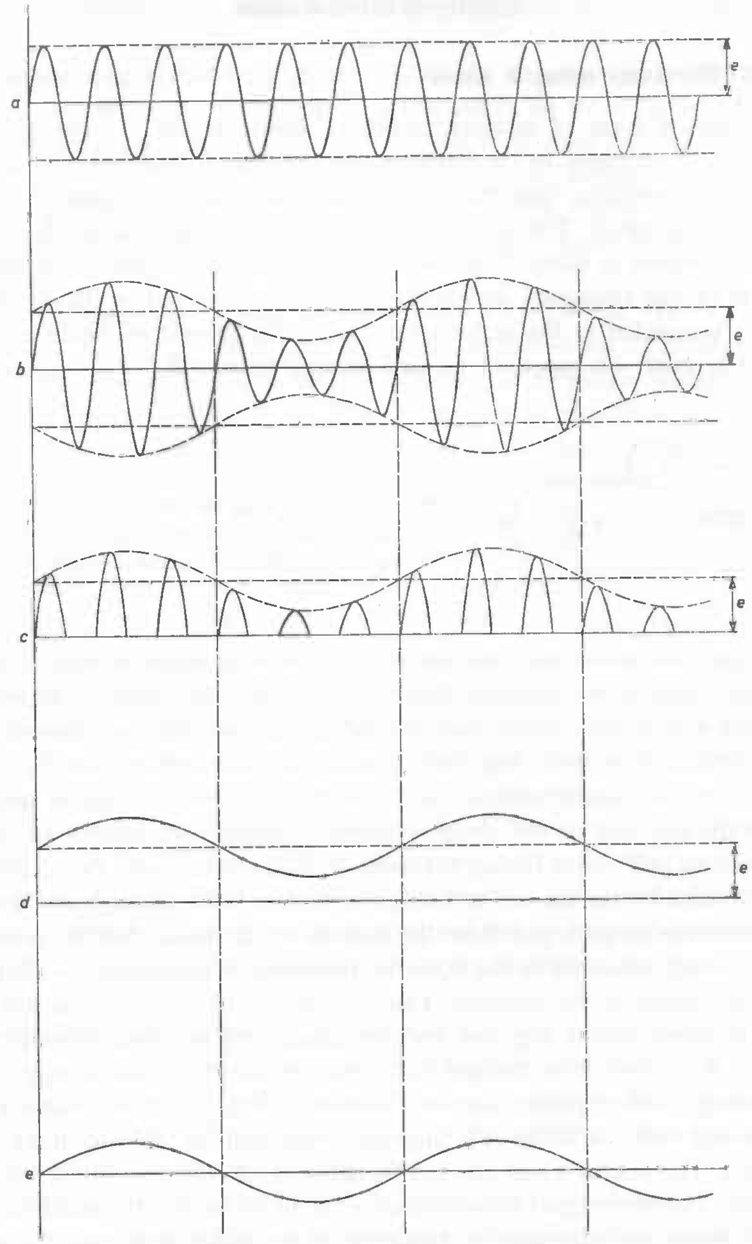


Fig. 6.

a. r.f. voltage (unmodulated) with peak value *e*.
b. modulated r.f. voltage
c. current through the diode
d. voltage on C_2.
e. a.f. voltage

of the cycles, is then as shown in Fig. 6*c*. As a result of capacitor C_2 discharging across resistor R after each charging period, the d.c. voltage to C_2 is also affected by the variation in the current amplitude. By a suitable choice of the value of R (not too high otherwise the capacitor may not charge and discharge quickly enough, yet not too low otherwise the capacitor may discharge too quickly thus reducing the average d.c. voltage too greatly) the voltage at C_2 will exactly follow the amplitude variations of the r.f. voltage. The a.f. signal with which the transmitted carrier wave is modulated thus reappears as a variation in the d.c. voltage at C_2 (Fig. 6*d*) and may be applied to headphones or an amplifier in the way as shown in Fig. 7, where capacitor C_3 has been inserted to block the d.c. component. The a.f. voltage is then as shown in Fig. 6*c*.

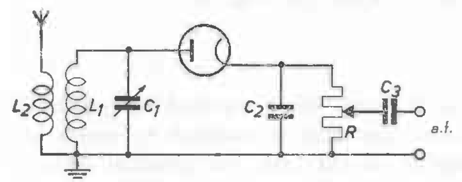


Fig. 7. Receiver with inductive aerial coupling. A potentiometer is chosen for R and C_3 acts as separating capacitor.

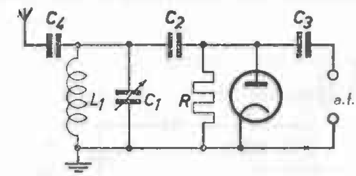


Fig. 8. Receiver with capacitance aerial coupling. Diode with earthed cathode. (Parallel detection).

We also see from Fig. 7 that R is a potentiometer; this is provided with a sliding contact to enable us to adjust the voltage and thereby the strength of the audio signal applied to the amplifier or headphones. Almost all receivers include such a signal strength or "gain" control. This circuit is also different in that the aerial is coupled inductively to the tuning circuit via L_2-L_1. The advantage of this arrangement is that, whilst the aerial has less effect on the quality of circuit L_1C_1, the effect by the capacitance of the aerial (i.e. the capacitance of the aerial plus lead-in to earth) on the tuning is greatly reduced. In the circuit shown in Fig. 5, the aerial capacitance is in parallel with C_1 and consequently has a considerable effect on the tuning. In the circuit shown in Fig. 7, however, this effect is reduced to a minimum by the coupling via the coils L_2 and L_1.

The circuit in Fig. 8 shows another solution to this problem. Here, the capacitor C_4 is connected in series with the aerial capacitance, thus reducing the overall effect on the tuning, whilst the loss in signal strength need only be very slight. Moreover, C_2 and the diode have changed places; this does not affect the operation, but may sometimes be useful when it is required to earth the cathode of the diode. The damping of the detector circuit will here be greater, however. This means that the circuit quality and the a.c. voltage across the circuit are also lower. The valve diode may be replaced with satisfactory results by a germanium diode, thus eliminating the battery required for the valve heater supply (see also Dr. S. Boon - Germanium diodes).

In this case it may be advantageous to connect the diode to a tap on the tuning circuit instead of to the top end with a view to reducing the effect of the damping of the detection circuit (see Fig. 9).

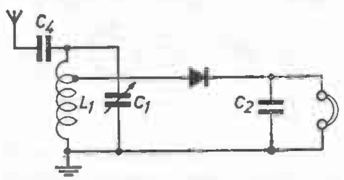


Fig. 9. Valve diode replaced by germanium diode. The diode is matched by means of a tapping on the coil. For practical data, see text.

For the benefit of those enthusiasts who wish to experiment with these simple types of receivers, we give some practical values of the components. It should be remembered, however, that the sensitivity of these receivers is very low, so that aerials should preferably be erected high and not be too short, unless the transmitter is in close proximity to the receiving station.

C_1 = 300 to 500 pF variable
C_2 = 50 pF or greater
C_3 = 1000 to 2000 pF
C_4 = 20 to 50 pF
R = 0.1 to 1 MΩ
L = approx. 150 μH (for medium wave)
approx. 6 μH (for short-wave range 90-40 m).

For medium wave reception, coil L consists of 110 to 120 turns of

32 S.W.G. enamel wire closely wound on a former about 1½" in diameter. For the diagram in Fig. 9, the coil is tapped at 50-60 turns from the "earthy" end. For short-waves (90-40 m) the coil consists of 17 turns of 18-24 S.W.G. enamel wire wound on a former about 1½" in diameter over a length of 1.4" and tapped at 8 turns from the earthy end.

3.3 Receivers with triode or pentode

Much better results may be obtained by replacing the diode by a triode which immediately amplifies the signal several tens of times. The disadvantage is that an extra source is required for supplying anode voltage which involves the purchase of an expensive battery or supply unit. An example of a circuit employing a triode is shown in Fig. 10, in which the a.f. voltage, after detection in the grid circuit, appears amplified in the anode circuit. R.F. voltages from the grid circuit are amplified as well however, and may give rise to unwanted effects. A capacitor of suitable value is therefore provided to by-pass the anode for r.f. potentials. The

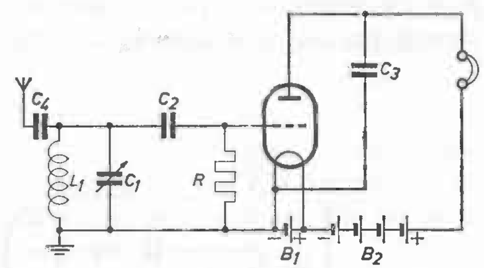


Fig. 10. The triode as detector. C_3 prevents r.f. voltages from reaching the headphones.

method of detection is similar to that shown in Fig. 8 and is therefore again accompanied by some damping in the tuning circuit. Compared to the amplification which is obtained this effect is negligible, however, provided that the values of the components have been chosen correctly.

With the triode it is possible to increase the amplification to an even higher extent by reducing the damping by the application of feedback, whereby part of the r.f. potential in the anode circuit is fed back to the grid circuit in the correct phase to add to the original signal voltage. This produces a higher anode voltage which in its turn produces a still higher grid voltage, etc. etc. The result is that the amplification of the triode is considerably increased. Thus, this circuit reduces the damping and, in fact, compensates all the loss factors (damping) of the tuned circuit.

If too much energy is fed back, a self-sustaining oscillation will be set up, i.e. the circuit will act as a low-power transmitter. Apart from the interference caused to others, the received signal will then be greatly distorted and with the circuit off tune a loud whistle will be heard owing to the incoming signal being mixed with the signal excited in the triode itself, resulting in a signal equal to the difference between these two frequencies. The further the receiver is detuned, the higher the whistle. When the receiver is tuned through a signal, the tone will first be heard as a very high whistle and will then go down to disappear at the point of tuning and rise again on the other side.

Conversely, if the feedback is too weak, no advantage is gained at all. It is therefore desirable to make the feedback continuously variable to enable this to be adjusted to the point where the receiver is nearly but not quite oscillating, i.e. is "on the verge of oscillation". This is achieved in the circuit in Fig. 11 by inserting a coil in the anode circuit and coupling it to the tuning coil. The r.f. current in the anode circuit then passes through the coil, thus inducing a voltage in the tuning coil and resulting

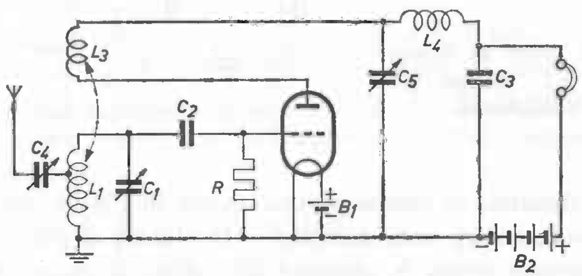


Fig. 11. The triode as detector with feedback by means of an extra coil. Adjustable with variable capacitor. L_4 and C_3 prevent r.f. voltages from reaching the headphones.

in a reduction in the damping. The current through L_3, and thus the feedback, may be varied by means of capacitor C_5.

Although this method may work very smoothly, it may also throw the tuning circuit considerably off tune. A better method, suitable for triodes only, is shown in Fig. 12, where adjustment is made by varying

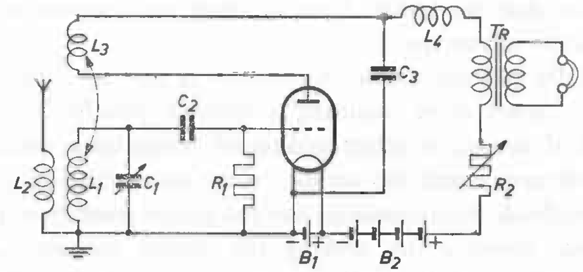


Fig. 12. Variable feedback by means of a variable series resistor. Headphones matched by means of a transformer.

the anode voltage which, when designed correctly, will cause practically no detuning. The value of the coupling coil and the degree of coupling to the tuning coil are very important. The coupling coil should be designed with a view to ensuring that the receiver oscillates at that position of R_2 where, without feedback, practically no increase in amplification occurs. The capacitance of C_3 is also important in this respect.

To avoid hand effect, i.e. the tendency of the frequency to be detuned when the controls are touched, it is essential that the spindles of the variable capacitors (rotating plates) are earthed; moreover the use of an earthed metal front panel is recommended.

Difficulty may be experienced with getting the receiver to oscillate, which when finally accomplished is attended by a loud click. This phenomenon is often accompanied by "dead spots" in the tuning, i.e. the point at which the circuit goes into oscillation does not coincide with that at which it goes out of oscillation. To end the oscillation in this case, the control has to be turned backwards much further than expected. This may be overcome by a correct choice of values of R_1 and C_2, whilst the application of a small bias to the control grid may also have a favourable effect.

Furthermore the coil should be so designed that the feedback coil is always placed at the earthy end of the tuning coil with the anode end furthest away.

A more modern type of valve is the pentode which has proved in actual practice that it is capable of fulfilling different valve functions in receiver circuits better than the triode. Even in single valve receivers the pentode may be used to advantage.

Although the pentode circuit in one-valvers may be identical with that for triodes, apart from requiring a suitable positive voltage for the screen grid of course, it offers additional possibilities which are worth examining in more detail. So, in the circuit shown in Fig. 13, the usual system of feedback from anode to control grid is used; here the feedback is controlled, however, by making the screen voltage variable, thus changing the slope of the valve and consequently also the alternating current in the anode circuit (which, of course, also flows through the

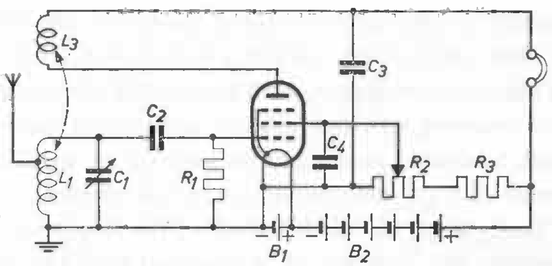


Fig. 13. The pentode as detector. Feedback from the anode, controlled by the screen grid voltage.

feedback coil). As with the triode, smooth control may be ensured by so adjusting the feedback that the valve goes into oscillation at that screen grid voltage at which, without feedback, no further increase in gain is obtained.

So far we have only mentioned battery valves, i.e. valves supplied from batteries. Since the heaters or filament are supplied with direct current, they are "directly heated", i.e. the heater also functions as the cathode (the electrode which emits the electrons). The heaters of valves used in receivers designed for a.c. supply cannot be heated directly, however,

since the a.c. heater supply would then produce a varying stream of electrons which would give rise to a loud hum. In this type of valve the heater is enclosed in an insulated nickel tube with emitting layer similar to that on the heaters of battery valves. In circuit diagrams the heater is then replaced by the cathode.

3.4 a.f. and r.f. amplification

To improve the reception, the next step is to add another valve to serve as an audio amplifier. The sole purpose of audio amplification is to increase the strength of the rectified signals produced by the preceding detector.

The two circuits are usually resistance-coupled, a resistance being used as the anode impedance of the detector valve. In the circuit shown in Fig. 14 an indirectly heated pentode is used as detector and an indirectly heated triode as a.f. amplifier. The a.f. voltage obtained across the anode

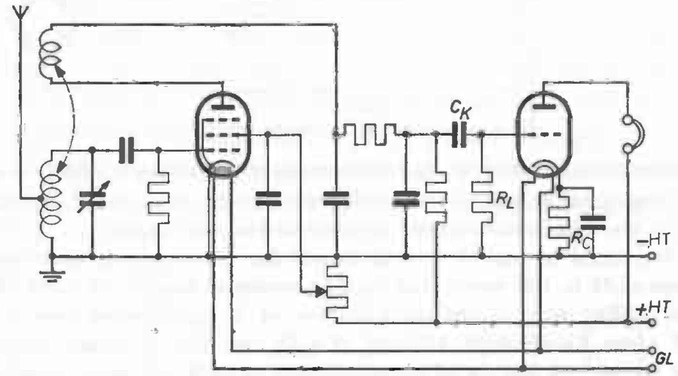


Fig. 14. Resistance-coupled detector and a.f. amplifier. An indirectly heated pentode is used as detector and an indirectly heated triode as a.f. amplifier.

load resistor after detection is applied to the grid of the a.f. amplifier via the coupling capacitor C_k. The d.c. current flowing through this valve also flows through cathode resistor R_c, so that the cathode is slightly positive with respect to earth. The grid which is at earth potential for d.c. voltage via leakage resistor R_1 is consequently slightly negative with respect to the cathode, thereby "setting" the valve to a suitable working point for a.f. amplification. Suitable values for these components may be found in the valve manufacturer's handbooks. R_c is bypassed by a capacitor which forms a low impedance path for alternating components of the current.

Another example is shown in Fig. 15 where a double-triode is employed. This valve comprises two triodes contained in one envelope, one being

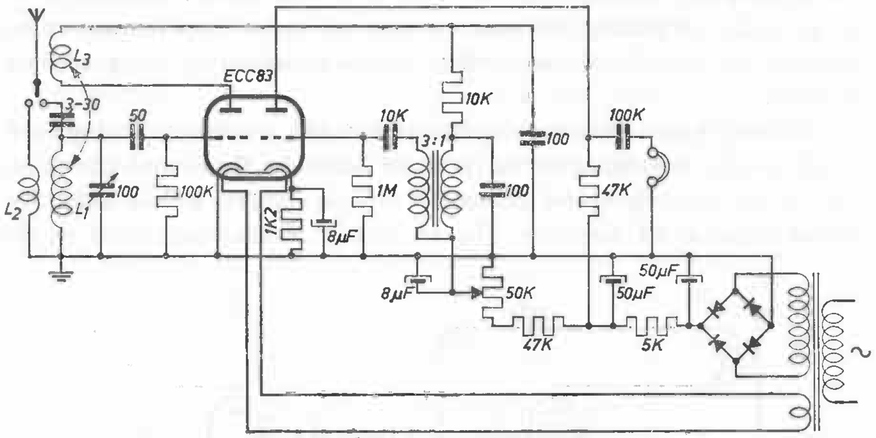


Fig. 15. Circuit diagram of a short-wave receiver employing a double-triode, type ECC 83. One triode system is used as detector and the other as a.f. amplifier. The two circuits are transformer-coupled (transformation ratio approx. 1 : 3). The aerial may be connected to one of several circuits for most suitable matching. For a wave range of 50 to 100 metres, coil L_1 may consist of roughly 55 turns of 0.5 mm enamelled copper wire wound on a former of 2 cm diameter over a winding length of 4 cm. L_2 of about 12 turns of 0.15 mm wire at 5 mm distance from L_1 at the earthy end and L_3 of about 15 turns of 0.15 mm wire wound between the lower turns of L_1 (earthy end).

connected as detector and the other as a.f. amplifier. The two systems are coupled by means of an a.f. transformer (transformer coupling) with the primary across which the detected a.f. voltage is produced inserted in the anode circuit of the detector. The ratio of primary to secondary turns being approximitely 1 : 3, this voltage is amplified in the secondary from

where it is applied to the grid of the second triode, amplified again and fed to the headphones in the anode circuit.

If we therefore build a receiver incorporating two valves according to the principle mentioned above, the incoming signal is first detected (first valve) and then amplified (second valve). Since it is a question of the a.f. signal being amplified, we speak of *a.f. amplification.*

Alternatively, the incoming signal may be amplified before being detected and this is known as *r.f. amplification.* As already mentioned, this is then followed by the usual detector circuit.

An example is given in Fig. 16 where the first valve, the r.f. amplifier, is a triode. The signal picked up by the aerial is applied to a tuned circuit via a coupling coil and from there to the grid of the r.f. valve. The cathode circuit is seen to include a resistor which provides the necessary grid bias. As in the previous circuit, this resistor is again by-passed by a capacitor which, in view of the much higher frequency of the signals to be amplified may have a much lower value than in the case of the a.f. amplifier. Resistance-coupling to the detector is again quite possible. As shown in the figure it is desirable to provide a circuit which may be tuned to the incoming signals. This is done for several reasons. Firstly many more stations can be received with r.f. amplification than without it owing to the fact that the sensitivity of the detector is subject to a threshold value, i.e. weak signals below a given strength are no longer detected. A different situation arises with r.f. amplification, because now the weak signals are amplified first, thus lowering the signal threshold

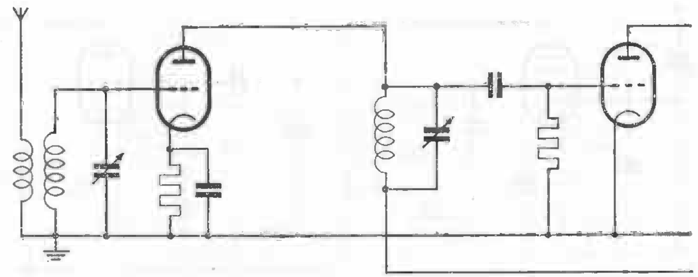


Fig. 16. Triode as r.f. amplifier with by-passed cathode resistor for correct adjustment of the negative bias. The heaters of the indirectly heated valves have been omitted in this and the next figures for the sake of simplicity.

value which in addition is now also determined by other factors. Consequently, more stations are received and the chance of interference is greater. The addition of a second tuned circuit enables us to tune to the required frequency a second time with the result that the selectivity of the receiver is increased. Secondly, to improve the selectivity and the gain, we want to continue employing the feedback circuit with the detector, so that yet another tuned circuit is required.

In practice triodes will seldom be used as r.f. amplifiers, however, because of the fairly considerable capacitance existing between the anode and the grid *inside the valve*. These two electrodes are placed round or next to each other and the capacitance may be as much as 1 to 3 pF. Consequently, a considerable part of the a.c. anode voltage across the second circuit is passed back to the grid circuit via this capacitance (denoted by C_{ag}), amplified again, passed back to the grid again, etc. This is the condition under which oscillation takes place, so that, instead of amplifying, the valve operates as a transmitter. Although this effect may be counteracted by employing special circuits (i.e. neutralizing circuits), it considerably limits the scope of the type of circuits which it would otherwise be possible to employ, besides lowering the characteristics of the amplifier stage. It is therefore much better to employ r.f. pentodes which are designed with a view to reducing the value of C_{ag} to a minimum (about 0.005 pF) and in which the screen grid which acts as a shield between the grid and the anode must be earthed for r.f. voltages (decoupling). An example of this is shown in Fig. 17.

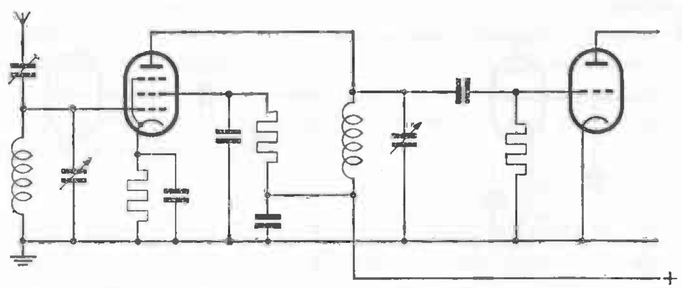


Fig. 17. The pentode as r.f. valve. The tuning capacitor of the detector circuit is connected direct to earth and the lower end of the tuning coil is connected to earth via a by-pass capacitor.

With respect to the second tuning circuit we note from Fig. 16 that the top of the parallel circuit is connected to the anode of the r.f. valve and the other end to the + H.T. This method is not found to be very satisfactory in practice. First we have to assume that the + H.T. connection is adequately by-passed for r.f. voltages. If not, an extra by-pass capacitor will have to be connected between the bottom end of the circuit and earth. An even greater disadvantage of this circuit is, however, that the rotating plates of the tuning capacitor are not earthed, but connected to + H.T., which means that the capacitor housing has to be insulated from the metal chassis and front plate. Although variable capacitors with a ceramic spindle are available, thus insulating the rotating plates from the housing, they are very expensive and easily damaged. The difficulties become even greater if the two tuning capacitors are combined in one housing (twin capacitors with single tuning control).

To overcome all these difficulties the tuning capacitor of the second circuit is connected to earth (Fig. 17) whereas the coil is connected to + H.T., but earthed for r.f. voltages by means of a by-pass capacitor, thus completing the parallel circuit. Another solution is shown in Fig. 18 where the entire second tuning circuit is earthed, but the signal from the r.f. valve is applied via a coupling coil through which the anode current of the r.f valve also passes. The bottom end of this coil is connected to + H.T and the coil is earthed for r.f. by a decoupling capacitor.

It is, of course, possible to employ one or more stages of both r.f. and a.f. amplification. A practical circuit for a short-wave receiver employing

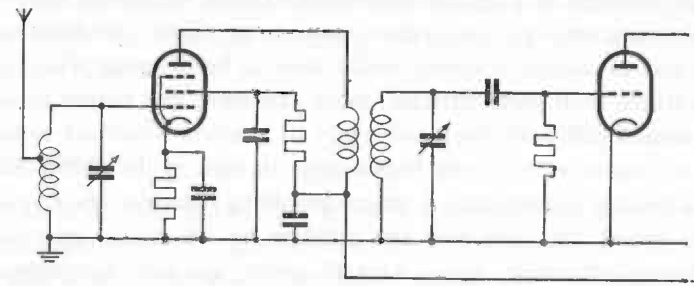


Fig. 18. The detector tuning circuit is earthed. The signal is received from the r.f. stage via a coupling coil.

one stage of r.f. amplification and two stages of a.f. amplification is given in Chapter 10, page 128.

3.5 Frequency changing (superheterodyne receivers)

The inclusion of more and more valves resulted in increased sensitivity and this obviously created a demand for better selectivity. If each r.f. stage includes only one tuning circuit, the selectivity does not of course, keep pace with the increased sensitivity. This lack of selectivity could be overcome by using band-pass filters instead of individual circuits. The circuit diagram of a receiver with two r.f. valves could conceivably be as shown in Fig. 19, where the band-pass filters are coupled inductively.

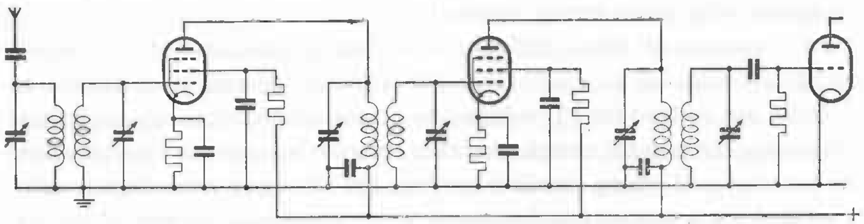


Fig. 19. Example of two stages of r.f. amplification, employing band-pass filters

It is obvious that a single tuning control was required, the necessary six-fold tuning capacitor would be very expensive, if obtainable at all. Furthermore, at the usual wave range ratio of 1 : 3, it would be impossible with single coupling to keep the bandwidth of such band-pass filters even moderately constant over the whole wave range. Thus, combinations of inductive and capacitive coupling would have to be designed which would make the whole even more intricate, more expensive and harder to adjust. The last-named difficulty does not apply to amateur receivers especially designed to receive very narrow bands only. In view of the above difficulties it is advisable to introduce a system involving *changing the frequency*. It will be found that this aids the addition of automatic gain control (a.g.c.), tuning indication, signal strength meter, and c.w. reception (telegraphy reception necessitating the use of a beat oscillator).

According to this system the frequency of the incoming signal is changed

to a previously selected frequency fixed by the design and known as the "intermediate frequency" (i.f.) and is subsequently amplified and selected by the i.f. amplifier in such a way that it conforms to our requirements. The signal is then detected and amplified in the normal manner. The great advantage of this system is that our requirements as to sensitivity and selectivity can be fulfilled without difficulty. The use of band-pass filters no longer presents any problems, because these need only be set to one frequency.

The incoming signal is changed in frequency by mixing it with a locally generated oscillation. This is based on the fact that when two signals of different frequencies are mixed, two new signals are produced equal to the sum and difference frequencies.

By suitably arranging the oscillator circuit to ensure that the difference between the signal carrier and local frequency is constant and equal to the selected intermediate frequency, we have achieved our object of changing every incoming signal into the intermediate frequency and amplifying and separating it from unwanted side frequencies in the i.f. amplifier.

Let us take as an example a receiver suitable for medium wave reception, e.g. frequencies from 500 to 1600 kc/s. The input circuit is, of course, designed especially with a view to receiving this frequency range.

If the intermediate frequency is taken to be 450 kc/s, the local oscillator should have a tunable range of, say, 950 to 2050 kc/s. This difference frequency should not only be true for the minimum and maximum frequencies (950 — 500 = 450 and 2050 — 1600 = 450), but throughout the frequency range. This constitutes a special requirement to be imposed on the tuning circuit of the local oscillator and is known as "padding". We speak of "padding" deviations if this condition is not completely fulfilled.

Mixer stage

Before entering into this subject in more detail, we will first describe the most common types of mixer circuits. By far the most well-known is that employing a triode heptode mixer valve. As the name indicates, this valve really consists of two systems combined in one envelope; for convenience these systems are shown separately in the circuit diagram in Fig. 20.

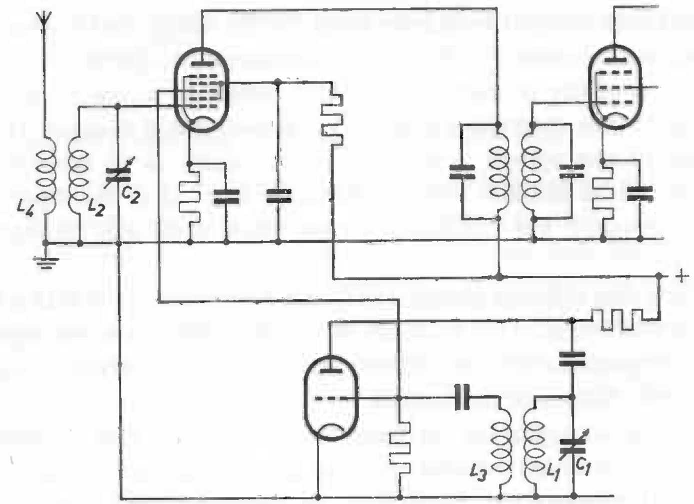


Fig. 20. Circuit diagram of frequency changing with separate valve for mixing and oscillating.

In conjunction with the tuning circuit C_1L_1 the triode functions as the local oscillator. The circuit resembles that of the triode detector employing feedback in Fig. 11, the important differences being, however, that the tuning circuit is here inserted in the anode circuit and the feedback coil in the grid circuit and that this coil is not variable, since the valve is to oscillate continuously, the coupling between coils L_1 and L_3 having been adjusted accordingly.

The actual mixer valve, the heptode system, has five grids between the cathode and the anode. The incoming signal is applied to the control grid and the signal from the local oscillator to the third (oscillator) grid. The second and fourth grids are strapped together and act as screening between the two signal grids and the anode, thus reducing the capacitive coupling to a minimum. Mixing is obtained by the combined effect on the electron flow to the anode by the voltages applied to the control grid and third grid (oscillator grid). The fifth grid has the same function as the third (suppressor) grid in the pentode, i.e. to prevent secondary electrons from passing from the anode to the screen grid and so having an adverse effect on the valve characteristics.

A complete circuit diagram of a simple superheterodyne receiver employing three valves is shown in Fig. 21. The first valve is the mixer (triode-heptode), the second a pentode operating as an i.f. amplifier and the third a double triode which amplifies the signal after detection by means of a germanium diode and finally passes the signal to a loud-speaker via a matching transformer.

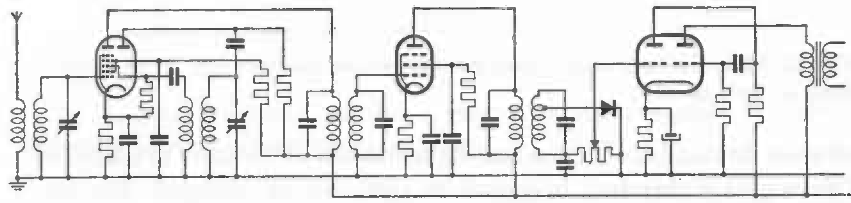


Fig. 21. Circuit diagram of a simple superheterodyne receiver employing three valves: a triode-heptode as mixer, a pentode as i.f. amplifier and a double-triode as two-stage audio amplifier. A germanium diode is used as detector.

When the mixer consists of a triode-heptode in which both electrode systems have a common cathode, the cathode circuit must include a cathode resistor and by-pass capacitor in order to bias the heptode system. To ensure that the triode oscillator functions properly, the grid should not be biased; the leakage resistor is therefore not connected to earth in this case but to the cathode. This difficulty does not arise with the other valves which are connected in the usual manner (cathode resistors and grids earthed for d.c. voltages).

To eliminate the necessity for a separate germanium diode an i.f. pentode with a built-in detection-diode is also possible; the i.f. + detection stage is then as shown in Fig. 22.

In receivers with battery valves where the consumption has to be kept as low as possible a simpler type of mixer valve, i.e. the heptode, is usually employed. A typical circuit is shown in Fig. 23. The triode section consisting of the heater and the first and second grids functions as the oscillator. The tuning circuit C_1L_1 determining the oscillator frequency is connected between the first (control) grid and the heater, whilst the excited r.f. voltage is fed back from the second grid to the tuning circuit. The third grid is the electrostatic screen which reduces the capacitive coupling

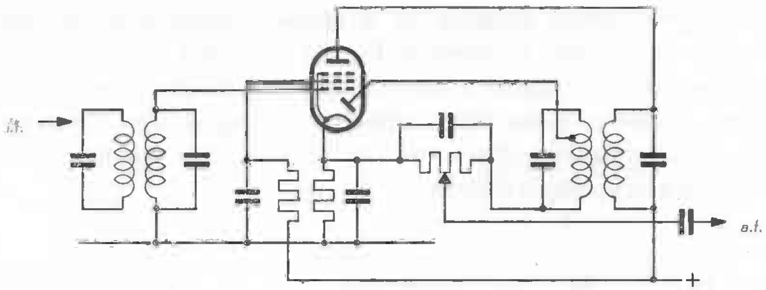


Fig. 22. Circuit arrangement where the germanium diode in Fig. 21 is omitted by using a diode-pentode.

between the oscillator section and the remainder of the valve to a minimum. This screen is therefore by-passed to earth for r.f. voltages. The fourth grid is the control grid to which the signal set up in the aerial is applied via the aerial tuning circuit and the fifth grid is employed here as a suppressor grid.

Whereas in the circuit diagrams in Figs. 20 and 21 the tuning circuit is included in the triode anode circuit, in Fig. 23 it is included in the grid circuit of the triode section functioning as an oscillator. It should be noted that there are many other oscillator circuits suitable for this purpose.

A more detailed description is given in the chapter on amateur transmitters where steps to be taken to ensure the stability of the frequency produced are also discussed.

In this respect it should be remembered that our oscillator itself constitutes a low-power transmitter and we should therefore take adequate steps to prevent the oscillator signal from reaching the aerial, for this would cause interference on neighbouring receivers. Fortunately, this is largely prevented by the screen between the triode oscillator and the tetrode control grid, though the circuit should be so arranged that the oscillator tuning circuit, where the r.f. voltage is greatest, is removed as far as possible from the aerial circuit.

This is why the tuned circuit in Fig. 20 and in Fig. 21 is included in the anode circuit of the triode, the oscillator voltage here being applied to the mixer valve via the triode grid and the third grid of the heptode. In the circuit shown in Fig. 23, however, the tuned circuit is inserted in the first grid circuit, this being furthest removed from the aerial.

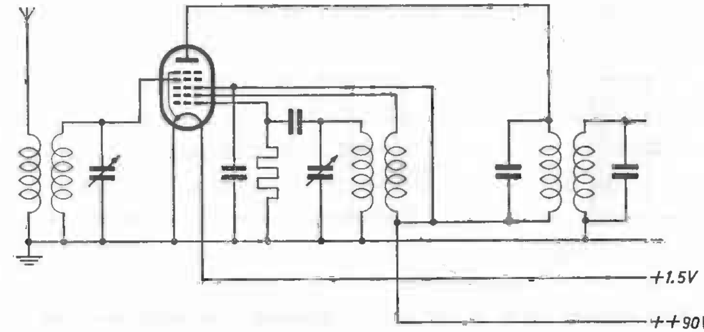


Fig. 23. In battery receivers, the mixer valve is usually a heptode in order to reduce the current consumption.

The possibilities of the r.f. oscillator voltages being transferred outside the valve should of course also be reduced to a minimum by correct arrangement of the components and by applying screening where necessary. It will be obvious that a receiver employing one or more r.f. amplifier stages with effective screening between the grid and anode circuits will have the better radiation properties. A considerable improvement is often obtained by ensuring correct adjustment of the oscillator, which should not supply more voltage than is strictly necessary for the conventional mixer-circuits.

I.F. amplifiers

As already mentioned at the beginning of this chapter, in i.f. amplifiers consisting of one or more stages, the voltage is usually transferred from one stage to the next by means of band-pass filters. The basic principles of band-pass filters have already been discussed in Chapter 2, but in view of their important function in receivers and because many amateurs are bound to want to make these filters themselves or to modify them, we feel that further discussion on this subject is justified.

As is known, band-pass filters consist basically of two separate tuned circuits spaced at a certain distance apart. A typical band-pass filter is shown in Fig. 24, where both circuits are assumed to be tuned exactly to the frequency to be amplified. If circuit L_1C_1 receives an r.f. voltage

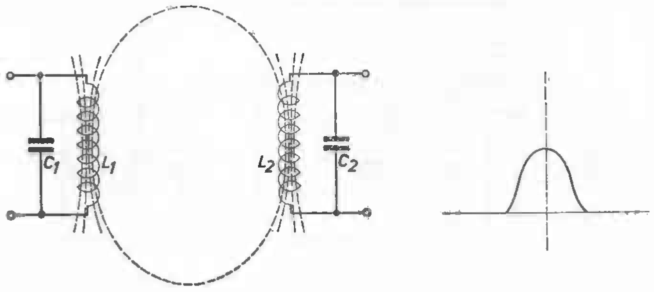


Fig. 24. Two circuits tuned to the same frequency. Coupling less than "critical".

of the tuning frequency of both circuits, the lines of force of the magnetic field consequently excited in coil L_1 will be concentrated inside and spread outside this coil. A relatively very small proportion of these lines will link with the turns of coil L_2. The field excited in this coil will therefore be very weak and the r.f. voltage of the same frequency produced across L_2C_2 very low. Both circuits operate as the conventional type of tuned circuit (see Chapter 2, page 12 and Fig. 3).

If the coils are brought closer together, the number of lines of force linking with L_2 will be greater and the voltage produced across it will be increased. The smaller the distance between L_1 and L_2, the tighter the coupling and the greater the voltage transferred to L_2 (see curve I, Fig. 25). This is subject to a maximum, however (critical coupling). If the coupling is increased beyond this point, the two coils will be so close together that they will affect each other mutually, consequently affecting the tuning frequencies, that of one circuit becoming lower, and that of the other higher than the resonant frequency. Instead of the single peak as shown

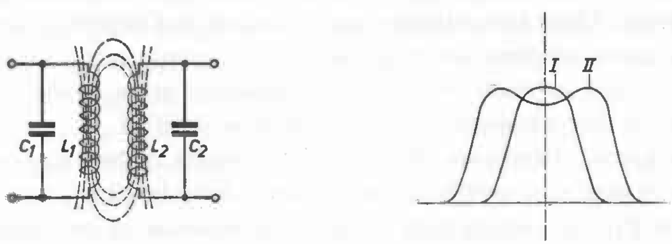


Fig. 25. Two circuits tuned to the same frequency. Coupling greater than "critical".

in curve I, Fig. 25, the tuning curve then has two peaks (II, Fig. 25). The tighter the coupling, the further the peaks will be spaced apart and the tuning curve will widen and become, as it were, flat-topped.

This appears to be a very suitable form of band-pass curve for use in conventional broadcast receivers, where the quality of reproduction of music is required to be high and the side bands, i.e. the higher modulation frequencies, must not be attenuated. For amateur receivers, selectivity is usually more important and here it is therefore essential to remain below the point of critical coupling, though not too far as this would reduce the amount of voltage transferred. Hence, critical coupling represents the ideal condition.

It should be borne in mind that the critical coupling is not a constant value capable of being adjusted in advance by the coil designer. The coupling factor at which critical coupling occurs, is also governed by the quality of the circuits (see Chapter 2). The higher the quality Q, the lower the degree of coupling at which critical coupling occurs. Thus, since the ultimate circuit quality does not only depend on the coil design itself, but also on the effect of the whole circuit, the coupling should be arranged (or adjusted) in dependence of the whole circuit to obtain critical coupling.

The effect of two amplifier valves connected by means of a band-pass filter on the quality of this filter (and hence on the critical coupling) will be fairly slight, provided the setting is selected correctly. The final band-pass filter in the i.f. amplifier will usually be loaded by one or more diodes, causing the Q-factor to drop considerably, so that the coupling factor must then be increased to obtain critical coupling.

With amateur receivers the need for a variable bandwidth is felt at a very early stage.

As has already been explained at the beginning of this chapter, various circumstances may arise under which greater selectivity is desirable than that required for the usual commercial type of broadcast receiver.

For this reason variable bandwidth is often adopted to enable the selectivity to be adjusted as required. One method of achieving this is by providing an extra coupling coil which may be either switched into, or out of the circuit (see Fig. 26). The coupling between the coils L_1 and L_2 is then adjusted to obtain maximum selectivity (curve I of Fig. 25),

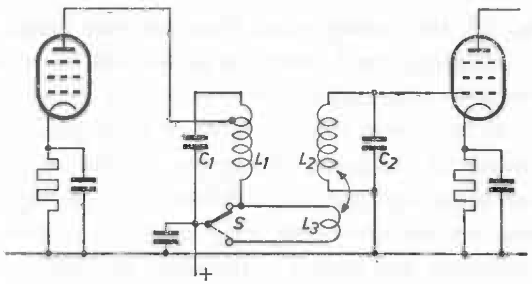


Fig. 26. Variable bandwidth with the aid of an extra coupling coil. (e.g. graphs I and II, Fig. 25).

whereas the bandwidth is increased to that shown, for instance, in curve II of Fig. 25 by inserting the extra coupling coil by means of *switch S*. This method need not be limited to one band-pass filter, but may be applied to several i.f. stages. Consequently, the use of this method does not imply an increase in maximum selectivity, which continues to be entirely dependent on the circuit quality.

A far more effective method, particularly suitable for telegraphy reception, is to use a crystal filter, as shown in Fig. 27. A quartz crystal behaves similarly to a series circuit having a very high quality factor Q which may amount to several thousands. The frequency depends on the dimensions and the type of crystal used whilst the impedance is very low. This means that at this frequency the coupling between L_1C_1 and L_2C_2 via the crystal is very tight, but is considerably reduced for all other frequencies owing to the high impedance of the crystal for these adjacent frequen-

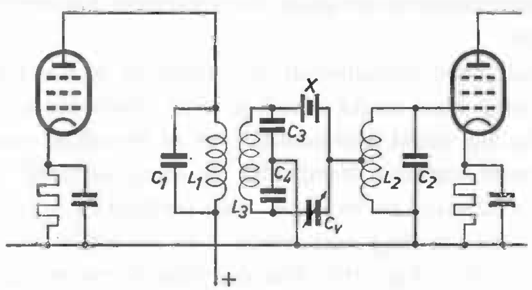


Fig. 27. I.F. band-pass filter with crystal filter for improved selectivity.

cies. The crystal in combination with its holder has a certain parallel capacitance, however, and causes a certain amount of capacitive voltage transfer to take place. This may cancel out the effect of the crystal to a considerable extent. This is the reason for including the variable capacitor C_v which receives a voltage from L_3 in phase opposition to that across the crystal. C_v is set to balance these two voltages. Further examination of this complicated filter shows that, if capacitor C_v is not set correctly, the whole obtains a capacitive or inductive character, causing a point of maximum attenuation to occur close to the point of maximum coupling, i.e. minimum attenuation.

The spacing between this maximum and minimum may be varied with C_v which thus constitutes a very effective means of tuning out interference close to the wanted signal. This involves a very careful adjustment of C_v which is known as the "phasing" capacitor, and of the "beat" oscillator which is always switched in for telegraphy reception and is to be discussed later.

Crystal filters employing more than one crystal are also frequently encountered in actual practice.

To be able to receive telegraphy signals produced by interrupting the carrier wave in the rhythm of the morse signals, another signal having a frequency close to the i.f. frequency is required. The difference between the frequencies then determines the audio frequency obtained after detection and should therefore be chosen accordingly. This is best achieved by making the "beat" variable to enable this to be suited to the circumstances (see crystal filters). To avoid serious distortion, the signal from the beat oscillator should be considerably stronger than the i.f. signal. In receivers employing automatic gain control (a.g.c.), however, a strong "beat" signal may operate the a.g.c. regardless of whether the incoming signals are weak or strong. The a.g.c. circuit is therefore usually rendered inoperative during telegraphy reception. A circuit diagram of an i.f. amplifier with a beat oscillator is shown in Fig. 28.

Like broadcast receivers, the better types of amateur receivers are also equipped with a.g.c. The signal used for this purpose is usually derived from the primary of the last i.f. band-pass filter and is detected by means

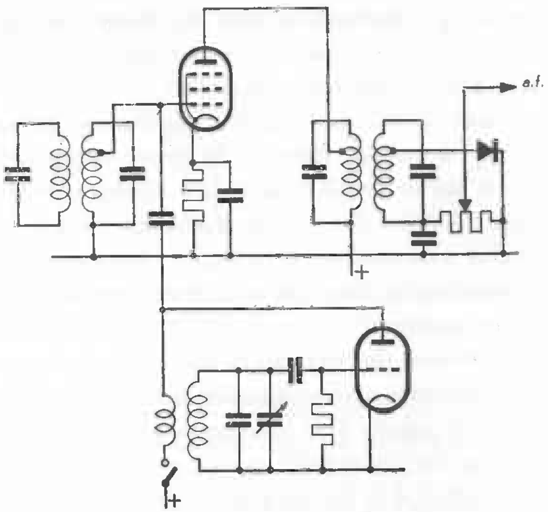


Fig. 28. I.F. amplifier with "beat-oscillator" for telegraphy reception.

of a diode. The negative voltage produced by the diode is applied as grid bias to the preceding valves, thus biasing them more negatively. An increase in signal strength therefore increases the grid bias and hence lowers the gain. An example of such a circuit is shown in Fig. 29.

It is also desirable to be able to control the gain independently of the signal strength, however, and for this reason a manual control is usually provided as well. A circuit combining a.g.c. and manual control is shown

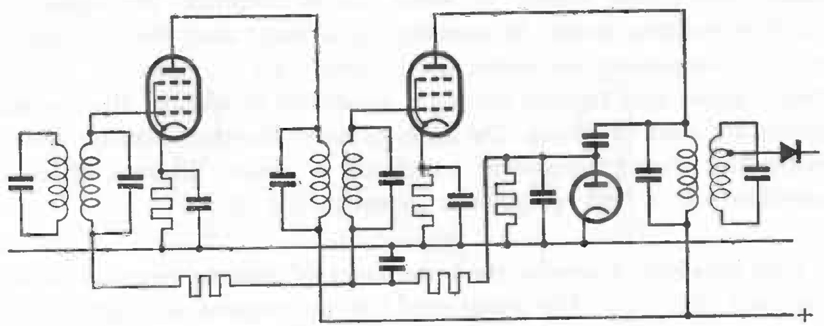


Fig. 29. I.F. amplifier with automatic gain control (a.g.c.).

in Fig. 30. Here, a fixed positive voltage is applied to the diode producing the bias, so that this voltage must be overcome before the a.g.c. comes into operation. This is done in order that no a.g.c. operation occurs on weak signals, this being naturally very undesirable, since it is exactly these signals which must be amplified to the fullest extent. This system is known as "biased gain control". The extra bias, adjustable by means of potentiometer *P*, may be applied to the a.g.c. line by switch *S*. Consequently the gain of the controlled stages is also adjustable by means of potentiometer *P*.

In the circuit diagrams shown both in Figs. 29 and 30, a separate diode drawing a.c. voltage from the primary circuit of the last band-pass filter was employed to produce the negative bias voltage. In simple circuits the bias is often taken from the detector diode so that, in addition to the a.f. modulation it also includes a d.c. voltage the value of which depends on the strength of the signal. The a.g.c. system aims at keeping this d.c. voltage constant, but this has unfortunately an adverse effect on the selectivity during tuning. By employing the a.c. voltage across the primary of the last band-pass filter, the a.g.c. system will keep this voltage constant, so that the selectivity of the secondary then ensures a better tuning accuracy.

For short-wave receivers, having several i.f. stages, it is generally preferable to adjust these stages without applying biased a.g.c., as shown in Fig. 30. On account of the noise properties it is desirable to apply a lower, and preferably biased, control voltage to the mixer valve. Where

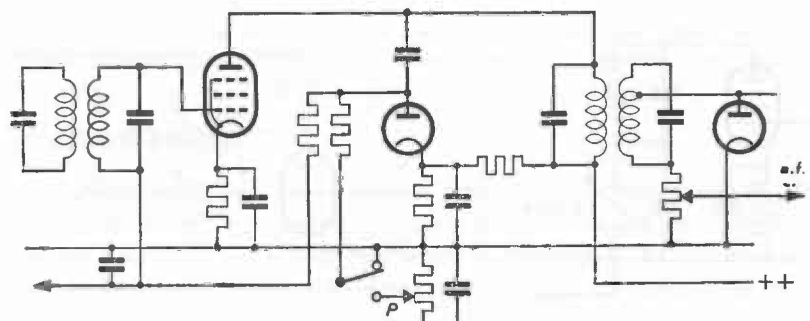


Fig. 30. Combined a.g.c. and manual control.

an r.f. stage is included in the receiver, this is controlled as well as the mixer valve. In receivers employing several r.f. stages, biased a.g.c. with a lower control voltage is applied to all of them, the mixer valve not then being controlled; this is preferable in any case on account of the stability on short waves, whilst straight a.g.c. is employed for the i.f. stages. With all these different systems, the grid spacing of the different valves should be watched, i.e. the control voltage at which the gain drops to zero should be ascertained for all the valves.

Many amateur short-wave receivers are equipped with an *S* (= signal strength) meter which gives a rough idea of the strength of the incoming signal. The scale may be calibrated in accordance with the *S*-scale.

A simple circuit is shown in Fig. 31 where a milliammeter is included in the anode circuit of one of the valves to which a.g.c. is applied, say an i.f. valve. If the signal strength increases, the a.g.c. voltage will increase and the anode current will drop. The zero of the meter used here should preferably be on the right-hand side of the scale, so that the pointer moves to the right with increasing signal (higher *S*-value). This could be done by turning the meter upside down, for instance. A disadvantage of this circuit is that the scale is not utilized to the full, unless compensation circuits are included.

A typical example of such a circuit is shown in Fig. 32 where a separate triode is included in a bridge circuit, the balance of the bridge being affected by the a.g.c. voltage on the grid. Advantages of this circuit are that the meter current increases with the strength of the signal and that a practically linear dB-scale is obtained).

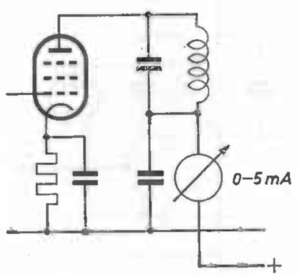


Fig. 31. Simple signal-strength meter.

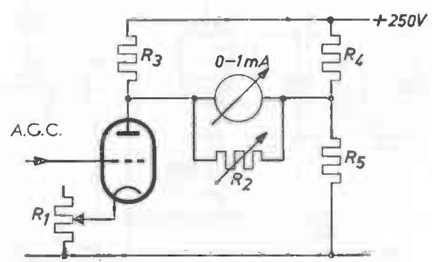


Fig. 32. Signal-strength meter with compensation circuit.

We now give some hints for those wishing to experiment with this circuit.

For R_3 and R_4 take values of about 1 kΩ. For R_5 choose the value at which the current through R_4 and R_5 is several times higher than that flowing through the milliammeter at maximum deflection. With the valve removed, adjust the current through the meter to maximum by means of R_2. With the valve heater connected and the grid short-circuited to earth, adjust the current through the meter to zero by means of R_1.

Interference caused by electrical equipment often gives rise to momentary peak voltages. Circuits to obviate the effect of interference are designed in such a way that when the interference peak exceeds the required modulation, the connection to the a.f. section of the circuit is interrupted momentarily. This is effected by means of diode D_2 in Fig. 33. The level of the interference voltage is variable by means of resistor R_1. This effect is enhanced by means of the diode D_3. The limiting circuit is inoperative in position 2 of switch *S*.

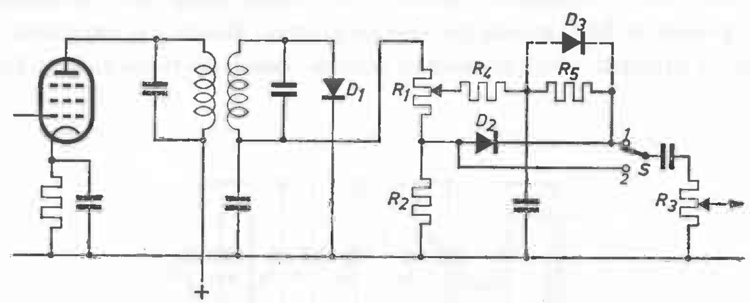


Fig. 33. Circuit diagram of interference limiter. Diode D_2 is the limiter and diode D_3 gives improved action. The limiter is disconnected in position 2 of switch *S*.

3.6 Bandspreading

The r.f. section of a receiver includes one or more tuned circuits. Th operation of tuned circuits has already been discussed in Chapter 2 where we saw that the tuning frequency is determined by the values of *L* and *C*, *L* being the total self-inductance, i.e. coil + connecting wires, in the circuit and *C* the total parallel capacitance.

If the circuit is tuned by means of a variable capacitor, it should be borne in mind that this has given capacitance variation and also a fixed capacitance, viz. zero-value. The capacitance variation is denoted by ΔC and the zero-capacitance by C_o. Thus, the C_o-value of a capacitor which varies between 10 and 500 pF is 10 pF and the ΔC-value: 490 pF.

The tuning frequency f being $\frac{1}{2\pi\sqrt{LC}}$, the change in f will then be determined by the change in $\sqrt{C}$. However, the total parallel capacitance is not only formed by C_o, but also includes the capacitances of the coil C_L, the valve C_b, the valve holder C_h, the wiring C_d and, where applicable, a trimmer C_{tr} and an extra capacitor C_e (see Fig. 34).

All these constant capacitances together form the minimum capacitance C_{min}.

Obviously, the maximum tuning frequency is determined by $\sqrt{C_{min}}$, and the minimum tuning frequency by $\sqrt{C_{min} + \Delta C}$. To obtain the greatest possible tuning range, the ratio $\Delta C : C_{min}$ has to be as high as possible.

In the case of amateur receivers, the tuning range of the circuits is usually made to line up with the special amateur bands, i.e. expanded scale tuning is effected over a selected narrow band of frequencies. This is

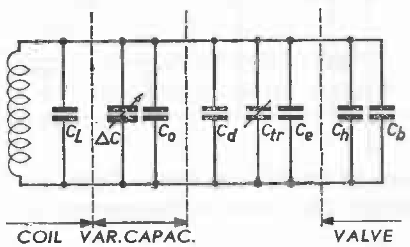


Fig. 34. Capacitances occurring in a tuning circuit.
C_L = capacitance of coil.
C_v = variable capacitance of variable capacitor.
C_o = minimum capacitance of variable capacitor.
C_d = capacitance of wiring.
C_{tr} = capacitance of trimmer when tuned.
C_e = extra capacitance included for bandspread.
C_h = capacitance of valve holder.
C_b = capacitance of valve.

known as bandspread and here the value of ΔC must be small compared to the fixed capacitance.

Another method frequently used is that whereby each circuit includes 2 variable capacitors, one having a large, and the other a small capacitance variation, the large capacitor covering a wide range and the small one a narrow range, thus enabling an amateur band to be expanded over the whole scale (see Fig. 35*a*).

The proportion of the various amateur bands to the total range being different the spread is not the same for all the ranges. An improvement to this effect may be obtained by connecting the small bandspread capacitor to a tapping on the coil. This reduces the effect on the whole circuit whereas the capacitance variation is proportionally smaller (see Fig. 35*b*).

A circuit employing only one variable capacitor is given in Fig. 35*c*, where a series and parallel capacitor is provided to obtain bandspread. For receivers intended exclusively for the amateur bands, the circuit shown in Fig. 35*d* is the most suitable. Here the variable capacitor C_v has a low value chosen in accordance with the required bandspread.

In order to obtain the required bandspread for each band, the last circuit can, of course, be used in conjunction with the method shown in Fig. 35*b*.

Calculation of bandspread is discussed in Appendix 1, page 133.

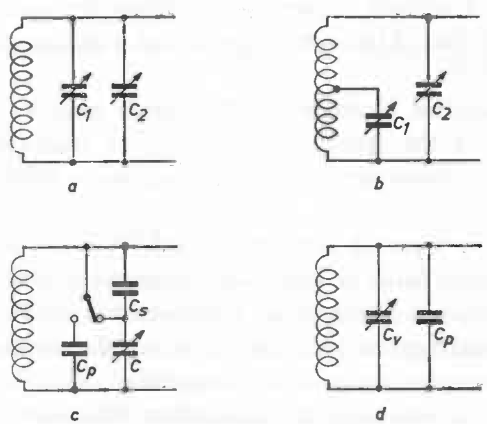


Fig. 35. Methods of bandspread.

CHAPTER 4

AMATEUR TRANSMITTERS

4.1 Introduction

Methods of transmission

There are several methods for transferring information via the transmitter to the receiver. The transmitter design will be in accordance with the method selected.

For the transmission of *telegraphy* information the transmitter can be switched on and off in the rhythm of the morse signals produced by means of the morse key. This system is known as telegraphy on *continuous waves* and is indicated by "A1".

Another method consists of the transmission of a constant carrier modulated with a tone. This (audible) tone is keyed. This is known as *modulated telegraphy* or "A2".

A third method consists of varying the carrier frequency by a constant amount in the rhythm of the morse signals and is known as *frequency shift telegraphy* or "F1".

For the transmission of *telephony,* the carrier must be modulated with the frequencies of the speech or music to be transmitted. The most commonly known types are *amplitude modulation* (A3) and *frequency modulation* (F3).

There are other types of modulation, but they are not of interest to amateurs. A special form of amplitude modulation is worth mentioning however. Normally two sidebands are transmitted in addition to the carrier; with a more recent type of modulation, the *single-sideband method,* one sideband together with the carrier is suppressed, thus reducing the total channel width and increasing the transmitter efficiency. This method of transmission is indicated by A3a.

Electrical design of transmitters

In this book we will only discuss valve transmitters. The earlier types of spark transmitters, rotary spark-gap transmitters and arc transmitters, though valuable in the past, are no longer used and are therefore of no interest to amateurs.

A transmitter may be constructed with a single valve by connecting this as an oscillator so as to produce electrical oscillations. Such a circuit has already been described in the chapter headed "Amateur receivers", i.e. the local oscillator of the superheterodyne receiver. If such an oscillator is coupled to an aerial, electromagnetic waves will be radiated.

This type of transmitter presents many difficulties however. Firstly, the excited power is usually low, unless a special transmitting valve is employed. Secondly, the transmission method causes the emitted energy to vary, thus producing a varying load on the oscillator and, usually, variations in the transmitted frequency.

For this reason, almost all transmitters consist of an *oscillator* or *driver stage,* followed by one or several *amplifier* and/or *buffer stages.* The final stage which should be capable of delivering the required power to the aerial is known as the *power amplifier* or *output stage* and thus determines the *power* of the transmitter.

Telephony transmitters include an extra section which amplifies the modulation and applies this to the transmitter. This stage is known as the *modulator.*

Lastly, a *power supply unit* is required to supply the correct voltages and currents to the valves.

4.2 The oscillator

The principle of the oscillator

The principle of the oscillator, i.e. the feeding back of a portion of the a.c. voltage present in the anode circuit to the grid circuit has already been referred to in the chapter on amateur receivers. Feedback may take place in various ways as will be shown in the oscillator circuits to be discussed later. There are two distinct cases however:

a. The voltage fed back to the grid circuit is *in phase opposition* to the original grid voltage; the resulting voltage at the grid will then be *less* than the original voltage and oscillation will not take place.

b. The voltage fed back to the grid circuit is *in phase* with the original grid voltage. If the grid circuit is tuned, the circuit voltage will be *higher* and the *damping* will be *reduced*.

We assumed here that the original grid voltage was already present (e.g. supplied from an outside source), which is of course not true in the case of oscillators. When the circuit is switched on, small a.c. voltages are produced in both the grid and anode circuits (switching effect). In case b there are two possibilities:

1. The feedback via the coupling circuit is very small, so that the energy delivered by the valve to the circuit is inadequate to compensate for circuit losses. In this case the oscillation will be quenched immediately.
2. The feedback is sufficiently high to compensate circuit losses. The oscillations are then undamped. The applied energy is usually greater than the circuit losses, so that the amplitude increases and the circuit losses rise to the level where equilibrium is restored. The valve is then oscillating.

The amount of feedback obviously depends on various factors, such as the amplification factor and the internal resistance of the valve, the impedance of the anode circuit and the coefficient of coupling, i.e. the coefficient indicating the degree of coupling between the circuit and coupling coils (Fig. 36).

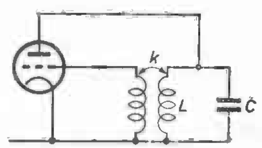


Fig. 36. Principle of oscillator circuit.

Grid capacitor and grid-leak resistor

To ensure that the anode current changes sufficiently (i.e. that sufficient a.c. anode voltage is available) when the oscillator is switched on, the d.c. operating conditions of the valve should adjust themselves accordingly. At the moment of switching on, as well as after the valve has achieved

equilibrium, the d.c. operating conditions should be such as to guarantee satisfactory operation. To achieve this the negative bias voltage should increase from zero to the value at which equilibrium is obtained. This is done by means of the grid capacitor C_G and grid-leak resistor R_L in the circuit shown in Fig. 37. At the moment of switching on, the difference

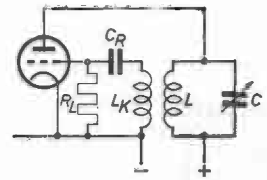


Fig. 37. Negative bias obtained by means of grid capacitor C_R and grid-leak resistor R_L. Tuned series-fed anode circuit.

in d.c. voltage between the grid and the anode is zero, so that the valve starts to oscillate without difficulty, since the slope is then maximum. As soon as an a.c. voltage is produced on the grid, however, this will be positive with respect to the cathode during the positive peaks, resulting in grid current which charges capacitor C_G. This charge wants to flow away via the grid-leak resistor R_L, so that the grid voltage is determined not only by the a.c. grid voltage, but also by the values of C_G and R_L. This d.c. grid voltage increases proportionally with the a.c. grid voltage and ensures that the slope is reduced gradually in such a way that equilibrium is obtained at the most favourable operating conditions for the valve.

Oscillator circuits

There are many types of oscillator circuit, several of which will be discussed.

The most common type of feedback oscillator, as already explained in the chapter on receiver circuits, is reproduced again in Fig. 38.

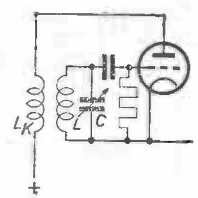


Fig. 38. Tuned grid circuit.

Although this circuit was very suitable for receivers, oscillators employed in transmitters (including one-valve transmitters) are expected to produce the maximum possible a.c. voltages. This condition is fulfilled by tuning the anode circuit instead of the grid circuit (Fig. 39). This is known as *reversed feedback* (in view of the grid and anode circuits being reversed). The difficulty which may arise as a result of the tuned circuit being at

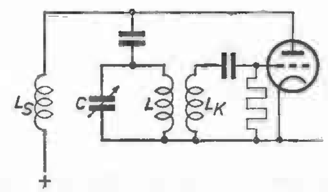


Fig. 39. Tuned anode circuit, parallel-fed via choke L_S.

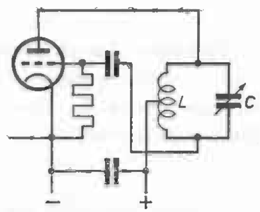


Fig. 40. Hartley oscillator, series-fed. Tapping on coil *L*.

positive potential (series-fed) may be overcome by applying parallel-feeding via an r.f. choke (Fig. 39). Unfortunately there is a risk of the choke being in resonance with the capacitance formed by the blocking capacitor, distributed capacitance of the choke, etc. which would constitute an unwanted load on the circuit. This may be overcome by replacing the choke with a resistor (*R*). However, the voltage drop (and power loss) caused by the resistor is considerable and is undesirable at higher powers.

Apart from the method employing a coupling coil, a portion of the a.c. voltage may also be fed back from a tapping on the circuit. The simplest way is to tap the tuning coil (see Fig. 40). To ensure that the phasing of the voltages is correct the *anode* is connected to the *top end* of the circuit, the *grid* to the *bottom end* and the *cathode* to the *tapping.*

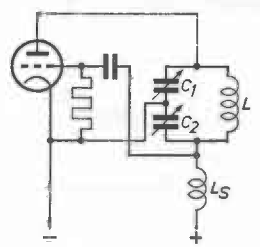


Fig. 41. Colpitts oscillator, series-fed. Tapping on junction between the two capacitors C_1 and C_2.

This is known as the Hartley circuit which is very popular because of its simplicity. The choice of the tapping determines the correct proportion of the voltages on the grid and anode. Parallel-feeding may also be adopted here by adding a separate blocking capacitor and r.f. choke, similar to the circuit diagram shown in Fig. 39.

In the Colpitts circuit the tapping is on the tuning capacitor (see Fig. 41). The advantage of this circuit is that no tapping is required on the coil; this for various reasons reduces the coil losses and simplifies switching or changing over to other tuning frequencies. The disadvantage is that the tapping ratio is determined by the double tuning capacitor C_1C_2 which may affect the correct operating conditions.

A very popular circuit is the E.C.O. (electron-coupled oscillator) which is based on a tetrode or pentode.

The actual oscillator circuit is built up round the cathode, control grid and screen grid; any of the previous basic circuits may be adopted. Fig. 42 shows a circuit evolved from the Hartley oscillator. The electron current of the pentode flowing from cathode to anode is affected by the oscillating triode and this alternating anode current produces an a.c. voltage across a suitable anode load. As the screen is *earthed* for r.f. voltages, there is little capacitive coupling between the anode and oscillator circuits, so that there is very little chance of variations in the anode load being fed back and affecting the frequency. The coupling is purely electronic, so that a high degree of frequency stability may be obtained with this type of oscillator.

Another oscillator circuit which has become very popular during recent

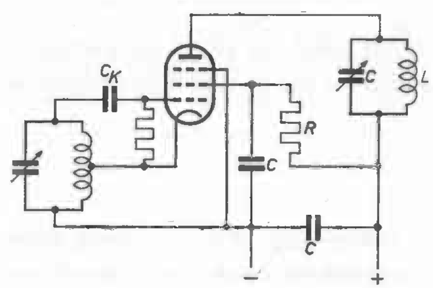


Fig. 42. Electron-coupled oscillator (ECO) with Hartley oscillator circuit.

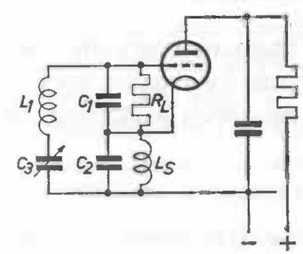


Fig. 43. Clapp oscillator.

years among radio amateurs is the Clapp oscillator. This is, in fact, a Colpitts circuit in which the anode is earthed for r.f. voltages (see Fig. 43) and the inductive branch of the tuned circuit has been made adjustable by connecting a small variable capacitor in series with the tuning coil. The great advantage over the conventional Colpitts circuit is that there is greater freedom in the choice of the correct tapping ratio with the fixed capacitors C_1 and C_2. Moreover, because of the series connection of C_1 and C_2 with C_3 the valve as a whole is tapped once again on the circuit, so that this is less affected by variations in the valve characteristics. The value of choke L_s should be high enough to ensure that its presence has little or no effect on the tuned circuit.

The Clapp oscillator is frequently employed in E.C.O. circuits, the Hartley circuit in the E.C.O. in Fig. 42 then being replaced by the Clapp oscillator (Fig. 44). A very stable driver stage can be obtained by means of this combination.

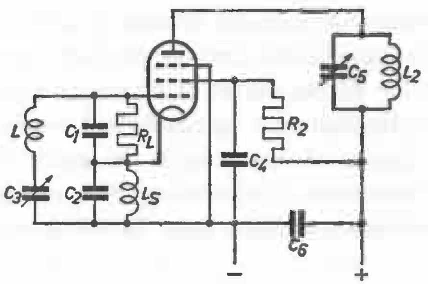


Fig. 44. **Electron-coupled oscillator with Clapp oscillator circuit.**

There are many other oscillator circuits which are either not particularly suitable for amateur work or are intended for use at very high frequencies, in measuring equipment, etc.

Frequency stability

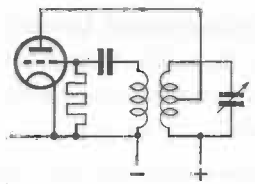
When an oscillator is employed as the driving stage of a transmitter, efforts will be made to obtain a circuit and construction which ensure a very high stability of frequency. It is clear that satisfactory reception of the transmitted signal is possible only if its frequency remains constant. As the

frequency transmitted is determined basically by the value of the components, the measures to be taken with regard to stability should aim at keeping these values as constant as possible during the operation of the transmitter. To this end:

1. The mechanical construction of the coil, the tuning capacitor, the wiring and all the other components determining the frequency should be as robust as possible in order to keep any variations in their electrical values due to mechanical vibrations or variations in temperature to a minimum.
2. Electrically these components should be of the highest possible quality. A high circuit quality (Q) is a considerable aid to frequency stability. This applies not only to the coil and tuning capacitor, but also to all the other components of the oscillator circuit, the quality of which should be such that they affect these electrical values as little as possible.
3. The oscillator valve should only oscillate weakly. Excessive oscillation may result in frequency drift.

It follows from the above that the tuned circuit should be coupled as "loosely" as possible to the valve and the other parts of the circuit. While the valve heats up after the transmitter is switched on, the valve capacitances, some of which are connected in parallel with the tuning circuit, will change in value, the greatest change usually being effected in the grid-cathode capacitance C_{gk}. For this reason the circuit shown in Fig. 37 will be better than that shown in Fig. 38. The feedback coil should contain as few turns as possible (e.g. L_K in Fig. 37) in order to reduce the effect of C_{gk} on the circuit via the transformer L_k-L to a minimum. If the grid is connected to the circuit by way of a grid capacitor (e.g. Fig. 42), this should be made as small as possible to minimize the effect of C_{gk}. Another method of reducing the effect of the valve capacitances consists in connecting the anode and/or grid to a tapping (Fig. 45). The effect may also be considerably reduced by making the value(s) of the parallel tuning capacitor(s) as high as possible. Let us assume that we employ a valve having a C_{gk} of 10 pF and that this changes by a value of 1 pF on heating up. If this is connected in parallel with a tuning capacitor whose value is also

Fig. 45. Anode connected to tapping on tuning circuit to reduce the effect of valve capacitance.



10 pF, the total circuit capacitance will be 20 pF. A variation of 1 pF after heating represents a change in capacitance of 5 %. However, if we can use a tuning capacitor of 90 pF, the total capacitance will be 90 + 10 = 100 pF and the 1 pF variation only represents 1 % of the total.

These considerations show clearly the great advantage of the Clapp-oscillator circuits shown in Figs. 43 and 44, in which capacitors of very high values are connected in parallel with the valve capacitances and, in addition, the anode is tapped capacitively on the total tuning capacitance. The values of capacitors C_1 and C_2 are often as high as several thousands of pF. These measures are, of course, subject to the condition that smooth oscillation occurs across the whole tuning range.

Another important point is the temperature. It is a well-known fact that the electrical properties of components are often greatly affected by temperature. Changes in the ambient temperature are not usually sufficient to give rise to undesirable effects. If the temperature in our driver stage which we prefer to be completely screened off is affected by the heat dissipation of one or more valves, however, the change in temperature may begin to play an important part; the consequent heating of the coils, capacitors, etc. may give rise to a considerable variation in frequency. As this heating process is very gradual the overall result is a continuously varying frequency.

In the construction of a driver stage great attention must therefore be paid to the cooling of the components determining the frequency. This may be achieved, for example, by mounting these components and the valves in separate spaces.

The crystal oscillator

A special method of keeping the frequency of a driver stage constant is by adopting the crystal oscillator, whereby use is being made of certain

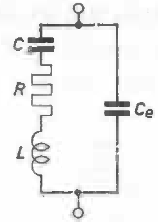


Fig. 46. Equivalent diagram of a quartz crystal. *CRL* represents the crystal, C_e the capacitance of the electrodes.

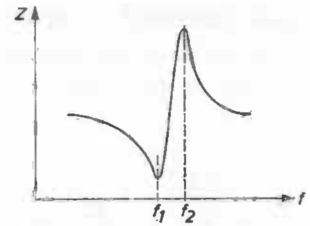


Fig. 47. Impedance curve of a quartz crystal. Series resonance at frequency f_1; parallel resonance at frequency f_2.

properties of a quartz crystal. The crystals used in transmitters consist of thin plates which are cut in the proper way from the natural quartz. Their operation in transmitters is based on the "piezo-electric" effect: if a quartz plate is subjected to mechanical pressure or tension the end faces become electrically charged. If conducting electrodes are fitted to the end faces, a voltage and an electric field counteracting the polarisation will be produced between them. If the electrodes are short-circuited the charge will be neutralised. Every change in pressure or tension will produce a new voltage between the electrodes. Conversely, if a voltage is applied to the electrodes of the crystal, this will contract or expand. An alternating voltage will cause the crystal to vibrate mechanically. The crystal will have a marked preference for one certain frequency, i.e. the natural frequency, at which the amplitudes may be very large at very much lower charges and load currents on the electrodes. This means that the crystal behaves as a tuned circuit with a certain resonant frequency. Owing to the low internal damping of the crystal the quality of the circuit is extremely high. The equivalent circuit is shown in Fig. 46, in which CRL represent the actual crystal where series resonance occurs at the natural frequency. The capacitance C_e of the electrodes is in parallel, so that parallel resonance then occurs at a frequency slightly above the natural frequency of the crystal.

The impedance-frequency curve is shown plotted in Fig. 47 where f_1 is the natural frequency of the crystal (series resonance, minimum impedance) and f_2 the parallel resonance (maximum impedance).

A simple circuit diagram of a crystal oscillator is shown in Fig. 48.

The crystal connected in the grid circuit determines the oscillating frequency. The anode circuit includes a normal tuned circuit, feedback taking place by way of the anode-grid capacitance of the triode.

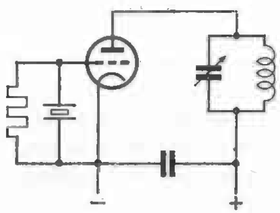


Fig. 48. Simple quartz crystal oscillator.

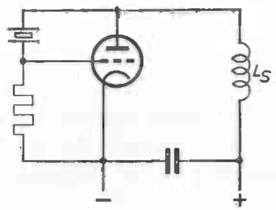


Fig. 49. "Pierce" oscillator.

A very popular type of oscillator is the "Pierce"-oscillator (Fig. 49) which only differs from a Hartley or Colpitts type oscillator in that the conventional type of tuned circuit is replaced by the crystal between the grid and the anode. This is a very simple circuit, the only disadvantage being that the amount of r.f. voltage delivered is small. An improvement is obtained by including an extra tuned circuit in the anode (Fig. 50).

Many other circuits are, of course, possible, but will not be discussed here. We would like to draw attention to the application of the crystal oscillator in the E.C.O. which results in the "improved Pierce"-type of oscillator shown in Fig. 51. Several interesting variations of this circuit arrangement are possible.

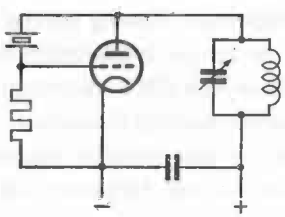


Fig. 50. Pierce oscillator with tuning circuit to increase the delivered r.f. voltage.

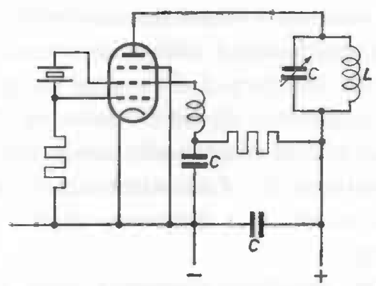


*Fig.*51. Improved Pierce oscillator, consisting in fact of an ECO with a crystal oscillator and combining the advantages of both these circuits.

4.3 The amplifier stages

Survey

As already mentioned in the first part of this chapter, most transmitters are built up from several stages. Single-stage transmitters are seldom met. The function of this single stage would indeed be very complicated, as in addition to having to determine and to keep constant the transmitted frequency (as oscillator), it would have to produce sufficient power for delivery to the aerial.

As already explained, the stability of the frequency depends largely on the variations in load and temperature. One-valve transmitters are particularly subject to these variations, because the power supplied to the valve would have to be fairly high to ensure that sufficient r.f. power is transferred to the aerial. This means a higher dissipation, resulting in all the known adverse effects on the frequency stability. One way to overcome this is by adopting crystal control, but this is subject to certain limitations, as the powers to be generated can only be small so as not to overload the crystal.

It is therefore common practice to add a separate stage for delivering the r.f. power the aerial. This stage, the output stage, is in effect a power amplifier and receives its drive from the oscillator. These two stages are frequently separated by one or several amplifier- or buffer stages, either to supply the required driving power to the output stage, or to separate this stage from the oscillator; for it is undesirable for power to be taken from the oscillator, as this would result in varying its load and lead to variations in frequency. This is the reason for the driving power being supplied by an amplifier stage which, in turn, may also require driving power, though this will be less. In that case a second and possibly even a third stage is employed.

Buffer stages sometimes also have another function. Amateurs are usually authorized to transmit in different frequency bands. It stands therefore to reason that the transmitter should preferably be tunable to several bands. Fortunately several amateur frequency bands are harmonically related, that is to say, one band is a multiple of the next lower one. This fact can be used to advantage by adopting a system known as frequency multiplication, i.e. one or more buffer stages are connected as frequency "doublers" or "triplers", and multiply the oscillator frequency by a factor of 2 or 3. The advantage of this arrangement is that the frequency of the oscillator remains unchanged, thus avoiding the possibility of varying the frequency as a result of switching elements.

The output stage

As already stated, the function of the output stage is to produce sufficient r.f. power for delivery to the aerial. The output valve should be so designed that it is capable of carrying out this function satisfactorily. The applied power is partly dissipated and partly converted into r.f. power for delivery to the aerial. Dissipation increases the temperature of the valve (and the surroundings) and this should be taken into account when the valve is designed. It will usually be necessary to supply the power at a higher voltage than usual and it is therefore clear that the output stage will have to be constructed with a view to withstanding the higher currents and voltages.

As far as the type of valve to be employed is concerned, we have a choice between triodes and pentodes (sometimes tetrodes as well). Without entering too deeply into details we give a comparison of the practical properties of these valves when used as transmitter amplifier:

1. The driving power (excitation) required by tetrodes and pentodes to obtain a given "output" (delivered r.f. power) is much lower than that required by triodes. The power amplification of the tetrode and pentode is much better.
2. Owing to the suppressor grid, the pentode may usually be driven further than a tetrode, so that the output and efficiency properties are better than those of a tetrode.
3. The capacitance between the control grid and the anode of tetrodes and pentodes is much lower than it is in triodes, owing to the presence of the screen grid which makes capacitive feedback almost impossible (passing r.f. power from the anode circuit back to the grid circuit which would result in instability or even oscillation).

It follows from all this that the choice of which type of valve to use in transmitters will usually fall on pentodes or tetrodes, though at very

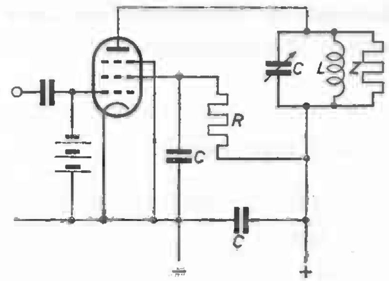


Fig. 52. Theoretical circuit diagram of an output stage. *Z* is the load to which the r.f. power is applied.

high frequencies other considerations have to be taken into account which may result in triodes being favoured.

The function of the tuned anode circuit (Fig. 52) is to deliver the r.f. power to the aerial. We may assume for the time being that the aerial is present in the form of an impedance *Z* parallel to the tuned circuit. It is clear that the valve will be so adjusted as to deliver the maximum power. This usually means that the load *Z* must have a given value. Though the radiation resistance of the aerial will usually have a different value, there are methods by which these values may be matched; we assume, therefore, that the value of *R* is optimum. The values of the coil and the capacitor of the tuned circuit are determined by the working frequency. The L/C ratio is so selected that, on the one hand, the efficiency of the output stage is not adversely affected and, on the other, the currents in the circuit are not increased too much as this would cause excessive losses in the circuit.

The operating conditions of the valve are such that maximum efficiency is obtained. The valve is operated as a class-C amplifier, which means that the negative bias applied to the control grid is greater than the value required to cut off the anode current. It also means that on application of an alternating voltage, anode current will flow only during less than half a cycle, so that this has a pulsating character which is an essential for obtaining the high efficiency desired. In general, the alternating voltage required on the grid in this case is fairly high and during the anode current peaks the grid will often be driven positive, so that grid current flows. This is indeed important, because this grid current is supplied in the form of r.f. power by the preceding buffer stage which in addition to compensating circuit losses should therefore be capable of supplying this extra power. This should certainly be taken into account in deciding the method of coupling to be adopted between the stages.

The buffer stages

In general, the construction of buffer stages operating as power amplifiers is the same as that of the output stage, except that the r.f. power to be produced is much lower than that to be delivered to the aerial and need only be sufficient to excite the output stage.

If the buffer stage is to operate as a frequency doubler, the output circuit is tuned to twice the fundamental frequency. The anode current of class-C amplifiers being pulsed, it contains, in addition to the fundamental frequency, a great number of harmonics. By tuning the circuit to the second harmonic (i.e. the double frequency), this frequency is, in fact, "picked out". It should be taken into consideration that the output power is now considerably less than that of a straight amplifier. Thus, if the valve is required to deliver the same power as in the last case, the operating conditions will have to be increased, e.g. more anode voltage will have to be applied. The driving voltage (and thus also the driving power) will then also obviously have to be increased, from which it follows that the power gain of a frequency doubler is considerably lower than that of a straight amplifier.

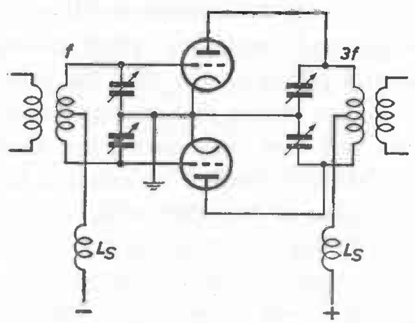


Fig. 53. "Push-pull" amplifier suitable as "trebler".

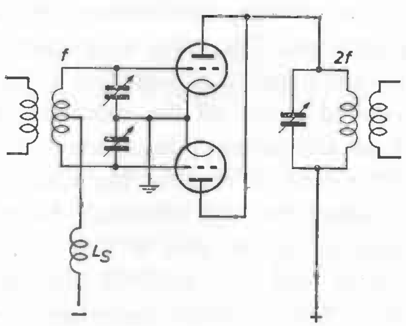


Fig. 54. "Push-push" amplifier specially suitable as "doubler".

Consequently, the power gain of a trebler will also be less than that of a doubler, so that adequate steps to compensate these losses will have to be taken in the transmitter design.

Two special frequency-multiplier circuits are worth mentioning. First, the balanced or push-pull amplifier in which the even harmonics in the anode circuit are suppressed; this circuit is therefore very suitable for use in treblers (Fig. 53). Secondly, the push-push amplifier in which, contrary to the push-pull amplifier, both anodes are connected in parallel (Fig. 54). Here the odd harmonics are suppressed, so that this is a particularly suitable circuit for use as a frequency doubler. A special application obtainable with this circuit is as a straight amplifier-doubler. If one of the heaters is switched off, thus putting one valve out of operation and the anode circuit, instead of being tuned to the second harmonic, is tuned to the fundamental frequency, the whole will operate as a straight amplifier. It should be noted, however, that in this case the anode-grid capacitance of the inoperative valve remains in circuit and operates as a neutrodyne capacitor, since the voltage which is fed back via this capacitance is equal to that fed back via the other valve. However, the two voltages are applied to the grid circuit in phase opposition and thus cancel each other out. This is known as neutralizing which, as has already been mentioned earlier, is exactly what is required for triode amplifiers to counteract instability.

Interstage coupling

The various stages of a transmitter should be coupled in such a way that each stage transfers the required r.f. voltage or power to the subsequent stage with the minimum amount of loss. We distinguish two methods of coupling: *capacitive* and *inductive*.

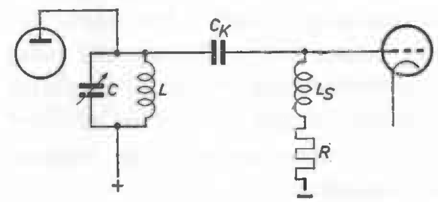


Fig. 55. Capacitive coupling between two transmitter stages.

Fig. 55 gives an example of capacitive coupling by means of which the voltage across the anode circuit of the preceding stage is transferred to the grid of the subsequent stage via the coupling capacitor C_c. The value of this capacitor determines the voltage on the grid and thus controls the degree of excitation. Alternatively, the capacitor C_c may be connected to a tapping instead of to the top end of the circuit, in which case also the tapping on the coil determines the grid voltage. A disadvantage of this arrangement is that it is usually necessary to insert a choke in the grid circuit to ensure that the operating conditions of the two valves do not affect each other. Moreover, the higher harmonics are also transferred via C_c to the next valve and this is not always desirable.

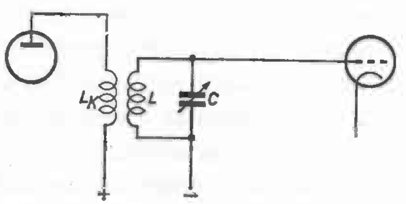


Fig. 56. Inductive coupling between two transmitter stages.

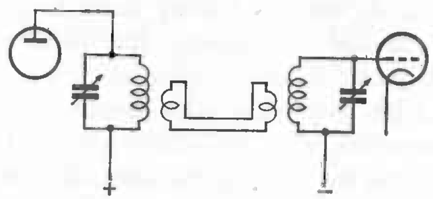


Fig. 57. Low-impedance coupling (link-coupling).

An example of inductive coupling is shown in the circuit diagram in Fig. 56. The excitation can be readily adjusted here by means of coupling coil L_c. A considerable advantage is that the anode and grid circuits are now completely separate, so that no H.T. is present on the variable capacitor which consequently may be of a smaller type (smaller plate distance).

Another method is *coupling* with *low impedance* by means of transmission lines (link-coupling) as shown in Fig. 57. The power in the anode circuit is stepped down to a low voltage and is then stepped up again in the grid circuit, the two coupling coils consisting of only a few turns. The adjustment of this method of coupling causes little difficulty and takes place without much loss of power. The construction is greatly simplified with this method, because the anode and grid circuits can now be mounted completely independently of each other, if necessary even on separate chassis or in different sections of the transmitter.

A very special method is that of *band-pass filter coupling,* in which the band-pass filter constitutes the sole coupling element. Here it is assumed that the amateur transmitter operates in a fairly narrow band within which the oscillator can be tuned to any frequency. Should the frequency *within* this band change, however, all the tuned circuits in the buffer stages and output stage would normally have to be readjusted accordingly. This procedure can be greatly simplified by adopting band-pass filter coupling, because the filter can be so adjusted that its bandwith (i.e. the frequency band within which power is transferred without appreciable loss) covers the band in which the transmitter operates, thus obviating the necessity of having to retune all the other circuits each time the frequency is changed. A disadvantage of this arrangement is that the preceding stage is then usually loaded with a considerably lower impedance, because extra damping may have to be provided for the circuits to ensure that the required bandwidth is obtained.

A second special method of coupling is that in which a π-*network* or Collins filter is employed. This filter, widely used for matching the output stage to the aerial, is now also used more and more frequently as coupling element between two stages. An example of a π-network between two transmitter stages is shown in Fig. 58 and the simplified equivalent circuit diagram in Fig. 59. The tuned circuit is seen to be formed by the coil L and the capacitors C_1 and C_2. By connecting these two capacitors in series, a tapping is provided across the total circuit impedance, the output impedance of the preceding stage (Z_1) being placed across the upper part, and the input impedance of the subsequent stage (Z_2) across

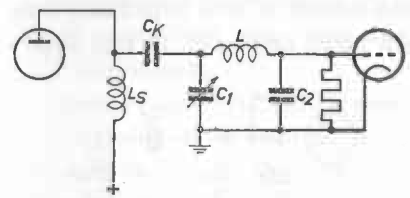


Fig. 58. Two transmitter stages coupled by means of a π-network.

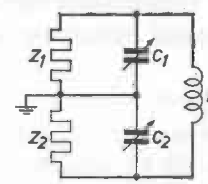


Fig. 59. Equivalent circuit diagram of the π-network;

Z_1 = output impedance of preceding stage;

Z_2 = input impedance of next stage.

the lower part of the circuit. The tapping may be varied simply by changing the values of C_1 and C_2; this is, of course, subject to the condition that the series connection of C_1 and C_2 must, in every case produce the correct capacitance for resonance at the tuning frequency. This means that any change in value of C_1 should be accompanied by an appropriate change in value of C_2 if the tuning is to be kept constant. A simple means has thus been provided for obtaining almost any required tapping ratio, enabling two stages to be matched without difficulty.

This matching is not generally very critical, however, and provided that the matching is correct at a given frequency, it will be sufficient, in the event of *slight frequency variations* having to be effected (which is common practice in the bands covered by amateur transmitters), to vary only one of the two capacitors (see Fig. 58). On switching over to a different frequency band, only the coil is changed; the two capacitors remain unchanged, because the transformation ratio of the valve impedance will also remain unchanged. Though we are bound to upset the L/C ratio to some extent, this is usually insufficient to prevent the buffer stages from functioning satisfactorily.

Aerial coupling

The problems are basically the same as with interstage coupling, the difference being that in practice the load impedance, in this case the radiation resistance of the aerial, will not be in the immediate vicinity of the output stage, but some distance away.

The power to be radiated must therefore be transferred to the aerial by way of transmission lines which often consist of low impedance lines such as coaxial cables, the situation then being analogous to that shown

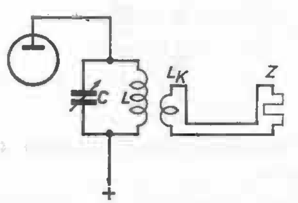


Fig. 60. High impedance matching between aerial and output stage.

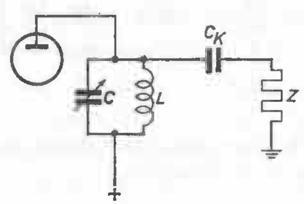


Fig. 61. High impedance matching between aerial and output stage.

in Fig. 57. The impedance at the aerial connecting point is then frequently low too, resulting in a circuit as shown in Fig. 60. If the impedance of the transmission line (and hence also of the aerial) is high, the coupling may be as shown in Fig. 61.

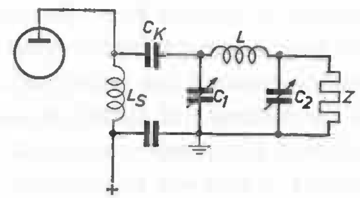


Fig. 62. π-network as coupling element between output stage and aerial.

As has already been mentioned above, the π-network has become very popular in recent years owing to the high degree of matching obtainable with it; it is therefore particularly suitable for use with different aerials and at different frequencies, since a correct matching is always ensured (Fig. 62). The capacitors C_1 and C_2 must both be variable in this case. The limits of the transformation ratio (and hence of the aerial impedances which can still be matched satisfactorily) depend on the capacitance ratios obtainable between C_1 and C_2 in tuning.

4.4 Methods of supplying the valves

To understand the operation of the practical circuits properly it is necessary to be acquainted with the various supply systems and their advantages and disadvantages.

Valves require certain currents and voltages to enable them to function satisfactorily. With transmitters, too, the operating conditions of the valves have to be correct to ensure satisfactory functioning. The voltages and currents required are usually supplied by a suitable supply unit (power supply). The method to be adopted depends on the circumstances, because the supply and the removal of r.f. alternating voltages and currents must not, of course, or at most only very slightly, be affected by the supply system.

Considering the *anode supply* first; we remember from the description of the oscillator circuits that we distinguish two methods: series and parallel supply. An example of *parallel supply* is shown in Fig. 63, where the H.T. source supplying the d.c. anode voltage is seen to be connected in parallel with the tuned circuit. The advantage of this arrangement is that the d.c. anode voltage is isolated from the tuned circuit by means of the capacitor C_c, thus greatly simplifying the construction of this circuit, e.g. the air gap between the plates of the tuning capacitor may be smaller.

The disadvantage is the necessity of having to include choke L_s which is connected in parallel with the tuned circuit and must therefore be of very good quality and have a very low capacitance to prevent the circuit capacitance from increasing to an undesirable level. Moreover, the choke may also cause parasitic resonances.

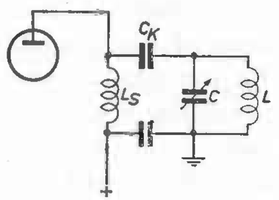


Fig. 63. Parallel-fed anode voltage of transmitter valve.

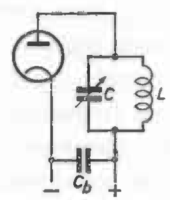


Fig. 64. Series-fed anode voltage of transmitter valve.

In the case of series supply (Fig. 64) the tuned circuit and the d.c. voltage source are connected in series so that the expensive choke is eliminated. However, the whole tuned circuit is now at high tension with respect to earth, and must therefore be effectively insulated from the latter whilst the H.T. source must be by-passed for r.f. voltages by means of capacitor C_b.

In low-power transmitters the screen grid voltage, where applicable, is drawn from the same source as the anode voltage. Since the former is usually lower, it is necessary to tap the anode voltage. This may be done by means of a potentiometer (bleeder), the screen-grid voltage then being taken from a tapping. By ensuring that a high total current flows through the bleeder resistor, any effect of screen-grid variations on the screen-grid voltage may be prevented. The additional load on the H.T. source and

the high wattage resistors required, however, increase the cost of this circuit (Fig. 65). A cheaper method is obtained by inserting a series resistor between the screen-grid and the H.T. source, but in this case the screen-grid voltage varies considerably with variations in the screen-grid current.

There are many methods of obtaining grid bias. For oscillator circuits, the method of grid capacitor and leak for producing automatic grid bias has already been discussed. The same system may be adopted for amplifier- and output stages, though in a modified form to prevent the valve (or valves) from being permanently damaged if the r.f. drive were to be interrupted for some reason or other, as this would result in a prohibitive increase in anode and screen-grid currents.

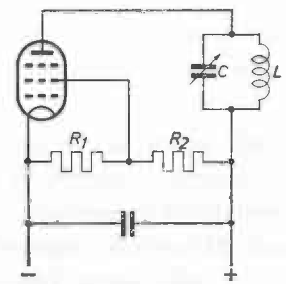


Fig. 65. Feeding the screen-grid by means of a potentiometer ("bleeder").

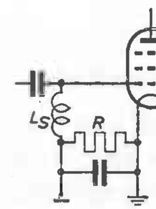


Fig. 66. Negative bias obtained from a separate supply source.

A separate supply unit for the grid bias is often employed for high-power transmitters, because the voltage is then independent of the operation of the valve. Here the voltage should again be applied to the grid via a choke (Fig. 66) or a tuned circuit (parallel and series feeding respectively). The function of resistor R plays a very important part in this case if the grid is driven positive, as without this resistor the resulting positive grid current pulses would be unable to pass through the H.T. unit where this consists of a rectifier fed from the a.c. mains (the current then being in the opposite direction). Where there is no possibility of the grid being driven positive the resistor R may be omitted. In this case even the choke L_s may often be replaced by a resistor of high d.c. value.

A third method comprises the inclusion of a cathode resistor, which technique will be familiar from receiver circuits (e.g. Fig. 14). It is then theoretically impossible to cut off the valve when in the stand-by condition, since the bias is produced by the anode current. Moreover the voltage produced is then obtained at the expense of the anode voltage (i.e. voltage between the anode and the cathode), because the total H.T. voltage is equal to the anode + cathode voltage.

If the provision of a separate supply source is too expensive the choice usually falls on a combination of cathode resistor with grid capacitor and grid leak. The value of the cathode resistor is taken to be such that the valve is just not overloaded if not driven. This requires only a small negative bias which is readily obtained from the anode supply. The remainder of the grid bias is then produced by the grid capacitor + grid leak.

4.5 Keying methods

Keying methods with telegraphy transmitters are understood to be those methods which are available to vary the carrier wave in sympathy with the signals to be transmitted (see Section 4-1, methods of transmission, A1). These signals, devised by the American professor Morse who invented the first practicable electric telegraph, are converted into electric pulses by means of a morse key inserted in a circuit. In our transmitter the function of this key is to interrupt the carrier wave, in other words, to transmit this in the rhythm of the signals. As the transmitter usually consists of several stages, the problem arises as to where to insert the key.

By inserting the key in the master oscillator stage we would completely suppress the carrier wave. We must ensure, however, that the subsequent stages are then so adjusted that they are not overloaded during the period of non-excitation and also that their operating conditions are such as to prevent self-oscillation. It is very difficult with this method to keep the frequency of the oscillator constant while the key is operated. Consequently it is theoretically better to key one of the amplifier stages, though this may give rise to "backwave", which consists of power from the oscillator or another stage still in operation leaking through to the aerial, resulting in an attenuated carrier wave being radiated instead of an interrupted one.

Another problem arising with telegraphy is that of "key clicks". There

are two types, namely the click which can be heard in receivers in the vicinity of the transmitter, even if they are not tuned to the transmitter frequency, and that heard on receiving the radiated signal, which may therefore be regarded as mutilation of the signals. Both these faults may be overcome by introducing suitable filters for slowing down the process of changing from the maximum carrier wave to zero.

With the present-day method of operation known as "break-in" it is necessary to key the oscillator stage, because this affords almost the only practical possibility by which the transmission may be interrupted by the receiving station. This means that the receiver is left continually in operation during the transmission and that reception is possible during the intervals between the signals. It is sometimes possible to key the next stage, but this involves a very high degree of screening of the oscillator stage, combined with a correct earthing system, etc.

Furthermore, keying may take place at different points in a particular stage. For example, the key may be connected directly in the high tension anode circuit. This has the disadvantage that the key is at high potential with all the risks attached to this for the amateur himself. The utilisation of a relay may of course provide the solution; the same applies if the key is connected in the primary circuit of the H.T. transformer where this is not required to supply other circuits. Cathode keying looks like providing an attractive solution, but has not many advantages over keying the anode circuit. When tetrode or pentode valves are used, keying may take place in the screen-grid circuit. In this case it is necessary to use a circuit whereby, with the key in the "up"-position, a negative voltage is applied

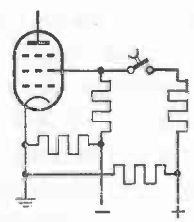


Fig. 67. Keying the screen-grid circuit with negative bias.

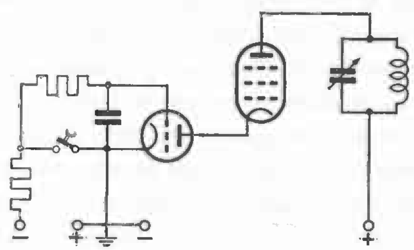


Fig. 68. Extra "keying" valve operates as electronic relay and cuts off the transmitter valve when the key is up.

to the screen-grid to ensure that the valve is completely cut off (Fig. 67). A frequently used method is that whereby the valve is cut off completely by applying a high negative voltage to the control-grid during the intervals in which the key is raised.

A popular method of keying involves using special "keyer" valves in place of a relay. They can be connected in the cathode keying circuits, in which case they operate as an electronic relay (Fig. 68). When the key is down the cathode current of the transmitting valve flows through the keyer valve, whilst the valve is completely cut off when the key is up, thus providing a very high impedance in the cathode circuit of the transmitter valve which is then also cut off.

CHAPTER 5

MODULATION SYSTEMS

5.1 Introduction

The various methods of conveying intelligence via the transmitter to the receiver have already been discussed in the introduction to Chapter 4 on "Amateur transmitters".

Amateurs usually transmit telegraphic information, in the form of morse signals, by means of the continuous wave or A1 system. Practical methods were described in Section 4.5 on "Keying methods".

For telephony, amateurs generally employ the amplitude modulation or A3 system, whilst the A3a (single sideband modulation) and F3 (frequency modulation) methods are also suitable. In this chapter we describe the various modulation systems used in telephony transmitters.

It has already been explained in Chapter 3 that as far as amateurs are concerned, intelligibility is more important than the fidelity with which a certain range of tones is transferred, so that for the purpose of speech transmission we may safely limit ourselves to a frequency range of 400 to 3000 c/s.

Fig. 6*a* showed an unmodulated radio-frequency signal and in Fig. 6*b* it was shown how this signal may be affected (modulated) by a certain audio signal. Since the audio signal is superimposed here on the *amplitude* of the r.f. oscillations, this system is known as *amplitude modulation.*

In Fig. 6*e* it was seen how the modulated a.f. voltage was reproduced after detection in the receiver. The strength of this signal clearly depends on the *depth* of the modulation, i.e. on the degree to which the *carrier* is modulated. Hence, the greater the amplitude variation in the r.f. signal, the greater the available a.f. voltage after detection.

Obviously, the aim should be to obtain *maximum efficiency* and this is realized if the amplitude variations are such that the minimum amplitude equals zero, i.e. if the *peak value* of the modulating a.f. signal is *equal* to that of the amplitude of the r.f. signal. At the *peaks* where the r.f. voltage is in fact *increased* by the a.f. voltage, the maximum amplitude is twice as great as the carrier, whilst in the *troughs* where the two voltages *oppose* each other, the amplitude becomes *zero*.

All this may be produced and adjusted by fairly simple means if the modulation consists of a *constant* a.f. signal. In the case of modulation with speech or music consisting of a great number of frequencies of varying strengths the matter is rather more difficult. The strength of the modulating a.f. signal must be so adjusted in that case that the peaks of this signal under *all* the conditions encountered *never* exceed the amplitude of the unmodulated carrier. Maximum modulation will therefore *only* be obtained at the peaks and in actual practice the *mean* modulation amplitude will be much lower than the maximum value. This is usually expressed as a percentage, *maximum* modulation corresponding to 100 % (amplitude of modulation = amplitude of carrier), whilst at an *average* modulation amplitude of 30 % the mean amplitude of the modulation is $0.3 \times$ the amplitude of the carrier.

Modulation exceeding 100 % would give rise to considerable distortion, apart from various other unwanted effects. To understand this we must bear in mind that an amplitude-modulated telephony transmitter has a certain bandwidth which, as may be derived theoretically, is determined by the highest frequency by which the carrier must be modulated. If we assume that in the case of speech the highest frequency to be reproduced for good intelligibility is about 3000 c/s and that the modulator circuit is arranged in such a way that frequencies above 3000 c/s are not passed to the transmitting circuit, our transmitter will be found to occupy a band of 3000 c/s on both sides of the carrier. Thus, if the carrier frequency is 1 Mc/s (1,000,000 cycles) the band which will be occupied by the transmission will range from 1,003,000 c/s to 997,000 c/s (1.003 to 0.997 Mc/s) under the above conditions. This is shown diagrammatically in Fig. 69 where f_o represents the position of the carrier in the frequency spectrum and the sidebands due to the modulation are shown shaded. If the maximum modulation frequency is f_m, the limits of the band will be indicated by $f_1 = f_o - f_m$ and $f_2 = f_o + f_m$, giving a total bandwidth of $2 \times f_m$.

We would like to point out once again that the region occupied by the band only indicates that the modulation frequencies employed in the transmitter are such that the *sidebands,* which at any given moment depend exclusively on the modulation present at that particular moment, will

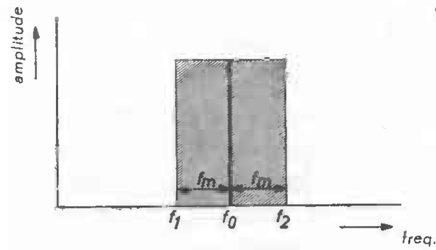


Fig. 69. Graphical representation of a carrier wave f_0 with side frequencies f_1 and f_2.

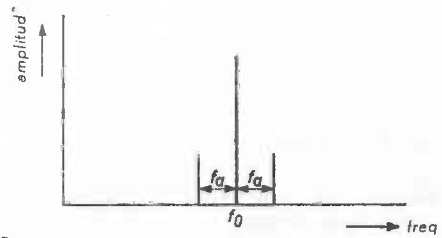


Fig. 70. Carrier wave f_0 modulated with a frequency f_a. Modulation amplitude approx. 30 %.

always be within this region. This is illustrated in Fig. 70 where the carrier frequency is modulated with one frequency f_a, so that the two side frequencies which are formed are $f_o + f_a$ and $f_o - f_a$. Apart from these three frequencies no other signal will occur, provided, of course, that the applied signal is purely sinusoidal.

The *strength* of the applied signal is determined by the *modulation amplitude* and is indicated in the figure by the length of the lines with respect to that of the carrier wave.

Distortion of a purely sinusoidal signal *will give rise to harmonics.* A harmonic is defined as an extra signal having a frequency which is an integral multiple of the fundamental frequency. Though harmonics usually have a much lower signal strength than the fundamental frequency, the mere fact of their presence indicates that the signal is distorted and this is often plainly audible.

Overmodulation (modulation exceeding 100 %) also gives rise to distortion, often very severe, because the modulation is clipped at the zero axis of the carrier frequency. What happens, in fact, is that if a carrier is originally modulated with one given frequency (e.g. f_a in Fig. 70), the carrier is now also modulated with frequencies $2f_a$, $3f_a$, and so on. As seen from Fig. 71, these harmonics form new sideband-frequencies correspondingly spaced from the carrier frequency. Clearly the bandwidth of the transmitted signal is then considerably and unnecessarily increased. If, during normal working, a second transmitter with a frequency adjacent to ours were operating and its signals received without difficulty, our

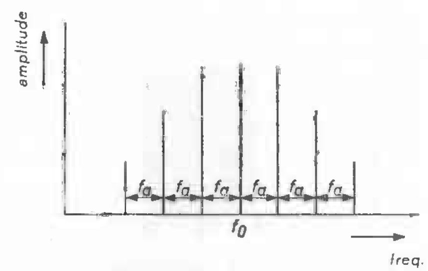


Fig. 71. Carrier wave f_0 modulated with frecuency f_a. Overmodulation occurred because the modulation amplitude is greater than 100 %.

additional sideband-frequencies associated with *overmodulation* would be audible in the adjacent channel and cause interference in the reception of this station. This effect is commonly known as "splatter".

5.2 Amplitude modulation

The following methods of amplitude modulation are generally suitable for use in simple oscillators (one-valve transmitters) and in the output stage of a multi-valve transmitter.

The amplitude of the r.f. voltage delivered by an oscillator or output valve may be varied in many ways. Basically, this amplitude which, in addition to the output impedance is also dependent on the alternating anode current, may be affected by varying the d.c. voltage of one or more electrodes. Thus, we distinguish *anode modulation* (in which the modulation is superimposed on the d.c. anode supply voltage), *control-grid modulation, screen-grid modulation* and *suppressor-grid modulation.* Combinations of different methods also occur, e.g. *anode-screen-grid modulation* in which both the anode and screen-grid voltages are modulated. Another system is *cathode modulation* by means of which the voltages to all the electrodes are changed simultaneously by variation of the cathode voltage.

Modulation applied to an oscillator (one-valve transmitter) is not generally recommended, as it has an adverse effect on the frequency stability,

besides always being accompanied by frequency modulation (FM) which considerably reduces the intelligibility.

Anode modulation has always been the most popular system of amplitude modulation. It causes very few difficulties, enables a very high quality to be obtained by simple means and yields a very high efficiency in the modulated amplifier. The required equipment, the modulator, is rather expensive, however, compared with that required for other modulation systems. This is obvious from the fact that for 100 % modulation the a.f. power to be delivered by the modulator should be equal to half the power absorbed by the output stage of the transmitter. Thus for a 100 W transmitter (consumption of the output stage without modulation), the modulator should deliver 50 W a.f. power. This is even higher in practice by virtue of some losses due to incorrect matching and losses in the modulation transformer, which should always be taken into account. If these are assumed to be approx. 20 % (and to obtain this the modulation transformer should be of very high quality) the driving power of the modulator will have to be 60 W.

Heising modulation is a popular method dating back to the beginning of amateur radio. The characteristic feature of this method (see Fig. 72) is the common choke through which the H.T. supply feeds both the modulator and the output valve. This never caused any difficulties in the case of triodes which were the only type of valve available in the early

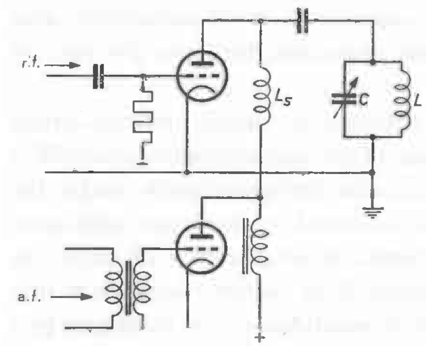


Fig. 72. Principle of Heising modulation, i.e. a form of anode modulation employing a choke.

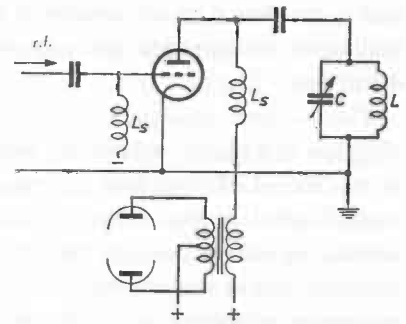


Fig. 73. Anode modulation with transformer coupling between transmitter and modulator.

years. A great disadvantage is, of course, that 100 % modulation is then impossible, because the anode voltage may never be reduced to zero. Some improvement may be obtained by including a smoothed series resistance in the transmitter supply circuit (between the a.f. and r.f. choke), thus reducing, in fact, the d.c. anode voltage at which the transmitter operates. Another method consists in connecting the modulator anode to a tapping on the choke, thus stepping up the a.c. voltage. The principal disadvantages are the cost of the choke which should have a high self inductance at a high direct current and the poor total efficiency owing to the modulator valve having to be operated under class-A conditions, resulting in a low efficiency.

Much better results are obtainable by adopting transformer coupling as shown in Fig. 73. Firstly, this enables the final modulator stage to be connected in *push-pull,* so that the modulator H.T. supply may be applied to a centre tap on the primary. Consequently, the currents in the two halves flow in opposite directions so that no pre-magnetisation occurs and this has a highly beneficial effect on the losses and the dimensions. Secondly, the modulator output stage may now be arranged as a class-B amplifier thus resulting in a considerable increase in efficiency. Lastly, optimum matching may be obtained by a correct choice of transformation ratio. It should be taken into account that the value of the anode load across the secondary winding is $\frac{V_a}{I_a}$, where V_a is the d.c. anode voltage and I_a the direct anode current of the output stage of the transmitter. This load may be regarded as constant and does not therefore give rise to distortion.

Control-grid modulation may be obtained by means of the circuit diagram in Fig. 74, where the grid bias of the radio frequency amplifier is modulated. To prevent overmodulation at the modulation peaks, the unmodulated output stage should be adjusted to *half* the maximum alternating anode current; this corresponds to an efficiency of 25 %. In practice, this is usually increased to about 30 % which corresponds to a maximum efficiency of 50 % at 100 % modulation. In principle, grid modulation is always accompanied by some distortion, as the valve characteristics are such that the relationship between the audio voltage and the modulated r.f. voltage is not completely linear. For amateur work

this effect, which is very difficult to control, should not be too serious.

The great advantage of this method is that much less audio power is required. The modulators should have a low internal resistance, however, to reduce the effect of the grid current pulses. The variations which occur

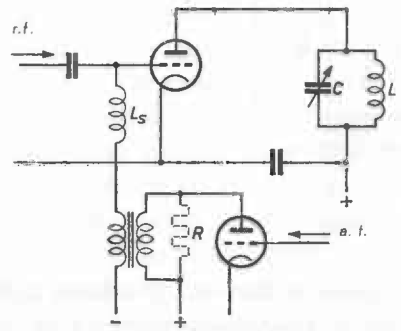


Fig. 74. Control-grid modulation. Transformer coupling.

in input impedance and -capacitance during modulation are likely to affect the operation of the preceding stage. If this stage is the oscillator, it usually means that the frequency and amplitude are affected, giving rise to fairly severe distortion at high modulation amplitudes.

In addition to the variable load of the transmitter it is recommended that a resistor be connected as a constant load across the secondary in the output circuit of the modulator. This could, for example, be approximately equal to the rated load at normal audio output (R, broken line in Fig. 74). It is also recommended that strong negative feedback should be applied to the modulator. A transformer ratio of 1 to 1 should be sufficient in most cases.

The operating principles of *screen-grid modulation* and the characteristics (low efficiency, distortion, etc.) are identical with those associated with control-grid modulation. The modulation is required to produce more power, however, whilst the maximum permissible screen-grid dissipation at maximum screen-grid voltages is exceeded fairly easily.

The circuit arrangement for *suppressor-grid modulation* is shown in Fig. 75. Again the efficiency is low and the negative bias applied to the suppressor-grid of the transmitting valve should be so adjusted that the alternating anode voltage drops to *half* the value with zero bias on this

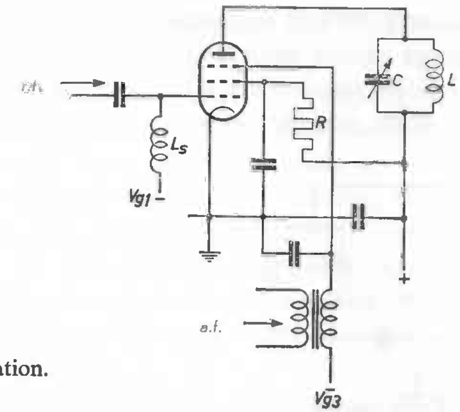


Fig. 75.
Suppressor modulation.

grid. In this case, too, the screen-grid dissipation may rise to a fairly high level and should therefore be measured. A modulation depth of up to about 90 % with little distortion is possible in most cases, whilst the power to be provided by the modulator is negligible. The voltages required to drive the transmitter are fairly high, however. The oscillator is practically unaffected.

Anode-screen-grid modulation is usually adopted in cases where the transmitting valve is a pentode, because if the modulation were applied to the anode only the screen-grid dissipation would almost always rise too much. The method by which the modulation is applied to both the anode and the screen-grid is shown in Fig. 76. The resistance of R should be

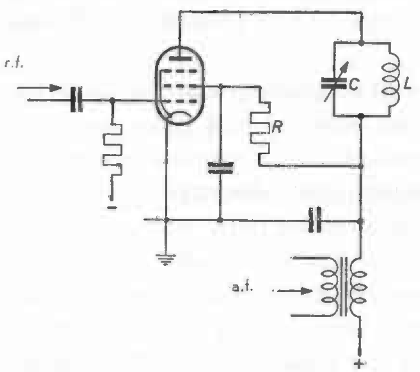


Fig. 76. Combined anode and screen-grid modulation. The correct screen-grid voltage is obtained by means of resistor R.

high enough to ensure that the screen-grid dissipation remains within certain limits. The transformer should match the value $\dfrac{V_a}{I_a + I_{g2}}$.

Clamp-tube modulation may be adopted in transmitters equipped with a screen-protective tube or "clamp" tube. If a transmitter is keyed by means of a negative bias on the control-grids of one or more valves, difficulties may arise if a screen-grid valve were used. No problem arises, however, if the screen-grid is fed from a strong bleeder circuit. The method of supply via a series resistor is considerably cheaper, however, and consequently very popular. A solution is provided in this case by employing a clamp tube in the arrangement shown in Fig. 77. If the excitation of the output valve drops to a level where the negative bias is inadequate, the anode- and screen-grid currents will automatically increase considerably. Since the clamp tube is then also without bias, however, this will represent a relatively low resistance and constitute, together with resistor R, a bleeder resistance across the H.T. supply; the screen-grid voltage consequently drops to a very low value, so that the anode- and screen-grid currents will also be very small.

The presence of a clamp tube can be utilised in such a way that the audio signal may be applied to its grid (see Fig. 78). This tube must be

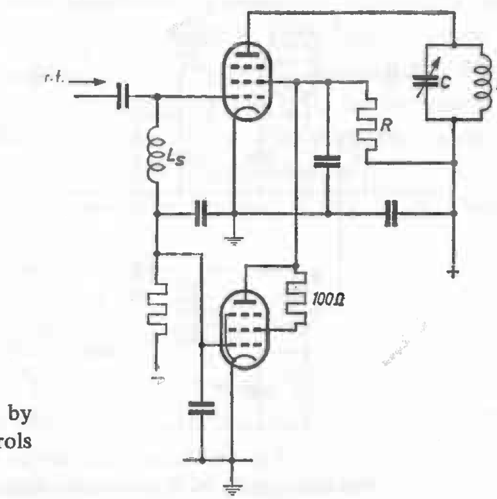


Fig. 77.
Protection of transmitter valve by means of clamp tube which controls the screen-grid voltage.

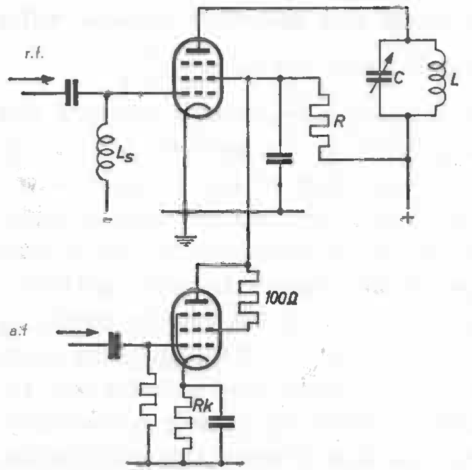


Fig. 78.
Screen-grid modulation with the aid of a clamp tube.

operated as a triode class-A amplifier. The system is basically very similar to Heising-anode modulation, but applied to the screen-grid with the resistance R substituted for the choke. The tube should be so selected that the value of R is approximately three times the normal load resistance

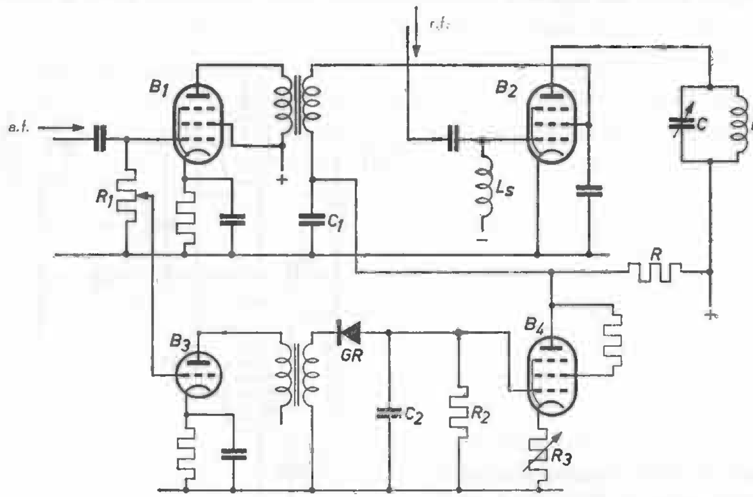


Fig. 79. Controlled carrier modulation.
The clamp tube B_4 is controlled according to the a.f. level.

required for class-A setting. The value of R_c should be such as to ensure that the current I_a of the output valve is half that required for ordinary telegraphy.

As with Heising modulation, 100 % modulation is not possible, unless a dropping resistor, by-passed for audio frequencies, is incorporated in the screen-grid circuit, so that the anode voltage of the clamp tube is slightly higher than the screen-grid voltage of the output valve.

Controlled carrier modulation is a modulation system in which the carrier is controlled by the modulation. During the periods of little or no modulation the input to the output valve is greatly reduced. This may be done without difficulty, for the carrier power, under all conditions, need only be just as high as is required for the modulation. Any extra power applied to the carrier is not really used to advantage. As the anode dissipation at this low modulation and reduced carrier power is of course also greatly reduced, the average anode dissipation will be lower and this can be utilised to obtain a higher output at 100 % modulation. An example of such an arrangement is shown in Fig. 79. The modulator B_1 modulates the screen-grid of the transmitting valve B_2. A portion of the audio voltage is fed from the potentiometer R_1 to the amplifier valve B_3 and, after being stepped up by the transformer, is rectified by a diode D so as to drive the clamp tube B_4 to cut-off by the resulting negative voltage. The higher the audio voltage, the higher the negative bias applied to output valve B_4, the higher the resistance of B_4 and the higher the screen-grid voltage of output valve B_2 and thus the greater the carrier power transmitted. When adjusted properly, the *output in the peaks can*, in fact, *be increased to twice* the output obtainable with constant carrier. The minimum input of the transmitter is adjusted by means of R_3. The product of $C_2 \times R_2$ (in μF and MΩ) should be about 0.1 and the product of $C_1 \times R$ should definitely be smaller.

5.3 Steps to prevent overmodulation with A.M.

Although the methods of controlling our transmitter will be described later, we give at this point several steps to be taken against the much-feared overmodulation or "splatter" which, as already mentioned, may cause serious interference in the reception of neighbouring stations.

One method of indicating overmodulation in amplitude-modulation circuits is shown in Fig. 80. Across the secondary winding of the modulation transformer a rectifier valve in series with a milliammeter is connected to earth. If overmodulation occurs the audio frequency voltage in the

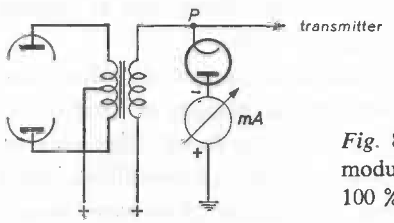


Fig. 80. Overmodulation indication for amplitude modulation systems with transformer. Indication at 100 % modulation.

negative peaks of the modulation will be increased to such an extent that the potential at point *P* will be momentarily negative with respect to earth. At that moment the rectifier will pass current which will be indicated on the milliammeter. Although this is a very simple method, it should be remembered that in the positive peaks the voltage at point *P* is twice the d.c. voltage applied to the transmitter so that the rectifier valve in the inversed voltage condition should be rated at least for this voltage. Furthermore, the heater of this valve must be fed from a transformer winding which should be insulated from the core and the primary winding so as to be capable of withstanding these high voltages. This difficulty does not arise if modern silicon rectifiers are employed.

If an indication is preferred before 100 % modulation is reached, thus introducing a certain safety margin, the circuit shown in Fig. 81 provides a suitable solution. The milliammeter is here connected to a bleeder resistor tapped, for instance, at $^1/_{10}$ of its value. Here, the voltage at which the diode passes current is equal to nine-tenths of the voltage in the first circuit, so that an indication is obtained when the modulation reaches 90 %. The capacitor *C* serves as audio by-pass and should have a value of 10 μF with a resistance of 1000 Ω. The milliammeter range may be 10 to 50 mA and could, if preferred, be replaced by an indicator tube or "magic eye" as shown in Fig. 82. In this case, too, the system with bleeder resistance for indicating modulations of less than 100 % may be adopted.

Apart from overmodulation indication there are several other steps

which may be taken to guard against splatter. To guarantee a narrow band in the frequency spectrum, it will be obvious that first of all steps will have to be taken to ensure that the audio frequency signals, i.e. the speech signals, fall within a given frequency range and that all the signals which

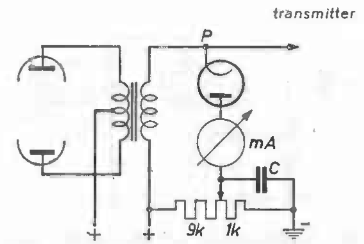


Fig. 81. Indication at modulation amplitudes of less than 100 %, in this figure 90 %. This is determined by the ratio of the bleeder resistors.

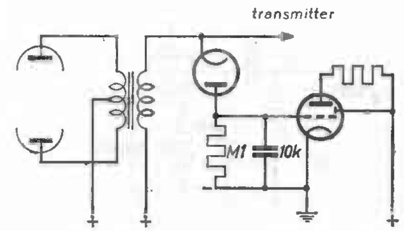


Fig. 82. Indication by means of a "magic eye".

are outside this range are suppressed. As already mentioned, most of the intelligibility of speech lies within the band between 400 and 3000 c/s, but a frequency band of 500 to 2500 c/s is usually adequate. The frequency curve of the modulator may be lined up accordingly, which means that all the frequencies at both the low and high ends of the audible range are deliberately suppressed.

Some simple methods of suppressing the lower frequencies are shown in Fig. 83. By placing a small coupling capacitor between two resistance-coupled stages and/or a low value by-pass capacitor across the cathode resistor, the frequencies below 500 c/s are greatly attenuated. Omission of the last capacitor usually results in loss in gain due to feedback.

The high tones may be suppressed by connecting capacitors in parallel with the resistors. Two methods are shown in Fig. 84. Capacitor C_1 may be connected in parallel with either a grid leak or a load resistor and should have a value of 300 to 500 pF. The value of C_2 depends greatly on the dimensions of the modulator stage and must be determined by trial and error.

A more effective method is provided by "speech clipping" (clipping the peaks of the speech modulation) in combination with a suitable low-frequency filter. Although the amplitude is of course limited very effectively by clipping the peaks, this method when used by itself, usually introduces a large number of harmonics, thus considerably increasing the frequency band again. This is prevented by inserting an effective filter *after* the

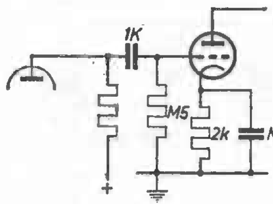


Fig. 83. Suppression of the low modulation frequencies by correct selection of capacitors.

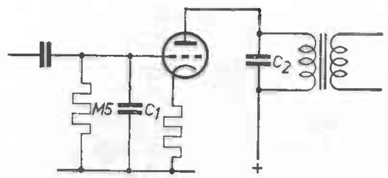


Fig. 84. Suppression of the high modulation frequencies by adding capacitors. C_1 may be 300–500 pF; C_2 is determined experimentally.

clipping circuit, which suppresses all the frequencies above about 2500 c/s.

With the system properly adjusted the average modulation depth may be increased considerably, producing more sideband power and greater intelligibility. One type of clipper-filter circuit which is best inserted immediately after the first microphone amplifier valve and before the gain control is shown in Fig. 85.

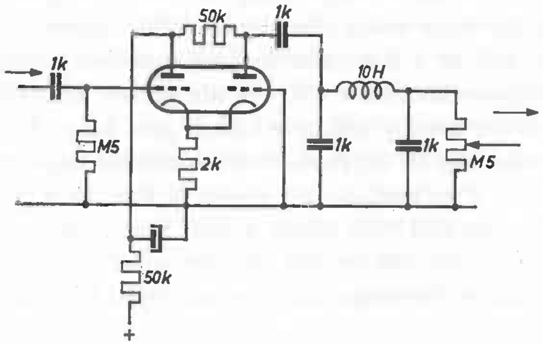


Fig. 85. Improvement of modulation by clipping the modulation peaks (speech clipping) and harmonic filter.

5.4 Frequency modulation (F.M.)

In addition to the system of amplitude modulation there are two other systems: *frequency modulation* and *phase modulation*. As the latter is not usually considered for amateur work, we will only give a description of *frequency modulation* which is of interest to amateurs in certain applications.

As implied by the designation, *the frequency* of the carrier *varies* in accordance *with the modulating signal*. The change in the carrier frequency, also known as *frequency deviation, varies proportionally to the instantaneous changes* in the *amplitude* of the modulating signal. The *rate* at which the carrier deviates *depends on the frequency of the audio signal.* The amplitude of the signal does not change.

It can be shown that this system, when applied to fairly high frequencies in the region of 100 Mc/s has great advantages with regard to the interference-free and distortionless transmission of high-quality music. This is the reason why this system is used extensively for broadcasting stations.

It is not very suitable for amateur work, however, as the amateur bands are already overcrowded and any system requiring a greater bandwidth would lead to even further congestion, apart from the fact that special types of detectors are necessary for the satisfactory reception of F.M. signals.

However, a system of "narrow-band" F.M. (NBFM) in which the

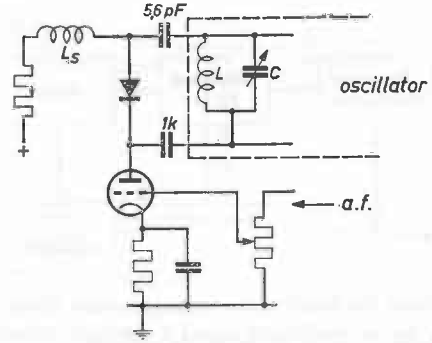


Fig. 86. Narrow band frequency modulation by means of a diode parallel to tuning circuit of the oscillator stage.

channel width is the same as that of a properly adjusted A.M. transmitter is available.

The modulator equipment is relatively simple and consists of only a slightly more elaborate oscillator (stage), so that this is very attractive for simple transmitters. It is not so easy to obtain a satisfactory modulation quality, although the intelligibility is often better than expected. Because it is possible to receive NBFM with the conventional type of A.M. detectors, whereby the receiver should be tuned to the flank of the tuning curve, everything depends on the slope of this curve with respect to the selected bandwidth of the F.M. signal.

An example is shown in Fig. 86 where a diode is connected in parallel, and a triode is connected in series with the oscillator circuit. The modulating signal changes the direct current passing through the diode resulting in a variation in the capacitive reactance and hence also in a variation in the frequency in sympathy with the audio-frequency voltages.

5.5 Single-sideband modulation

Single-sideband modulation (SSB) is, in fact, a form of amplitude modulation, in which one sideband and the carrier in the transmitter are suppressed. This system is becoming more and more popular in amateur work during recent years owing to the very great advantages associated

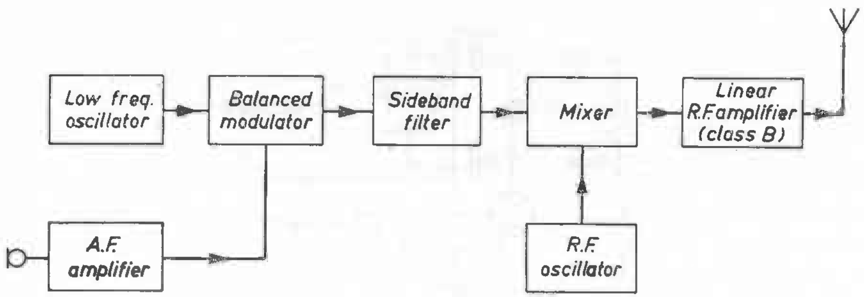


Fig. 87. Single-sideband modulation according to the "filter" system. The audio signal, together with an a.f. oscillator signal is fed into a balanced modulator, the carrier wave being suppressed. The sideband filter filters out one sideband. This is then transformed to the correct frequency.

with it. Because only one of the two sidebands is transmitted, the channel width is immediately cut in half, thus reducing interference. No problems arise, because all the audio information contained in the two sidebands is of course identical, so that the transmission of one sideband is sufficient. By also suppressing the carrier, two invaluable advantages are obtained: elimination of the heterodyning interference (which can be very tiring after listening for a long time) and, at equal input, a much greater effective power output (up to eight times greater) than with the conventional A.M. method.

SSB can be received without difficulty on any conventional amateur receiver, provided that it is provided with a beat oscillator and that the automatic gain control can be switched off (as is of course also necessary for the reception of telegraphy). The tuning of the receiver will be slightly more critical, however.

Although it is outside the scope of this book to enter very deeply into the technical and practical details of SSB, as this method of communication is rather more the concern of the more advanced amateur, we will now give some idea of the fundamentals.

Fig. 87 shows a block diagram of the "filter" system. The oscillator is adjusted to a low frequency and its output is modulated with the audio signal in a balanced modulator, in which the carrier is suppressed. By a very sharp band-pass filter (hence the name of the system), one sideband is suppressed and the other is passed. As at high frequencies the construc-

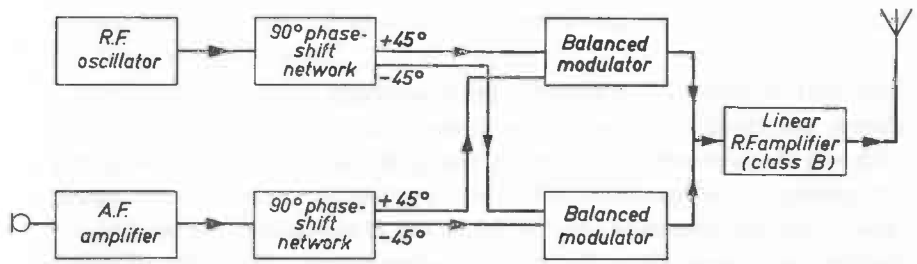


Fig. 88. Single-sideband modulation according to the phase-displacement system. By means of 90° phase-shift networks, the phases of both the carrier wave and the modulation are changed 90°. In the balanced modulators in which the carrier is suppressed again, the signals are combined in such a way that one sideband is suppressed.

tion of this filter presents even more difficulties than at low frequencies, the oscillator frequency is taken to be about 500 kc/s or sometimes even as low as 10-20 kc/s. The SSB signal is then passed to the mixer, where it is mixed with the signal from the r.f. oscillator to obtain the required radio frequency and then applied to the aerial via a linear r.f. amplifier. Very low oscillator frequencies, e.g. 10 to 20 kc/s, are usually stepped up twice.

The second system works by means of phase-displacement. As shown in Fig. 88, a phase-shift network is employed both after the a.f. amplifier and the r.f. oscillator, so that there are two r.f. signals and two audio signals, each having a phase difference of 90°, present in the circuit. The signals are then passed through the balanced modulators in which the respective carriers are suppressed and combine at the output stage, where the phases of the sidebands are such that one sideband is suppressed and the other accentuated. The r.f. amplifier must be linear again.

Many different systems derived to a greater or lesser extent from the above-mentioned systems are used in practice, all associated with typical advantages and disadvantages. The system to be adopted in a given case frequently depends on the available components or on the measuring equipment available for accurately tuning the various elements.

CHAPTER 6

AERIALS

6.1 Introduction

The aerial is an essential part of all transmitting and receiving installations. With transmitters, they are the media by which the radio-frequency power, modulated or unmodulated, is converted into alternating electromagnetic fields or waves which are characteristic in that they propagate freely in space, i.e. without the aid of intermediate wires or conductors.

These fields have an electrical and a magnetic component, so that at a random distance from the transmitter both a magnetic and an electric field can be measured.

The purpose of the receiving aerial is to pick up some of the power generated by the transmitter and to feed it into the receiver as r.f. voltage. As a general rule, aerial systems consist of:

a. the actual aerial or radiator;
b. the transmission lines or feeders through which the power is passed to or from the aerial;
c. the coupling units, if necessary, for matching the aerial to the transmitter or the receiver.

Obviously, an aerial functions most efficiently if erected as high and clear as possible. This is particularly important for transmitting aerials with a view to ensuring that the power is radiated as effectively as possible. Hence the importance of feeders, which should be capable of passing the power from the transmitter to the aerial with the minimum amount of loss. Basically, this applies also to receiver aerials, where the process is reversed. If the conditions are favourable, the aerial may sometimes be coupled direct to the receiver or even built in, as is common practice with broadcast receivers. For amateur work, however, the aerial should be erected in the most suitable position to ensure that the best possible results are obtained.

6.2 Aerials with single radiator

In addition to the available space, the type of transmitting aerial depends on the frequency or frequencies at which it is to be used. So, for broadcast transmitters the vertical aerial is usually employed, the dimensions being determined by the working frequency. For the amateur bands from 3.5 to 30 Mc/s, horizontal aerials are more common, though for the higher frequencies vertical types are used as well. For frequencies above 30 Mc/s more intricate types of aerials are often used.

Since the function of the aerial is to radiate the power applied to it to the maximum possible extent, this will determine its form. The aerial has therefore the properties of a tuned circuit; for this purpose a wire of a length of half the wavelength or a multiple thereof is most suitable.

In Chapter 2, the relationship between wavelength and frequency has already been given by the expression:

$$\lambda = \frac{300{,}000{,}000}{f}$$

where λ (lambda) = wavelength in metres,
f = frequency in cycles/second,

and the number 300,000,000 is the speed at which electromagnetic radio waves travel in free space and also that of radio frequency currents in good electrical conductors.

The concept of wavelength and the relationship between wavelength and frequency will be explained with the aid of Fig. 89.

The transmitter Z supplies the r.f. power to the aerial in which, as in every tuned circuit, an alternating current of the same frequency is produced. Let us examine what takes place during one cycle (that is one complete alternation) of this aerial current.

In Fig. 89*a* the moment at which the current in the aerial is zero is shown (0). Along the horizontal line which represents the propagation in a given direction, the situation at each point is shown plotted. Although the current in this aerial is zero at moment 0, the oscillation at the various points along this line is seen to differ from one point to the next. At point P, for instance, the oscillation is at a maximum.

In Fig. 89*b* the moment at which the aerial current is at a positive maximum is shown. Hence, the wave-train is maximum at the point

where the curve intersects the aerial. At point P, the amplitude of the oscillation is zero.

In Fig. 89*c*, the aerial current has dropped to zero again, the situation

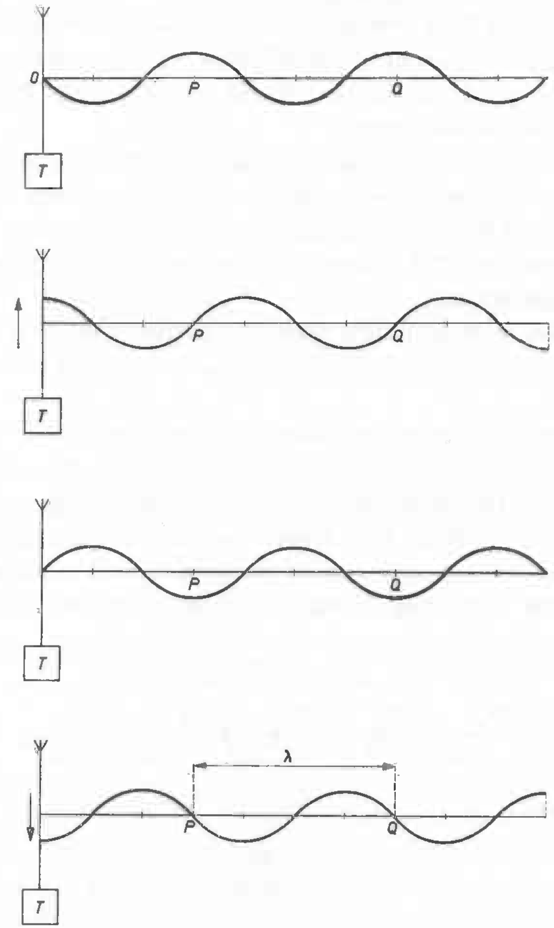


Fig. 89.

a. Current in transmitter aerial is zero. Max. amplitude at point P.
b. Current in aerial positive maximum. Zero-amplitude at point P.
c. Current in aerial zero. Max. amplitude at point P, but negative.
d. Current in aerial negative maximum. Zero-amplitude at point P. Distance $PQ = \lambda$ (wavelength).

at the other points having changed correspondingly. At point *P* the amplitude is at a negative maximum.

In Fig. 89*d*, the aerial current is maximum again, but negative and the amplitude is zero again at point *P*.

A comparison of these four figures shows that the current moves slowly from the transmitting aerial in the direction of propagation. At point *Q*, the situation is seen always to correspond to that at point *P*. The distance *PQ* is known as the wavelength.

It will be clear that the higher the frequency of the transmitter carrier wave, the lower the wavelength, at the same propagation velocity. This is illustrated in Fig. 90 where the frequency is twice that in Fig. 89. Here, the wavelength *PQ* is seen to be halved; this is confirmed by the expression given above.

On examination of a straight wire of a length equal to a whole wavelength (Fig. 91), the situation shown in (*a*) is identical with that shown in Fig. 89*a*.

Disregarding the manner in which this aerial is fed for the moment, it is obvious that the current will always be zero at the ends *P* and *Q*. In the ideal case, the phase difference between the voltage and the current will always be 90°, both with respect to the time and the place. This means that the voltage and current maxima do not occur at the same place or at the same time. Since the situation in the aerial shown in

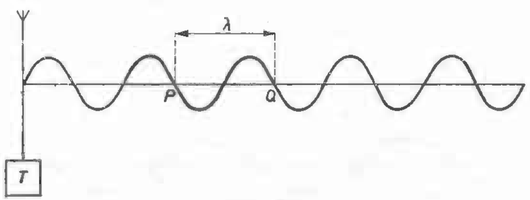


Fig. 90.
At a frequency twice that in Fig. 89, the distance $PQ = \lambda$ is halved.

Fig. 91 corresponds to that in Fig. 89*a*, the current at all points in the aerial will be zero at this instant. The voltage is maximum, however, and is distributed according to the sine curve *E*. The voltage is positive maximum at point *P* and also at point *Q*, but negative maximum at point S.

Immediately following this moment compensating currents will want

to flow from *P* to *S* and from *Q* to *S*. This is illustrated in Fig. 91*ab* in which the current is distributed in accordance with the curve I. Immedi-

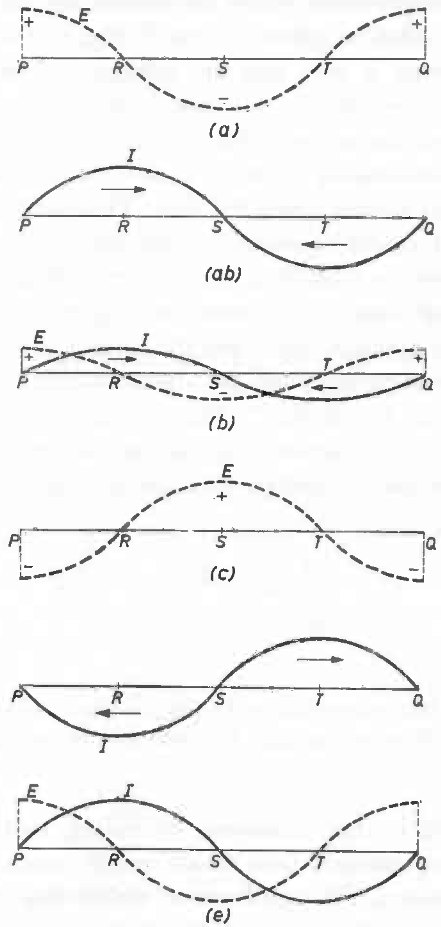


Fig. 91.

a. Voltage distribution along aerial wire of Fig. 89. Situation similar to that in Fig. 89a. Current is zero.
ab. Situation immediately after that in Fig. 89a. Voltage drops. Current rises.
b. Current distribution similar to that in Fig. 89b. Voltage is zero.
c. Voltage distribution similar to that in Fig. 89c. Current is zero.
d. Current distribution similar to that in Fig. 89d. Voltage is zero.
e. Usual representation of voltage and current distribution along aerials.

ately the current rises the voltage drops as indicated by curve *E*. Fig. 91*b* corresponds to Fig. 89*b* as far as the aerial is concerned; here the voltage is seen to be zero everywhere, whilst the current has reached its maximum value. The maxima fall at points *R* and *T*. Fig. 91*c* shows the situation in which the current is zero and the voltage negative maximum. The final situation is shown in Fig. 91*d* where the voltage is zero again and the current at a maximum, but in the opposite direction.

Fig. 91*e* is a combination of curves *a* to *d*, showing the local distribution of current and voltage along the wire. This manner of illustration is used frequently. It should be borne in mind, however, that this represents the situation shown in Figs. 91*a* to *d*. A typical aerial often used in practice is the half-wave aerial shown in Fig. 92. The voltage is at a maximum again at points *P* and *S* and the current at point *R*.

The power is transported from the transmitter to the aerial by means of transmission lines or "feeders". They are best coupled to one of the ends (Fig. 93) or in the centre (Fig. 94) of the aerial system. Feeders usually consist of a pair of parallel wires spaced close together. The reason

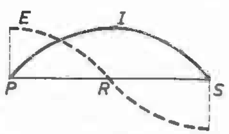


Fig. 92. Half-wave radiator (λ/2) in contrast with the radiator in Fig. 91 which is equal to a complete wavelength (λ).

for using this type is that a current- or voltage distribution may also develop on the transmission lines which would consequently participate in the radiation process. This is, of course, undesirable, because the power radiated from them is likely to be absorbed by surrounding obstacles, resulting in loss in power. By employing two transmission lines and feeding them in such a way that the voltages and currents occur simultaneously but in opposite directions at identical points in the two lines, they will balance each other out and not radiate any power.

If the radiator is fed at one of the ends, e.g. at point *S*, where the voltage is maximum and the current zero, the voltage and current at

the radiator end of the feeders should also be maximum and zero respectively to ensure that the power is transferred correctly. This point is known as a point of high impedance (high voltage and low current means high resistance) and this type of aerial is known as the "Zeppelin" aerial ("Zepp").

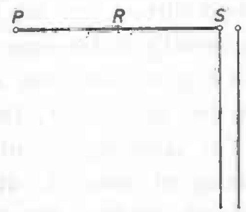


Fig. 93. Half-wave radiator, fed at one end (Zeppelin aerial).

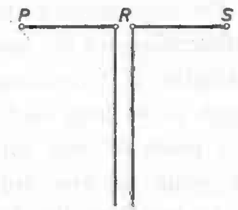


Fig. 94. Half-wave radiator, fed in the centre (dipole or Herz aerial).

If the radiator is fed at point *R*, however, the impedance at that point will be low (low voltage, high current) and the feeders should be matched accordingly. This type of aerial is known as the "dipole" or "Herz" aerial.

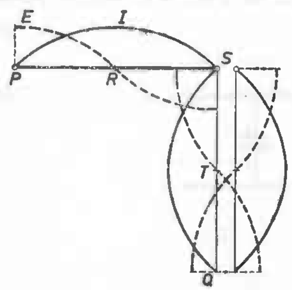


Fig. 95. Zeppelin aerial with distribution of current (*I*) and voltage (*E*) along radiator and feeders.

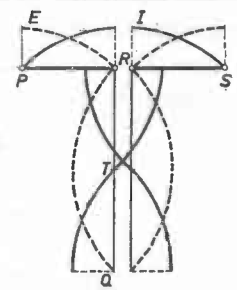


Fig. 96. Dipole with distribution of current and voltage along radiator and feeders.

Let us assume that the length of both the feeders and the aerial is equal to half a wavelength (λ/2). When the aerial is end-fed, the distribution of current and voltage will be as shown in Fig. 95. This is similar to

Fig. 91*c*, but at a right angle, whilst the values of current and voltage in the free feeder are opposite to those in the other feeder. At point *Q* (ends of the feeders) the impedance is seen to be high again, so that the transmitter should be matched in such a way that the power from it is delivered to a high impedance.

When the aerial is centre-fed (Fig. 96), the reverse is the case, namely, the impedance at point *Q* is low (high current and low voltage).

The dimensions of the feeders need not necessarily be the same at those of the radiator. If, for example, the feeders in Fig. 96 were only a quarter wavelength ($\lambda/4$) long and the radiator was fed at point *T*, this would give us a point of high impedance again. The same applies to Fig. 95 where a point of low impedance is available at point *T*. It is also possible to lengthen the feeders by $\lambda/4$, giving another corresponding point at which the radiator can be fed. Which impedance is most suitable for transmitters? Several methods of coupling have already been discussed in Chapter 4 where circuits for pure low and high resistance loads were shown in Figs. 60 and 61 respectively. In Fig. 60 the aerial is seen to be coupled to the output stage by means of a twin feeder and small coupling coil, but the method shown in Fig. 61 employs only a single feeder. If a symmetrical system were to be adopted here, an extra tuned circuit not connected to earth, as shown in Fig. 97, would be necessary.

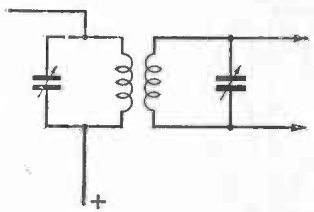


Fig. 97. Matching to feeders with high input impedance.

Amateurs tend to pay rather attention to this coupling, because transmissions are not usually confined to one single band, so that the aerial system has to be suitable for working under different conditions.

If the half-wave radiator is suitable, say, for the 3.5 Mc/s band, it will also serve as a full-wave radiator for the 7 Mc/s band. If the feeders

were made $\lambda/4$ long for the 80 metre band, say, they would be $\lambda/2$ long for the 40 metre band. The associated current distribution can be seen from Figs. 98 *a* and 98*b* respectively, where the voltage distribution has been omitted in order to simplify matters. For the 80 metre band the

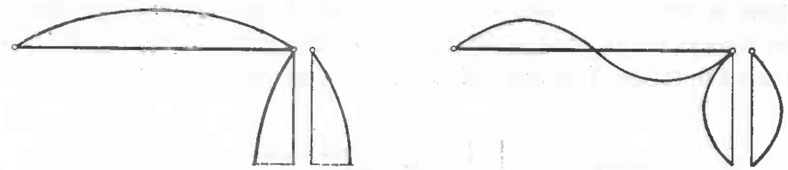


Fig. 98. Zeppelin aerial (Zepp) with radiator ($\lambda/2$) on 80 metres and feeders ($\lambda/4$).
a. Current distribution on 80 m, low-impedance feed point.
b. Current distribution on 40 m. Length of radiator equal to the wavelength, length of the feeders equal to half a wavelength. High-impedance feed point.

coupling to the transmitter is effected with maximum current (low impedance), whilst for the 40 metre band the impedance is high (minimum current). In this case the coupling system should be so arranged as to be capable of absorbing this difference.

One solution which is frequently used is to make the feeders one-sixth of a wavelength long instead of one-quarter of a wavelength for the 80 metre band; for the 40 metre band they are then $\lambda/3$ long. With the coupling shown in Fig. 99 (two variable capacitors in series), fairly

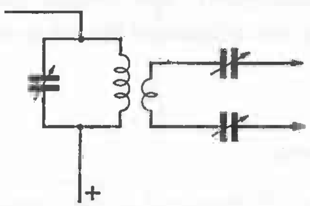


Fig. 99. Matching the feeders by means of series capacitors.

good matching for both bands is found to be obtainable, because the matching impedance at the feeder ends is about the same for both these bands.

For universal use, means are often provided for switching the aerial unit to parallel- or series tuning as required. (Figs. 97 and 99 respectively). An example of such a circuit is shown in Fig. 100. The unit is coupled to the transmitter by means of a link-coupling and can therefore be mounted in a suitable position. The coupling may be varied by changing the spacing between L and L_2 or by means of the variable capacitor C_3. If the feeders are connected to points AA, the capacitors C_1 and C_2 are connected in series. The value of L_2 can be reduced by short-circuiting HJ

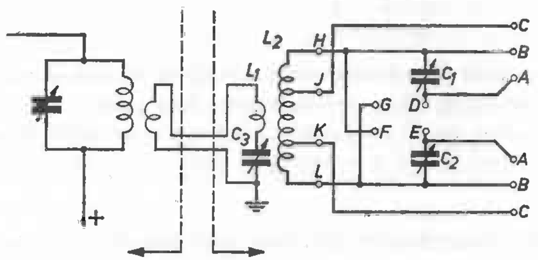


Fig. 100. Aerial coupling unit for matching to high and low-impedance.
$C_1 = C_2 =$ 200 pF.
$C_3 =$ 350 to 500 pF.

and KL. When connected to BB, the feeders are placed directly across coil L_2, parallel tuning then being obtained by connecting D to E (C_1 in series with C_2, hence low capacitance) or D to G and E to F (C_1 and C_2 in parallel, hence high capacitance). The feeders may also be connected to CC, in which case they are connected to the tappings.

6.3 Radiation patterns

When the aerial is properly matched to the transmitter via the coupling unit, so that the maximum quantity of power is radiated, we may ask ourselves in what direction this occurs. To find out, it is possible to make a "radiation pattern" of the aerial. The theoretical radiation pattern of simple aerials, indicating the radiation in all directions, is known and applies to aerials erected in free space. In practice, the actual situation

may be measured with the aid of special equipment. A description of how this is done falls outside the scope of this book.

The radiation pattern of a half-wave radiator is shown in Fig. 101. PQ represents the radiator. The pattern shows the radiation in any plane

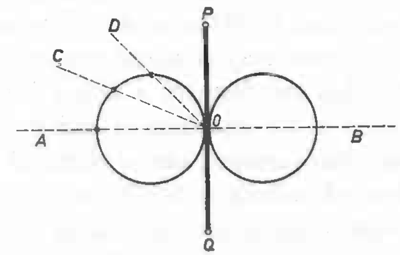


Fig. 101. Radiation pattern of halve-wave aerial ($l = \lambda/2$).

through the radiator PQ and is seen to consist of two circles arranged in such a way that the radiation is at a maximum in the directions A and B perpendicular to the radiator (indicated by the distances OA and OB respectively). In any other direction the radiation is less strong, e.g. in direction C this is represented by the distance OC, in direction D by OD, and so on. The radiation along the axis of the radiator itself is seen to be zero.

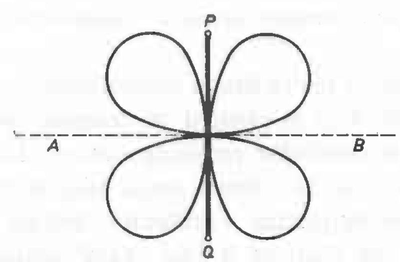


Fig. 102. Radiation pattern of full-wave aerial ($l = \lambda$).

In the case of vertical radiators, no radiation takes place in the upward and downward directions, but it is maximum in all the horizontal directions. The pattern always applies, at all planes through PQ. This is therefore a very suitable arrangement if energy is to be radiated equally in all directions. For the 80 metre band, however, this would mean an aerial of a length of 40 metres (approx. 120 ft) which is impracticable for most amateurs.

If the radiator is erected horizontally, the radiation pattern must certainly be taken into account and it should be borne in mind that no radiation occurs in the directions *P* and *Q*. When used for several bands (multi-band aerial) the length of the aerial may be made equal to the wavelength. The radiation pattern then has the form of a clover leaf (see Fig. 102) in which case the radiation in the directions *A* and *B* is also zero.

To overcome these disadvantages, omnidirectional radiators are used. An example of this type of radiator is the "Turnstile aerial" which consists of two half-wave aerials (dipoles) arranged in the form of a right-angled cross, the excitation of the dipoles being 90° out of phase. The lay-out and pattern are shown in Fig. 103.

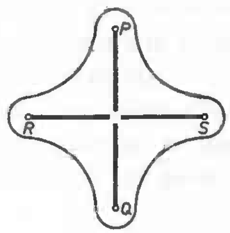


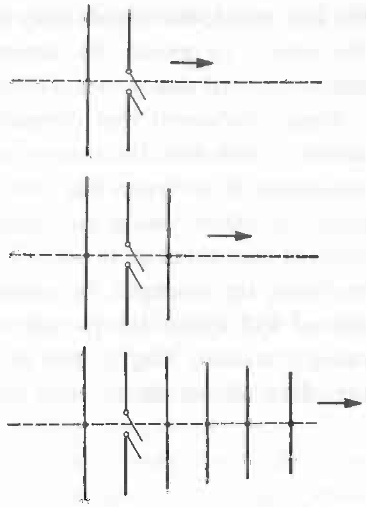
Fig. 103. Turnstile aerial is "omnidirectional".

In certain aerial arrays the radiation pattern tends to extend to one side. This is then suitable if it is desired to transmit power in one given direction, e.g. to one particular receiving station. The radiation is then magnified with respect to that from a single wire aerial ("beam arrays"). This may be achieved by placing a "reflector" behind the dipole and one or more "directors" in front of it (the "Yagi" aerial). Three different arrays of Yagi aerial are shown in Fig. 104; a dipole with a reflector (2-element Yagi); a dipole, a reflector and a director (3-element Yagi); and a dipole, a reflector and four directors (6-element Yagi).

To give an idea of the effect of the reflector and the directors, comparative data of these three types are given in the following table (the letters refer to the figures).

Fig. 104. Yagi aerials as directive aerials (beams).

a. 2-element Yagi.
b. 3-element Yagi.
c. 6-element Yagi.



	2-element Yagi	3-element Yagi	6-element Yagi
L	0.475 λ	0.475 λ	0.47 λ
L_R	0.5 λ	0.5 λ	0.49 λ
d_R	0.15 λ	0.15 λ	0.15 λ
L_1	—	0.455 λ	0.45 λ
d_1	—	0.1 λ	0.07 λ
L_2	—	—	0.435 λ
d_2	—	—	0.16 λ
L_3	—	—	0.42 λ
d_3	—	—	0.25 λ
L_4	—	—	0.41 λ
d_4	—	—	0.25 λ
Impedance (Z)	25 Ω	10 Ω	18 Ω
Gain	1.8 ×	2.5 ×	4 ×

The table only gives an idea of the possibilities. It should be pointed out that many variations on the dimensions given above are possible; on the one hand, the object may be to obtain the highest possible gain, on the other, to avoid the impedance falling below a given value. The importance of this value will be explained later.

Many variations and extensions are possible. The design of the Yagi aerial is such that the power is beamed in the horizontal plane. Another possibility is to beam the power in the vertical plane by taking special steps, in other words, to eliminate the radiation in the downward and upward directions in favour of that in the horizontal direction. This may be done, for example, by placing two or more aerials above each other spaced $\lambda/2$ apart. Frequently two Yagi aerials are placed one above the other ("stacked Yagi") and at high frequencies 3 or 4 Turnstile aerials are often placed above each other ("stacked Turnstile").

6.4 Transmission lines

The necessity of transmission lines or "feeders" has already been explained during the discussion of single-wire aerials and several feeder circuits were given, but these were all based on the tuned system. This presents no difficulties as far as the bands between 80 and 10 metres (3.5 to 30 Mc/s) are concerned.

Matters are different, however, for operation on the 2 metre and 70 centimetre bands (144 and 420 Mc/s). Let us assume that a dipole is used for working on the 2 metre band ($\lambda/2 = 1$ metre) and that this is mounted on a mast. The feeders will then be about 15 metres (= 45 ft) long. To obtain resonance with such a line immediately becomes more difficult in view of the tuning components which are required, apart from the fact that, unless the feeders are placed very close together, compensation of the radiation fields will be quite inadequate, resulting in strong radiation by the feeders, so that hardly any power reaches the actual aerial (radiator).

A different method is therefore adopted in this case. The first-named feeders have "standing waves", i.e. owing to being tuned, the voltage and current maxima occur at fixed points. At higher frequencies, however, use is made of "travelling waves", i.e. the r.f. currents have the character of the alternating electromagnetic fields as shown in Fig. 89 and pass

gradually through the feeders. This effect may be produced by utilising the "characteristic impedance" of the feeders.

Depending on the type, each pair of feeders has a given inductance and a given capacitance per metric length, which is called the "characteristic impedance". If the end of the line is terminated with a resistor of a value equal to the characteristic impedance, all the power applied at the input end of the line will be transported to the other end in the form of travelling waves and finally reach the resistor. The value of the resistor *must* be equal to the characteristic impedance, however, (good matching or termination of the line). If this is not so, the concept of "infinite length" is lost and some of the power would be bounced back with the result that standing waves would occur, with their well-known adverse effects. A great advantage of this type of line is that its length is immaterial.

To ensure that the maximum transfer of power takes place, the power source (in this case, the transmitter) should also match the characteristic impedance of the line.

Many types of transmission lines having various characteristic impedances are available commercially. Two types are distinguished: the "twin" or "balanced feeder" consisting of two parallel conductors enclosed in a strip of insulating material, and the "coaxial line" consisting of a round conductor placed in the centre of a circular tube which forms the second conductor. The former are used in symmetrical systems and the latter in asymmetrical systems in which the tube is earthed and acts as a shield for the inner conductor.

The impedance of the most commonly used twin feeder is 300 Ω and that of the most popular coaxial cable 75 Ω.

The use of these feeders with travelling waves has many attractive advantages, but necessitates matching the impedance. Considering only the above-mentioned values of 300 Ω for symmetrical systems and 75 Ω for asymmetrical systems for the moment, we immediately encounter difficulties with the single wire radiator. As a dipole (centre-fed) it has a low d.c. resistance and appears to have an impedance of about 75 Ω. But the dipole constitutes a symmetrical system, although the cable is not always suitable for the transport of transmitter power.

A solution is provided by using the "folded" dipole shown in Fig. 105. By adding a second conductor close to the first and interconnecting them at both ends, the impedance at the input terminals is found to be 300 Ω. The 300 Ω twin feeder is therefore excellent for this purpose.

The matching impedance for the 6-element Yagi is seen from the table to be 18 Ω. By folding the dipole this impedance is 4 × greater than this, i.e. 72 Ω which is sufficiently close for a good matching to a 75 Ω line. If another wire is erected parallel to the dipole (hence a total of 3-elements,

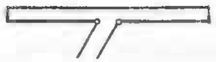


Fig. 105. "Folded" dipole with second, non interrupted radiator.

that is one dipole and two radiators), the impedance will be 3 × 3 = 9 times greater. This would mean an impedance of 9 × 18 = 162 Ω for the 6-element Yagi, which is not very practicable. With 4 radiators (3 extra wires) the impedance is 4 × 4 = 16 times greater, hence 16 × 18 = 288 Ω, which provides a good match to the 300 Ω twin feeder. For the 3-element Yagi with an impedance of 10 Ω, up to 6 radiators may therefore be used, resulting in a total impedance of 25 × 10 = 250 Ω. The extra radiators should be placed close to, and symmetrically about the dipole.

There are many other methods by which the impedance of twin feeder may be matched to the aerial, but these are outside the scope of this book. If desired, special books dealing with this subject should be consulted.

We would point out that the principle of the transmission line has already been discussed in the chapter dealing with transmitter circuits, in the form of link-coupling, where the correct matching has to be obtained by means of coupling coils.

CHAPTER 7

MEASUREMENTS AND MEASURING EQUIPMENT

Although pioneers in radio engineering, like the first radio amateurs, had to do without suitable measuring equipment during the first years of laborious research work, it is at present almost unthinkable to undertake any serious radio research work without using measuring equipment. The same applies to amateur work; although the average radio amateur will not have expensive and extensive laboratory equipment at his disposal, he should possess some simple measuring instruments.

The checking and trimming of newly-built equipment, the taking of control measurements during operation and the tracing and curing of faults, all this is almost unthinkable nowadays without the aid of measuring equipment.

Some measurements and the equipment required to carry them out are discussed in this chapter. The subject is very extensive, however, and can only be dealt with superficially in a book of this size.

First of all, the amateur should be able to measure voltages and currents, since they determine the proper setting and operation of any electronic apparatus. So, means should be available for measuring the principal operating voltages and currents of any valve, whether it be in a receiver, a transmitter or in auxiliary equipment, including the grid and heater voltages, the anode, screen-grid and (sometimes) control-grid currents. It is often desirable to measure r.f. voltages in transmitters or receivers, and this requires different types of meters.

The most suitable instrument for measuring direct currents and voltages is the *moving-coil meter*. In this instrument a coil of very light mechanical construction is mounted on pivots between the poles of a permanent magnet; the reading is obtained by means of a pointer fixed to the coil. If a current is passed through the coil, the resultant magnetic field, in combination with the field of the permanent magnet, will cause the coil to rotate until equilibrium is reached. The resulting deflection of the pointer measures the applied current.

This type of meter is suitable for the measurement of direct currents only. The scale is practically linear.

Moving-iron meters represent the second group of instruments, in which a moving iron is attracted by the field of a fixed coil through which the current to be measured is passing. The scale may be made practically linear by adopting a special method of construction. Moving-iron meters are suitable for the measurement of both direct and alternating currents.

There are various other types of meters suitable for the measurement of current or voltage, but these are not normally used by amateurs as frequently as the two above-mentioned types.

The measuring range of a meter is usually indicated on a scale. Thus, a meter which indicates a voltage of 300 V when fully deflected is suitable for measuring voltages between zero and 300 V and a meter with a range of 100 mA is suitable for the measurement of currents between zero and 100 mA.

Suppose we have a meter system, say an ammeter, which deflects fully at 1 mA and has an internal resistance of 100 Ω. According to Ohm's Law, the voltage required to produce full deflection is then 0.1 V, so that the meter may also be regarded as a voltmeter with a range of 0 to 0.1 V.

The sensitivity of a meter is usually expressed in ohms per volt. In the above example with 100 Ω per 0.1 V, the sensitivity would be 1000 Ω per volt. The higher this figure, the more sensitive the meter, because less current is required for a given meter indication.

If the meter is to be used as a voltmeter, the measuring range must be increased, however. This may be done by means of series resistors. If, for example, we connect a 900 Ω resistance in series with the above meter, the total meter resistance will in effect be increased to 1000 Ω (see Fig. 106). For full deflection a current of 1 mA is again required, so that the total voltage is 1 V, i.e. 0.1 V across the meter and 0.9 V across the series resistor. By connecting the resistor, we have increased the measuring range from 0.1 to 1 V.

With the aid of the sensitivity-figure (1000 Ω per V) the resistance for each required measuring range may be determined without difficulty. For

a full deflection of 10 V the total resistance should be 10,000 Ω (1000 Ω + 9,900 Ω resistor), whilst for a range of 300 V the total resistance should be 300,000 Ω. Several ranges may of course be combined. In the case of the two above-mentioned ranges (10 and 300 V) two resistors may be

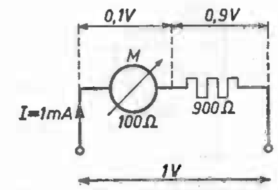


Fig. 106. Use of a series resistor to extend the measuring range of a voltmeter.

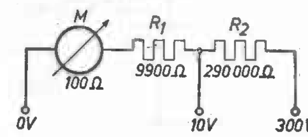


Fig. 107. Use of several resistors in series for various measuring ranges of the voltmeter.

connected in series, as shown in Fig. 107. The values which are required are then 100 Ω (meter) + 9,900 Ω (10 V range) + 290,000 Ω (300 V range). The possibility of obtaining a combination of many measuring ranges with only one meter system is of course very attractive.

The sensitivity also indicates the suitability of the meter for measuring voltages in certain circuits. It should be borne in mind that each meter has a certain consumption. In the example given above the current consumption is 1 mA at full meter deflection, independent of the voltmeter range. If the voltage at a certain point in some equipment is to be measured and the meter is connected to this point, this voltage is likely to change owing to the meter consumption. If the equipment is an H.T. unit capable of supplying a 100 mA current, the consumption of 1 mA of the 100 mA will, of course, have no effect on the voltage, but the situation is different where it concerns the measurement of the screen-grid voltage on a valve. A valve working under normal conditions is shown in Fig. 108*a*. When the meter is connected (Fig. 108*b*) the consumption of the meter causes a considerable drop in screen-grid voltage. If the screen-grid current is assumed constant at 0.5 mA (which is not quite true), the voltage will drop to 43 V when the meter is connected and this will be indicated. The meter is therefore completely unsuitable for this circuit. Even if a meter with a sensitivity of 10,000 Ω/V were used, the error would still amount to about 10 V. We should therefore be very careful and not just accept the reading on a meter.

If the meter is to be used as a current meter (ammeter or milliammeter), the ranges may be extended by connecting resistors in parallel

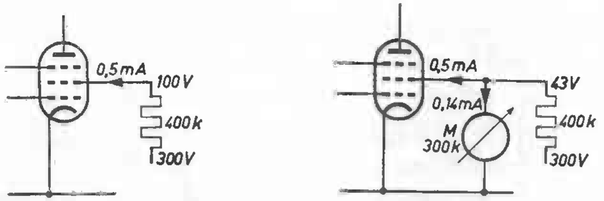


Fig. 108. Effect of a voltmeter on the actual voltage on the screen-grid of a valve during measurement.

a. Situation without meter.

b. Situation with meter connected. The voltage drops from 100 to 43 V owing to the extra current consumed by the meter.

(shunt resistor). For example, if a 100 Ω resistor is connected in parallel with the meter, the current to be measured will be distributed equally across the meter and the shunt (see Fig. 109). To obtain full deflection (1 mA through the meter), the current through the shunt should also be 1 mA, so that the total current is then 2 mA, i.e. twice the original range.

To increase the range to 10 mA, the current flowing through the shunt will have to be 9 mA. Since the voltage across the meter and the shunt is the same, the resistance of the shunt must be 9 times less than that of the meter, because the current through it is to be nine times greater. The shunt resistance is then $\frac{100}{9} = 11.1\ \Omega$. For a 100 mA range the shunt resistance is $\frac{100}{99} = 1.11\ \Omega$. In this way the values required to obtain different measuring ranges can be computed.

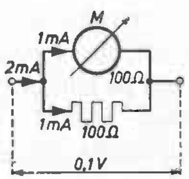


Fig. 109. Use of a parallel resistor (shunt) to extend the measuring range as ammeter.

In many cases a "universal" shunt is employed. This consists of a tapped resistor connected across the meter. Instead of tapping one resistor, separate resistors are, of course, also suitable (Fig. 110).

In universal measuring instruments, one measuring system is used for a large number of voltage and current ranges. The selected range is, as a rule, obtained by inserting the correct resistor(s) into the circuit by means of a good quality switch. In home-built instruments the selector switch is sometimes replaced by plug sockets.

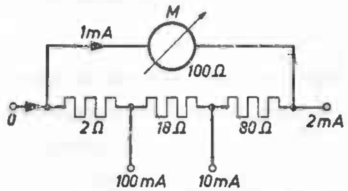


Fig. 110. Principle of the universal shunt.

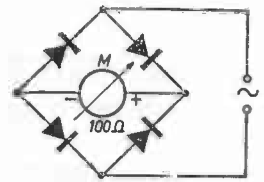


Fig. 111. Graetz-circuit for rectifying the alternating voltage to be measured by means of a d.c. meter.

Although alternating voltages are often measured by means of a moving-iron meter, the moving-coil type is generally preferred in a universal meter. In this case a.c. voltages are rectified by means of selenium cells or germanium diodes in the "Graetz" circuit (see Fig. 111); these are of course disconnected for measurements of direct currents. The cells cause a slight voltage drop so that the same series resistors are not usually suitable for identical d.c. and a.c. ranges. Alternating currents can usually be measured only with the aid of a transformer. The construction of this arrangement is far from simple, however, and falls outside the scope of this book.

Although it was not stated, the alternating voltages referred to above were understood to be voltages of audio frequencies, e.g. those from the mains, or in any case, those of frequencies below about 1000 c/s. For the measurement of r.f. voltages, however, the above-mentioned systems are usually unsuitable; they are measured by means of valve voltmeters (Fig. 112). The moving-coil milliammeter is here inserted in the anode circuit of a triode and the r.f. voltages to be measured are applied to the grid. Demodulation will cause the anode current to rise and this is indicated by the meter.

This type of meter has two very great advantages over ordinary meters; firstly, the fact that the valve amplifies makes this meter particularly suitable for the measurement of very small voltages; secondly, the damping exercised by the meter on the circuit is very slight and amounts to no more than that due to the grid leak. Another type of meter is the diode meter, in which the diode rectifies and the triode (or the pentode) serves only as

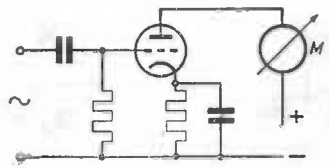


Fig. 112. Valve detector for the measurement of alternating voltages (valve voltmeter).

an amplifier. The operation can be improved by adding compensation circuits (thus enabling the meter scale to be utilised to the fullest extent), by adding more valves for increasing the sensitivity and by inserting a voltage divider in the input circuit for increasing the range or, alternatively, changing the range by means of a switch.

For the measurement of component values the following considerations apply:

Resistors may be measured by applying Ohm's Law ($E = I \times R$ or $R = \frac{E}{I}$). If a current is passed through the resistor to be measured (from a battery or other voltage source) and both the voltage across, and the current flowing through the resistor are measured, it is possible to determine the value of R (see Fig. 113). A correction must be applied to the milliammeter since this also indicates the current flowing through the voltmeter. If small resistances are measured and the current is many times greater than that flowing through the voltmeter, the latter may usually be disregarded. In the case of high resistance it is usually preferred to adopt the method shown in Fig. 114, where the voltage across the milliammeter is included in the reading. If the internal resistance of the milliam-

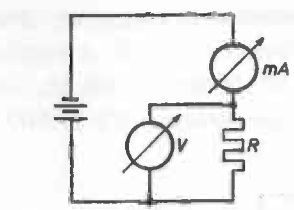


Fig. 113. Resistance measurement by means of ammeter and voltmeter. The milliammeter also indicates the current consumption of the voltmeter.

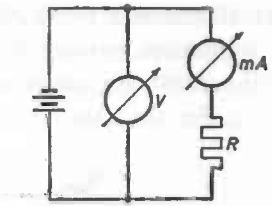


Fig. 114. Resistance measurement by means of ammeter and voltmeter. The voltmeter also indicates the voltage drop across the milliammeter.

meter is known, the correction to be applied can be found quite simply and may even be disregarded if this resistance is very small compared with resistance R.

The voltmeter may be omitted if the measuring voltage is known sufficiently accurately or can be adjusted to a known value. This applies to universal meters which include one or two positions for resistance measurement.

Resistances can be measured accurately with a Wheatstone Bridge (Fig. 115). This consists of the potentiometer R_1R_2 and terminals to

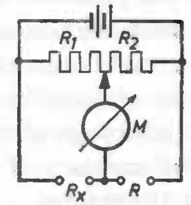


Fig. 115. Resistance measurement by means of the Wheatstone bridge. The resistor R_x to be measured is compared with a known resistance R.

which a calibrated resistance R and the resistance to be measured are connected. It may be deduced that $R_x = R \times \frac{R_1}{R_2}$. If the scale of the potentiometer is calibrated to the ratio $\frac{R_1}{R_2}$, the value of R_x may be determined without difficulty if R is known. Usually several standard resistors are built in and are connected by means of a switch. Fig. 116 shows a typical example in which 5 standard resistors are employed whose resistances are multiples of successive powers of ten. By taking a potentiometer of 500 Ω with two 125 Ω resistors connected in series, we obtain a scale calibration varying from 0.2 to 5. Thus, for the 10 Ω standard resistor the measuring range extends from 0.2 × 10 to 5 × 10, i.e. from 2 to 50 Ω. For the 100 Ω standard resistor, this becomes 20 to 500 Ω

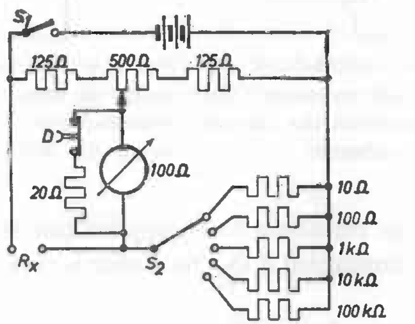


Fig. 116. Practical example of a Wheatstone bridge for resistance measurement. Switch S_2 selects the measuring range. The sensitive meter position is obtained by means of push button *D*.

and so on. The indicator is taken to be a meter with an internal resistance of 100 Ω; this is shunted by a 20 Ω resistor which may be disconnected by means of the push-button *D*. In this way the meter is protected from overloading when the potentiometer is on the wrong setting. After coarse adjustment, a more accurate setting and, consequently, a more accurate reading may be obtained by pressing push-button *D*.

The great advantage of this method is that the battery voltage does not affect the accuracy of the measurement, but only determines the sensitivity of the reading.

A similar bridge may be used for the measurement of *capacitors*. The battery is then replaced by a low frequency oscillator (producing a tone of, say, 1000 c/s) and the meter by headphones. The calibrated resistors are replaced by calibrated capacitors or the switch may be extended to cover such capacitors, since resistors may of course also be measured by means of a.c. voltage. An example of such an arrangement is shown in Fig. 117, where the a.c. voltage is derived from a neon oscillator. It should be noted that the bridge measures, in fact, impedances, so that in the case of capacitance measurement the potentiometer reading must be inverted. The

operation is very simple when the 50 c/s voltage from a heater transformer is used as measuring voltage, though the accuracy of the measurement is less good and the tone tends to become annoying when the bridge is used for prolonged periods.

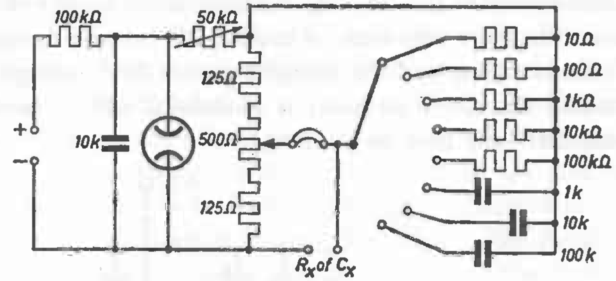


Fig. 117. Wheatstone bridge with a.c. voltage source, suitable for resistance and capacitance measurement. Headphones as indicator.

A useful instrument for measuring frequencies is the *absorption frequency meter*. In its simplest form this consists of a very robust variable capacitor mounted in a strong metal box, with its tuning dial clearly graduated in terms of frequency and provided with a good quality vernier. The box is provided with sockets for plugging in the coils required for the different wave ranges. To determine the frequency of a transmitter, the coil is coupled to the tuning coil of the oscillator. When the capacitor is tuned through resonance, maximum power is extracted from the oscillator. This is indicated on an anode- or grid current meter. With very tight coupling the oscillator may even cease to oscillate altogether; this could be checked by means of a monitoring receiver. The oscillator is usually completely screened, however, and in this case the r.f. power has to be extracted from the tank circuit. The power in this circuit is usually sufficiently high to operate a neon indicator connected in parallel with the absorption circuit (Fig. 118).

In all cases the accuracy is greatest when the meter is coupled as loosely as possible to the coil.

An interesting example is shown in Fig. 119. The absorption meter is provided with a milliammeter as indicator; this considerably increases the sensitivity. Rectification is carried out by the diode *D*. The circuit is provided with an aerial connection to which a vertical rod of a length of, say, 1 m is connected. The meter then operates as a field strength meter and is highly suitable for checking the tuning frequency of transmitters. An output for headphones enables the instrument to be used also as a *modulation monitor* for checking the modulation quality of one's own transmissions. The neon tube may, of course, still be used as indicator for frequency measurements and the headphones for field strength measurements, provided that the transmitter is modulated with a constant tone. The milliammeter may then be omitted.

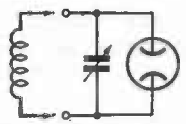


Fig. 118. Absorption frequency meter with interchangeable coil and neon indicator lamp.

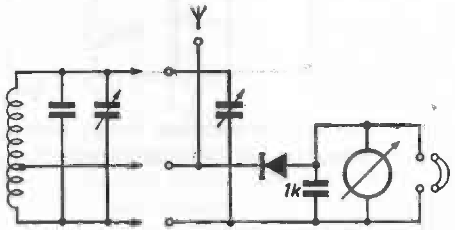


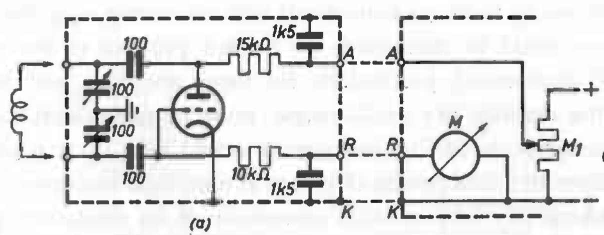
Fig. 119. Absorption meter, also field strength meter and modulation monitor. Coils have their own parallel capacitances for bandspread.

The coil in this circuit diagram is provided with a tapping to which the diode and the ferrite rod aerial are connected, thus ensuring that the quality and the accuracy of the tuned circuit are affected as little as possible. The coil is also provided with an extra capacitance by connecting a fixed capacitor and a trimmer across it. The values of these capacitors are chosen so that a good bandspread is obtained by means of the small variable capacitor; in this way the measuring accuracy is increased considerably. Suitably tuned plug-in coils are now available for each band.

Frequency measurements can also be carried out by means of the heterodyne method. The signal from a calibrated oscillator is heterodyned with that from the transmitter. A suitable receiver may be used as indicator. When the two frequencies are different, the resulting beat note is heard in the headphones or loudspeaker. When they are the same, however, no beat note occurs (zero beat) and the frequency is then read on the meter.

Another very useful instrument for amateur work is the *grid-dip meter*. This is a real multi-purpose instrument, the useful absorption meter having in fact been extended with a valve which can be connected as oscillator. A typical circuit diagram is shown in Fig. 120*a*, where the triode oscillator is a Colpitt circuit. If a miniature valve is used, this circuit can be built into the absorption meter without difficulty. A separate supply unit is then also provided, together with a microammeter and a sensitivity control (Fig. 120*b*). The microammeter indicates the grid current. If this "transmitting" wavemeter is placed in the vicinity of the tuned circuit and is in resonance with it, the circuit to be measured will extract power from the grid-dip meter, causing a considerable "dip" in the grid current. To enable this meter also to be used as absorption meter with transmitters the valve may be connected as a diode (Fig. 120*c*). This circuit also shows how the sensitivity of the meter may be increased. The potentiometer is inserted to keep the reading "on scale".

For amateurs it is not always easy to obtain such sensitive meters which, moreover, are easily damaged. A more suitable circuit employing a double-triode in which the second system amplifies the grid voltage variations in the first system is shown in Fig. 121. Switch *S* is the oscillator/diode switch.



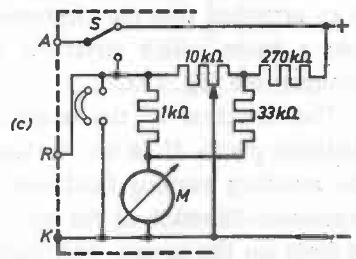


Fig. 120. Grid-dip oscillator.
a. Oscillator section with tuning circuit.
b. Supply unit with meter.
c. Supply unit with meter and improved sensitivity control.
Headphone connection.
S = oscillator/diode switch.
M = 0—200 μA to 0—500 μA.

It is recommended that the grid-dip meter is provided with a connection for headphones as shown in the circuit diagram in Fig. 120*c*. Headphones also constitute a sensitive indicating medium and enable the correct signal to be selected in cases of doubt.

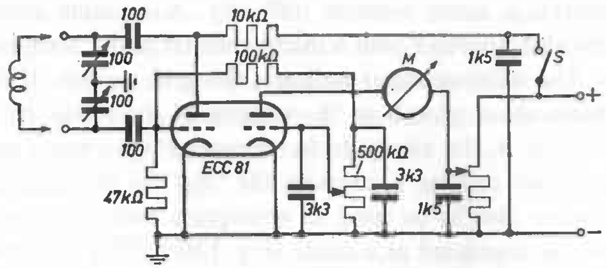


Fig. 121. Grid-dip oscillator with amplifier.
Meter M = 0—2 mA to 0—6 mA.

The circuit may be further extended by adding a modulator to enable the transmitted signal to be modulated when the switch is in the "oscillator" position. This would considerably extend the scope of the grid-dip meter which would, in fact, then also be suitable for use as trimming transmitter, beat oscillator, etc. A typical circuit diagram is shown in Fig. 122.

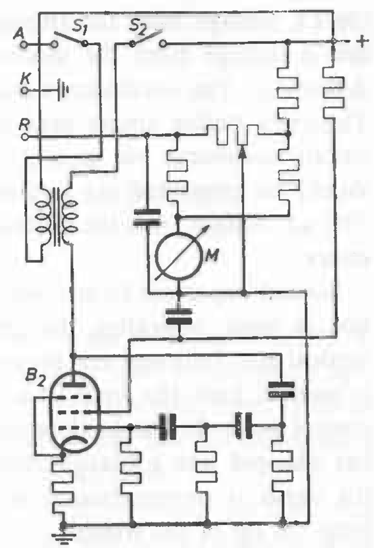
Although many more measurements and measuring equipment of interest to amateurs could be discussed, we do not propose to do so here. One very useful instrument, particularly for those amateurs working on "phone", viz. the cathode ray oscilloscope, must be mentioned, however.

A full description of this instrument would take up a whole book; we limit ourselves to a description of its use as a *modulation control instrument.*

The cathode ray tube consists essentially of an electrode system which is so arranged that the electrons emitted by the cathode are concentrated into a beam which strikes a fluorescent screen at high velocity (high voltage); see Fig. 123.

The direction of the beam may be changed by means of a pair of deflector plates. If an a.c. voltage is applied to the vertical deflector plates, the resulting varying field will move the electron beam to and fro in a horizontal direction at the same frequency. As the beam produces a spot of light on the screen, this spot is seen to move to and fro. When this

Fig. 122. Grid-dip meter with modulator. B_1 is the oscillator valve, B_2 the modulator valve. Switch S_1 changes the valve over from oscillator to diode operation, S_2 is the modulation "on-off" switch.



occurs at a sufficiently high frequency this will be seen as a horizontal line.

Similarly, a voltage applied to the horizontal deflector plates will move the spot in a vertical direction, so that by means of a combination of these two voltages, the spot may be moved anywhere on the screen.

The quality of the modulation may be determined by applying some of

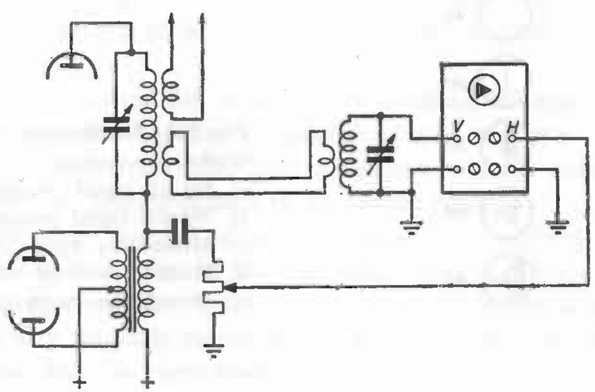


Fig. 123. Modulation depth measurement with an AM-modulated transmitter by means of an oscilloscope.

the r.f. voltage from the transmitter to the plates for vertical deflection and a voltage from the modulator output to the plates for horizontal deflection. The oscilloscope may be connected as shown in Fig. 123. The extra tuning circuit near the terminals for vertical deflection is not strictly necessary, but greatly improves the sensitivity. The tank circuit should be connected via a "link" to eliminate undesirable r.f. radiation. The a.f. voltage from the modulator is adjusted by means of the potentiometer.

Several important figures are given in Fig. 124. In (*a*) only a horizontal line is seen, indicating the presence of a.f. voltage only. In (*b*) the vertical line indicates the presence of r.f. voltage only. In (*c*) the figure is seen to have the form of a trapezium, which is characteristic of this control method. The modulation is here < 100 %. In (*d*) the trapezium has changed into a triangle, the modulation being exactly 100 %. In (*e*) the signal is overmodulated as is seen by the horizontal line extending from the tip of the triangle.

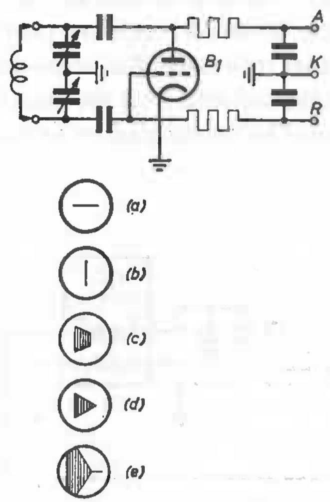


Fig. 124. Oscilloscope figures with modulation control.
a. No r.f. signal present.
b. No a.f. signal present.
c. Modulation depth < 100 %.
d. Modulation depth = 100 %.
e. Modulation depth > 100 %.

CHAPTER 8

STATION PLANNING AND BUILDING

The aim of this chapter is to give some idea of the problems involved in setting up an amateur station. Whether this is to be used for reception only or for transmission as well as reception, whether the equipment is to be simple or elaborate, there are certain rules which are best not disregarded and also some practical hints which apply in all cases.

When the amateur, after having studied the appropriate literature and having consulted more experienced colleagues, has finally decided what he wants, he should proceed as follows:

First he should draw a circuit diagram of the equipment to be built and ascertain that all the components are available by referring to the list of components. If necessary, the circuit may be modified to include available components. For example, if a receiver circuit employs the EF 85 valve and only the EF 43 is available, the latter would be equally suitable, because the characteristics are very similar. It should then be decided which components are to be changed (e.g. different screen-grid supply, valve-holder, etc.).

If all the components are available, an assembly diagram should be made, preferably showing the components spaced well apart to obviate undesirable mutual effects. The best results are naturally obtained if the layout follows the general pattern of the circuit diagram.

If the transmitter consists of several stages, it is simplest to position them adjacent to each other in one line. Only if the circuit is copied from an existing design may the layout shown therein be followed exactly (the components then probably taking up less room), because this has already been tried out and the worst faults corrected.

Care should be taken that the equipment does not pick up undesirable voltages at sensitive parts of the circuits. In receivers, all the control grids and associated leads are very sensitive, with particular emphasis on the aerial circuits and the grid circuits of the first audio stage. Sources of severe interference include heater leads which may produce strong variable fields, and H.T. transformers with strong stray fields which may induce undesirable voltages in, say, the i.f. transformers.

As a rule, all the necessary pieces of equipment, whether receivers, transmitters, parts of transmitters, measuring equipment or H.T. units, are built on metal chassis. All the operating and control units must, of course, be mounted on a metal front plate.

One method, in common use with amateurs for many years, consists in mounting the equipment on standard racks to which the standard front panels of transmitters, receivers, H.T. units, etc. are readily fixed. Apart from providing a neat way of building up the equipment, it enables individual units to be removed very easily for modification.

The one disadvantage associated with rack mounting is that long leads are often required for connections to H.F. units, aerial panels, etc.

The whole is difficult to screen effectively and the equipment may cause interference in neighbouring broadcast and television receivers due to radiation (BCI = broadcast interference; TVI = television interference).

Special constructions for transmitters and receivers of given types are being published to an ever greater extent to ensure that they meet the maximum requirements with regard to screening and length of leads (as short as possible), each piece of equipment usually complete with H.T. unit being housed in a special metal box.

Used in conjunction with adequate decoupling of the mains wiring and an aerial coupling designed to suppress harmonics, the metal box construction, when screened satisfactorily, meets the requirements with regard to the prevention of BCI and TVI.

The following rules should be followed when the equipment in the shack is connected to the mains:

A double-pole master switch by means of which all the power to the station can be switched off should be fitted on the table containing the receiver, auxiliary and measuring equipment and possibly also the transmitter. This will be found very useful in practice as this obviates the necessity of having to switch off all the individual equipment separately on leaving the shack, only to discover the next day that the soldering iron

had been left on. For this purpose the station should be provided with a number of sockets which become "live" on closing the master switch and to which all the equipment not belonging to the transmitter may be connected, including the receiver, measuring equipment, soldering iron. The transmitter may only be connected to these points if fitted with a mains switch. This is in any case advisable for all the equipment which, in addition, should be fitted with an indicator lamp whenever possible. The transmitter supply may be divided into two sections:

1. the transformers for feeding the heaters of the transmitting valves and rectifiers, the negative grid bias and all those circuits not opened on changing over from transmitting to receiving. Under certain conditions, the latter include the supply to the master oscillator;
2. that part of the H.T. unit which is disconnected during the "off" periods of the transmitter. This section could be supplied via an extra mains switch to which voltage is applied only if the first section is switched on. The extra switch may be replaced by a relay operated by means of the send-receive switch which is within easy reach of the operator.

The safety of the amateur station is enhanced by ensuring that all the electrical wiring, inside or outside the equipment, is properly carried out. All the equipment should be provided with fuses and the whole installation with a main fuse near the master switch to avoid putting the whole house in darkness if a short-circuit should occur.

Another safety precaution consists in connecting high resistances across all H.T. units to ensure that the smoothing capacitors do not remain charged when the units are switched off, thus avoiding electric shocks while work is carried out inside the equipment.

All the controls on the receivers, transmitters and auxiliary equipment should be clearly marked. Apart from simplifying the operation, it considerably enhances the reputation of your station, as it enables others to follow your actions without difficulty. All the switches should be marked "ON-OFF".

Where high and long aerials are used, it is recommended that they are earthed via a spark gap in order to carry off excessive charges caused by lightning.

After the station is set up and one or several parts of the equipment have been fitted, these must be trimmed and checked. This should be done with the greatest care and you should not be satisfied until everything works satisfactorily. The receiver should be trimmed as accurately as possible and be checked for quick and stable operation under all circumstances. The presence of any symptoms of instability should be checked with the potentiometers on the receivers set to maximum and minimum, etc. and should be corrected, as this would otherwise be a constant source of irritation.

The transmitter should never be tested on the outside aerial, but always on a dummy aerial, thus sparing your fellow-amateurs the dubious pleasure of having to listen to your experiments. The modulator should not be tested on one or more powerful loudspeakers, but on a ballast resistor provided with tappings to which the loudspeaker or headphones are connected.

Someone else should be asked to speak into the microphone to enable you to listen carefully on the monitor, first with only the modulator switched on and then with the modulator connected to the transmitter.

The aerial should not be connected before the equipment is working completely satisfactorily. It is then tuned . . . and the fun can begin.

CHAPTER 9

OPERATING A STATION

Assuming that you have obtained a licence permitting you to operate an amateur transmitter for experimental purposes, as is issued on passing the examination set by the Post Office, it should be remembered that the use of this licence is subject to several conditions which vary from country to country and must of course be strictly observed.

Moreover, radio amateurs have concluded several international agreements, among other things, on the internal distribution of amateur bands for use of telegraphy, telephony, etc. (see the attached table showing the frequency bands). You should cooperate fully in this respect as it increases the chance of making good communications.

Work only under the call sign allocated to you and take care always to remain within the amateur bands. This implies regular checks on your frequency and the quality of your tone or modulation. Pay attention to stability, hum, distortion, etc.

Communicate only with licenced amateurs. Official stations should, in fact, not be listened to at all and on no account should the contents of their messages be made known or passed to others.

Always be courteous. Try to reduce interference with your fellow-amateurs to a minimum. Confine your conversation to the subjects on hand. If your transmission should cause interference, either in the band or in your neighbours' sets, try to find a satisfactory and reasonable solution.

Radio communications are made in accordance with a certain operating procedure with which the operator should familiarise himself to ensure that reliable contacts are made with the minimum delay.

As a rule the band in which transmission is to take place is searched to find out which stations are on the air. It is not unusual to hear a station sending the general-enquiry call (CQ), in which case we may tune in the VFO (variable frequency oscillator) on this frequency. As soon as the relevant station has ended his call, we switch on the other transmitter stages and call him back. If no station is heard sending a general-enquiry call we may transmit such a call ourselves. It means of course that we wish to communicate with any station. In the case of telegraphy, the procedure is as follows:

CQ CQ CQ de PAØAAA PAØAAA PAØAAA K

CQ is the international abbreviation for "general-enquiry call" and is repeated three times, followed by "de" and one's own station call sent three times and the letter "K" which is the go-ahead for any station to answer your call. Station PAØBBB would answer as follows:

PAØAAA PAØAAA PAØAAA de PAØBBB PAØBBB PAØBBB $\overline{\text{AR}}$

The signal $\overline{\text{AR}}$, which is keyed without the interval between the letters, is always used after a call to a specific station before contact has been established.

PAØAAA can now open the communication as follows:

PAØBBB de PAØAAA R GN OM TNX FR CALL - . . . - UR SIGS RST 578 - . . . - QTH LONDON NAME JOHN - . . . - OK?
PAØBBB de PAØAAA $\overline{\text{KN}}$

The contents of this message are readily understood with the aid of the morse code, Q-code, RST-code and the table of abbreviations attached to this book. We would point out that the signal $\overline{\text{KN}}$ at the end of the message means the go-ahead for a specific station to the exclusion of all others. When there is no objection to theirs breaking in, the signal K may suffice.

After information has been exchanged, the contact is ended as follows:

PAØBBB de PAØAAA R TNX FR QSO 73 GUD LUCK ES HPE CUAGN $\overline{\text{SK}}$ PAØBB DE PAØAAA.

The signal $\overline{\text{SK}}$ indicates the end of the contact; this is followed by the call (3 ×). If the station goes off the air this may be followed immediately by CL, otherwise another general-enquiry call may be given.

If the station is equipped for break-in working, this fact is made known by including the letters BK in the call:

CQ BK CQ BK CQ BK de PAØAAA, etc.

This means, therefore, that the station is listening out on its own frequency while the call is being made.

The telephony procedure is as follows:

General enquiry call:

CQ (repeated about five times), this is PAØAAA calling CQ (to be repeated several times). (The call sign should appear at least once every 5 or 6 CQ's). The reply is:

PAØAAA, this is PAØBBB, over (or "go-ahead" or "come in please"), upon which the actual QSO takes place. The QSO is ended as follows: PAØAAA, this is PAØBBB over and out, on which PAØAAA replies: PAØBBB, this is PAØAAA, closing down and out.

Every transmitting amateur is required to keep a complete record of all the contacts and other observations in a station log. In addition to the date, the time and all calls heard (whether two-way contacts resulted or not), it should show the frequency, the RST data of the station which was heard as well as the RST report received (where applicable) and all further particulars.

Every contact should be confirmed by means of a QSL-card. This is a special card on which all the data of the contact and the most important data of one's own station are entered. Fill in the card as fully as possible and send it in quickly via the respective QSL-bureau.

CHAPTER 10

PRACTICAL EXAMPLES

In this chapter several very simple receiver and transmitter circuits particularly suitable for beginners are described. We would strongly advice all beginners against buying intricate and elaborate equipment at once. They should start with a simple set-up and the following examples should help them towards acquiring the necessary practice.

10.1 A straight receiver

In a straight receiver the r.f. signal (possibly after amplification) is fed straight to the detector, as distinct from the superhet where frequency changing takes place first. The receiver includes one r.f. stage, the detector stage and two audio frequency stages, three valves being required (+ another in the H.T. supply section). The r.f. stage employs the EF 80, the screen-grid of which is fed via a potentiometer; the gain of this stage is thus controlled by means of the screen voltage. The aerial is connected via a 100 pF variable capacitor to ensure that any type of aerial is matched to the best possible extent.

A switch is provided for switching the two tuned circuits (one for the r.f. valve and the other between the r.f. stage and the detector) to the 80, 40 and 20 metre bands; each band can be adjusted separately by means of trimmers connected across the fixed capacitors.

In the detector stage, employing the EF 80, feedback takes place from the anode- to the grid-circuit. The feedback may be properly aligned for each band by means of trimmers and is controlled by varying the screen-grid voltage by means of a potentiometer. For the correct procedure see Chapter 3.

The detected signal is passed to the audio amplifier via a potentiometer

(the "gain" control). This amplifier consists of two stages, the triode section of the ECL 80 being used as first amplifier and the pentode section as power amplifier for delivering sufficient power to a loudspeaker. If the receiver is to be suitable for headphone reception only, a double triode such as the ECC 83 may suffice (see Fig. 21). The power consumption is then considerably less, so that the rating of the power transformer may be reduced correspondingly.

Because the negative grid bias for the triode section of the ECL 80 need only be approximately 4 V and that for the pentode approximately 7.3 V, the lower end of the gain control is connected to a tapping on the cathode resistor.

The voltage of the H.T. units is approximately 170 V (voltage on the second electrolytic smoothing capacitor). A higher voltage is obtainable (up to 250 V); this does not improve the sensitivity, but enables a slightly higher output to be obtained. The superfluous voltage is absorbed by the smoothing resistor between the two electrolytics, which is cheaper than a good quality choke.

The coil data are shown in the following table.

Band	80 metres	40 metres	20 metres
selected freq. range	3.4—3.9 Mc/s	6.8—7.5 Mc/s	13.8—14.6 Mc/s
$\Delta f/f_{max}$	12.8 %	10 %	5.7 %
ΔC	25 pF	25 pF	7.5 (seen at top of coil)
C_{min}	75 pF	110 pF	60 pF
L	22 μH	4.2 μH	2 μH
coil former diameter	29 mm	29 mm	29 mm
wire diameter	0.5 mm	0.5 mm	0.5 mm
winding length	30 mm	30 mm	30 mm
tuned coil	35 turns	15 turns	10.5 turns (tapping at 6 turns)
aerial coupling coil	5 turns	4 turns	3 turns
feedback coil	10 turns	7 turns	6 turns

It should be emphasised that these data are to be regarded only as a guide, for the exact number of turns are determined by the design, lay-out, etc. and can therefore be determined only by trial and error.

10.2 A short-wave superhet

This circuit has been designed by Philips, Eindhoven, The Netherlands, who gave permission for publication in this book. Full description and constructional details for building this receiver are obtainable from Philips.

This superheterodyne receiver consists of an r.f. amplifier (EF 85), frequency changer (ECH 81), i.f. amplifier and detector (EBF 89), and audio amplifier (ECL 82). It also includes an EF 89 as BFO (beat frequency oscillator) which is inserted into the circuit by means of switch Sk_1.

The receiver covers the whole range of frequencies from 1.5 to 30 Mc/s (200 to 10 metres) in six ranges, each with three tuned circuits.

The r.f. and a.f. amplifiers are controlled separately, the former by varying the screen-grid voltage of the r.f. or i.f. stages, the latter by means of a potentiometer in the input circuit of the audio stage.

The oscillator coils of the three higher ranges are connected in a fairly complicated feedback circuit. In addition to the normal coupling coil, another coupling coil is employed for providing the extra coupling required to ensure that the oscillator continues to oscillate fairly constantly over the fairly wide frequency ranges involved, thus guaranteeing an almost constant amplification by the frequency changer.

As the beat oscillator, the detection diode is connected to the last i.f. circuit (secondary of second band-pass filter). The a.g.c. diode (automatic gain control) receives its voltage from the third circuit, however, and tends to keep the voltage to this circuit constant. This system provides quieter tuning than when the a.g.c. is applied to the last i.f. circuit. To improve the noise properties of the receiver, the r.f. and mixer valves are biased less strongly. The suppressor of the i.f. valve applies bias to the r.f. and mixer valves only after a threshold value is exceeded.

10.3 A one-valve telegraphy transmitter

In one-valve transmitters special steps must be taken with regard to the

frequency stability. As shown in the accompanying circuit diagram a crystal oscillator is used. A 50 mA signal lamp (flashlight bulb) is connected in series with the crystal to indicate the presence of r.f. current. The lamp also acts as a fuse in case the current increases to such an extent that the crystal may be damaged. The anode current is read on the milliammeter and aerial current is indicated by means of a 300 mA flashlight bulb. The aerial is coupled via a π-network (see Chapter 4, Fig. 62).

The 150 + 480 pF variable capacitor is set to maximum capacitance and the extra capacitor (600 pF) switched into circuit. The circuit is then aligned by means of the 250 pF variable capacitor, the point of resonance being indicated by a dip in the anode current. If we now adjust the 150 + 480 pF capacitor slowly, keeping the meter in the dip by also readjusting the 250 pF capacitor, the power in the aerial will increase gradually; this is indicated by the 300 mA bulb which lights. This is continued until a further reduction in the capacitance yields no appreciable change in aerial power.

If necessary, a long aerial may be connected via the 47 pF capacitor for better matching.

If the aerial current exceeds 300 mA, the bulb may be shunted with a thin piece of copper wire.

The morse key is plugged in at *SL*.

An H.T. unit supplying 200-400 V, 125 mA is adequate. The input (hence also the output) depends on the power consumption.

The transmitter is suitable for working in the 80- and 40-metre bands, the required band being switched in by means of the coil.

For 80-metre operation an 80-metre crystal is required. The frequency is doubled for 40-metre operation. A separate 40-metre crystal will benefit the output on this band.

The mechanical construction is very simple and gives plenty of scope for carrying out experiments.

10.4 A three-stage transmitter for the 80-, 40- and 20-metre bands

This transmitter is provided with a VFO (variable frequency oscillator) connected in a Clapp circuit (Chapter 4, Fig. 44) which covers the 80-metre band and can therefore be tuned straight to any frequency in this band.

The anode circuit is tuned permanently to 80 metres, the centre of the band being obtained by means of a trimmer. The anode circuit of the second stage is arranged as a frequency doubler and is tuned permanently to 40 metres. The output stage is the same as that shown in Fig. 60 (low-impedance aerial coupling). The respective coil-tappings for 80-, 40-, and 20-metre operation are selected by means of a switch.

The drive through the EL 84 is adequate for operating the QE 06/50 at maximum ratings for 80-metre operation. The output stage acts straight for 40-metre operation, but the frequency is doubled for 20-metre operation.

For telegraphy all the stages are provided with extra negative bias which is short-circuited when the key is closed, thus cutting off the valves.

The oscillator can be switched on separately by means of switch S_1, thus enabling the transmitter to be tuned to the frequency of the calling station while listening to it, by heterodyning in the receiver. S_2 is in parallel with the key and thus functions as an ON-OFF switch for the transmitter when the modulator is plugged in to the terminals marked MOD.

The modulator consists of a push-pull stage (2 × EL 84) by means of which the transmitter may be modulated 100 % up to a transmitter input of about 30 W. The ECC 83 operates as a preamplifier and phase inverter and the EF 86 serves as a speech amplifier for less sensitive microphones (crystal microphone, etc.). Highly sensitive carbon microphones may sometimes be connected via a transformer to the pick-up terminals.

The transmitter, the modulator and the power supply unit are all built on separate chassis to reduce stray coupling and facilitate experiments. To enhance the frequency stability the construction has been made as robust as possible.

We would point out, however, that, although the given circuits have been properly worked out and tested, the circuits may have to be modified in individual cases, since the electrical properties can be considerably affected by the method of construction. The photographs may provide considerable assistance in this respect.

APPENDIX I

BANDSPREAD CALCULATIONS

For a receiver covering the whole short-wave range from about 2 to 30 Mc/s in, say, 5 bands, in consecutive or even slightly overlapping ranges, the vernier required for tuning stations in the amateur bands (and also in the broadcast bands) should have a fairly high gear ratio.

Even where the accuracy and stability of the vernier are adequate, the need for spreading out the stations on the scale will still be felt, as this will provide a much clearer indication of the position of the tuned frequency on the scale.

As amateurs are as a rule only interested in receiving the official amateur bands, they will want to extract these bands and spread each of them across the whole scale. This can be arranged entirely by electrical means by properly dimensioning the tuned circuit. Several methods of doing this have already been described in Chapter 3.

It should be borne in mind that a tuned circuit is mainly determined by three quantities: the self inductance L, the variable capacitance ΔC (delta C) and the minimum capacitance.

L is mainly the inductance of the tuning coil, although at high frequencies that of the wiring also plays a part; ΔC is the difference between the maximum and the minimum capacitance of the variable capacitor and C_{min} is the total circuit capacitance with the variable capacitor set to minimum capacitance (plates out), thus comprising the zero capacitance of the variable capacitor, the capacitances of the coil, the wiring and of any trimmers and/or other parallel capacitors present, including the capacitances of the valve and the valve holder, if these are in parallel with the circuit capacitance.

It can be shown that the *ratio* of the minimum frequency to the maximum frequency to which a circuit may be tuned is determined by the ratio of maximum to minimum capacitance. The actual frequency band for which the circuit is suitable is thus determined by the *inductance L*. If the capacitance of a 100 pF variable capacitor is inserted in a circuit, so that $C_{min} = 33$ pF, then $C_{min} : C_{max} = 1 : 4$ (viz. 33 to 133 pF). The frequency ratio is now $1 : \sqrt{4} = 1 : 2$. With this circuit, a band of, say, 3 to 6 Mc/s or 5 to 10 Mc/s may be covered, in fact any band having a ratio of 1 : 2. The actual frequency is determined by the value of the inductance *L*, however.

The nomogram of PAØWP shown in Fig. 125, which is based on this premise, makes use of the values of ΔC and C_{min}, so that the frequency variation Δf may be expressed as a percentage of f_{max}.

To illustrate this, let us calculate a tuned circuit suitable for bandspread in the 80-metre band. This band ranges from 3500-3800 kc/s, but in view of possible minor differences between theory and practice we take 3450-3850 kc/s, i.e. a bandwidth of 400 kc/s.

The left-hand column of the nomogram shows the $\Delta f / f_{max}$ in % on the left, i.e. in this case 400 : 3850 = 10.4 %. For convenience, we take this to be 10.5 % and find this on the scale.

The value of ΔC must also be known. For tuned circuits on short waves this value is preferably selected low to obtain a high *L/C*-ratio, which means that the circuit impedance is high. A high capacitance is often desirable for an oscillator circuit to ensure a satisfactory frequency stability.

We take $\Delta C = 20$ pF. Place a rule from the point 10.5 % in the left-hand column through the point 20 pF on the right-hand side of the centre column and read the point where the line intersects the right-hand column. C_{min} is found to be 80, which is therefore the capacitance of the whole tuned circuit.

From this point, swing the ruler to the point $f_{max} = 3850$ kc/s (3.85 Mc/s) on the right-hand side of the column on the left. The rule intersects the centre column, where the self inductance *L* is read off on the left-hand side. This gives 21 μH.

The value found for $C_{min} = 80$ pF must be examined more closely. If the zero-capacitance of the variable capacitor is assumed to be 3 to 5 pF (for capacitors in broadcast receivers this is 10 to 15 pF), the coil capacitance also 3 to 5 pF, the valve capacitance 5 to 15 pF, that of the valve holder 1.5 to 3 pF and that of the wiring 1 to 10 pF, the average total

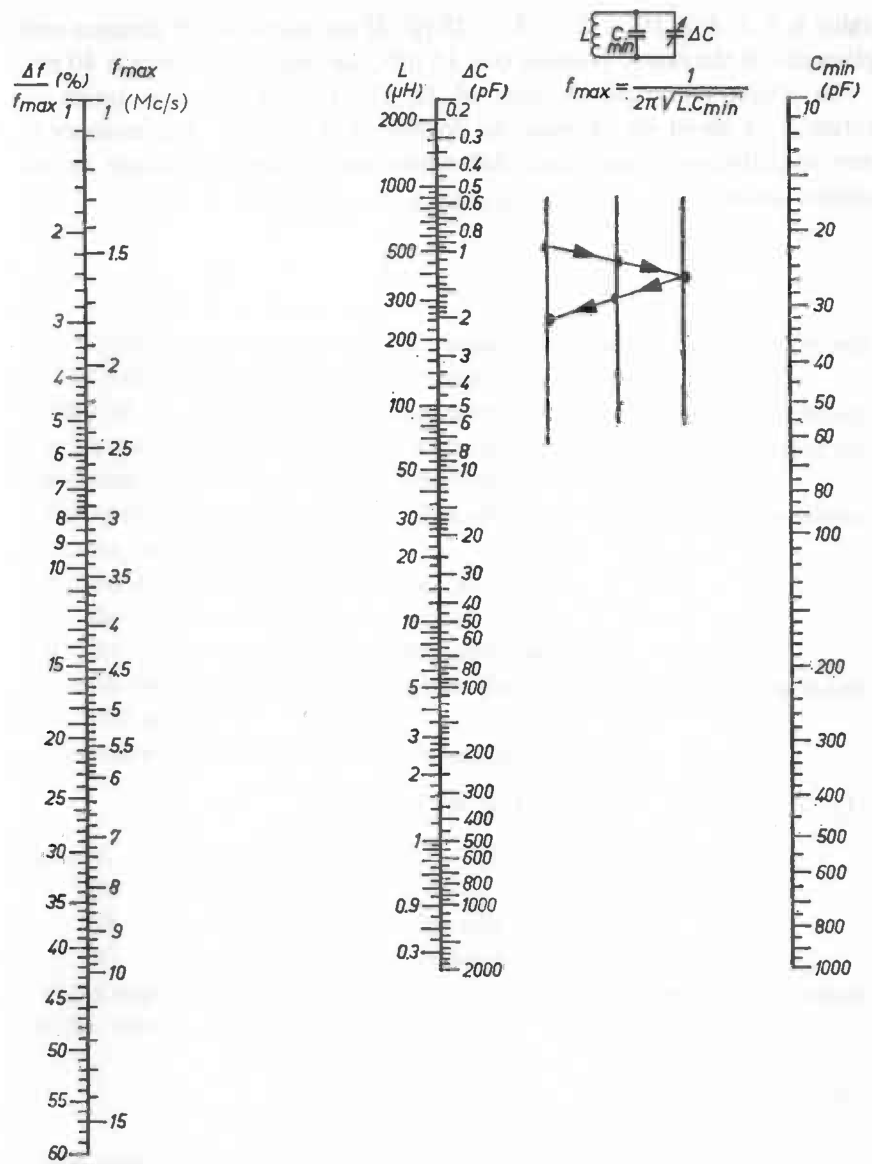


Fig. 125. Nomogram for bandspread calculations.

value is $4 + 4 + 10 + 2 + 5 = 25$ pF. If we take a 30 pF trimmer and place this in the centre position (i.e. 15 pF), the total capacitance is 40 pF.

To obtain the required value of 80 pF, a fixed capacitor (mica or ceramic) of about 40 pF must be connected in parallel. The trimmer is now available to correct small differences and to tune the circuit to the correct value.

APPENDIX 2

COIL CALCULATIONS

The experimenting amateur will not always be able to buy the exact coil for his requirements and will often have to make one himself.

First of all, the required inductance will have to be determined, which may be done in the case of tuned circuits for instance with the aid of the nomogram used for bandspread computation.

For convenience, the computation is subject to the following conditions:

a. the coil has no iron core.
b. the coil is without screening can.
c. the coil is wound in one layer.
d. the coil is wound from solid wire (not Litz).
e. the working frequency is higher than 3 Mc/s (wavelenghts below 100 metre).

The inductance of the coil is determined as follows:

$$L = F \times n^2 \times D \tag{1}$$

where L = inductance in μH
n = number of turns
D = outer diameter of the coil
F = form factor which depends on the design.

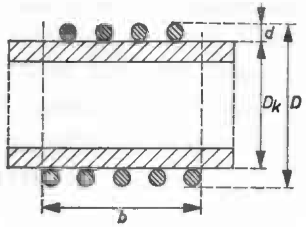
If the required inductance L is known and n is to be found, the formula may be written as follows:

$$n = \sqrt{\frac{L}{D \times F}} \tag{2}$$

The main dimensions of the coil are shown in Fig. 126.

We start with a former diameter of D_K, which is known. If the wire diameter is d, $D = D_K + 2 \times d$. The maximum winding length b is to be

Fig. 126. Sketch showing coil dimensions.
b = winding length
d = thickness of wire
D_k = outer diameter of former
D = outer diameter of coil
(all dimensions in cm)



determined. We take the ratio $\frac{b}{D}$ which may be 0.5, 0.1, 1.5, 2.0 or 3.0. The ratio $\frac{d}{D}$ is determined. The form factor F can now be obtained from the graph in Fig. 127.

All the data are then known and the values of n and L can be calculated by means of the formulae.

As an *example* let us calculate the coil required in the example from the bandspread calculation, where the inductance was found to be 21 μH.

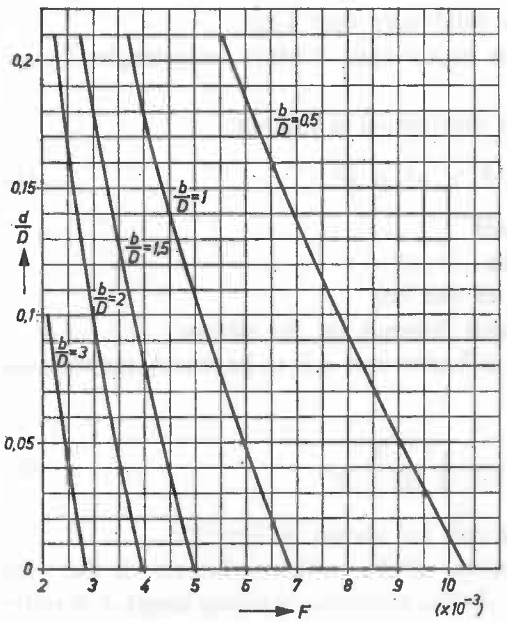


Fig. 127.
Graph for determining the form factor F from $\frac{d}{D}$ and $\frac{b}{D}$

Assume that we use a former with a diameter of 3 cm and that the diameter of the copper wire is 1 mm, then:

$$D = D_K + 2d = 3 + 0.2 = 3.2 \text{ cm}.$$

If the length b is taken to be 6.4 cm:

$$\frac{b}{D} = \frac{6.4}{3.2} = 2.0 \quad \text{and} \quad \frac{d}{D} = \frac{0.1}{3.2} \approx 0.03.$$

From the graph:

$$F = 3.6 \times 10^{-3}.$$

The number of turns is now obtained from the formula:

$$n = \sqrt{\frac{L}{D \times F}} = \sqrt{\frac{21}{3.2 \times 3.6 \times 10^{-3}}} = \sqrt{\frac{21 \times 10^3}{3.2 \times 3.6}} = 43.$$

Check: From the wire table (Appendix 3) the outer diameter of 1 mm enamel wire is seen to be 1.05, so that a width of 45.15 mm is required with the wire wound closely together. The minimum length obtainable in practice is about 48 mm; in this case ample space is available on the chosen winding length of 64 mm. If the number of turns is greater than can be accommodated on the chosen winding length, it is necessary either to increase this length or the diameter of the former or to reduce the wire diameter. In all these cases the value of n must be recalculated.

A random choice of the dimensions of the coil according to the above method will always produce the correct result for the inductance, although it is by no means certain that the quality (Q-factor) of the coil is satisfactory. This may be checked roughly (in as far as the Q-value depends on the dimensions) with the aid of Table 128 and the formula:

$$d_1 = C \times \frac{D}{n} \qquad (3)$$

$\frac{b}{D}$	C	P
0.5	0.4	24.7
1.0	0.7	20
1.5	1.0	20
2.0	1.4	20
3.0	2.0	20

Fig. 128. Table for determining constants C and P, required when checking the optimum shape and quality of the coil (formulae 3 and 4).

Against the selected value $\frac{b}{D}$, the value of C is found from the table. (In our example for $\frac{b}{D} = 2 : C = 1.4$). This substituted in formula (3) yields:

$$d_1 = 1.4 \times \frac{3.2}{43} = 0.105 \text{ cm.}$$

Our choice was therefore fairly accurate. Although this figure is not very critical, it should never be a few times greater or smaller than the selected diameter, as the departure from the maximum Q-value would then be too great.

The quality of the optimum (or practically optimum) coil can be determined approximately from the formula:

$$Q \backsimeq \frac{D \times \sqrt{f}}{P} \qquad (4)$$

where f = working frequency in c/s.

P = a factor, also dependent on $\frac{b}{D}$ and also obtained from Fig. 128.

In our case ($\frac{b}{D} = 2$), this factor is found to be $P = 20$. This value substituted in formula (4) at a working frequency of 3.5 Mc/s yields:

$$Q \backsimeq \frac{3.2 \times \sqrt{3.5 \times 10^6}}{20} \backsimeq 300.$$

In actual practice this value may be considerably lower, however, as it also depends on the construction of the coil (leakage and dielectric losses). It is very useful for comparison with other coil designs.

Instead of being round, coil formers are often ribbed, resulting in an angular cross-section. In this case the value of D_K is determined as follows:

When the cross-section is *square*, D_K is equal to 0.8 times the dimension across the corners (diagonal), when *hexagonal*: 0.9 times the dimension across the corners and when *octagonal*: 0.95 times the dimension across the corners.

Use of iron core

If it is desirable to use an iron core, e.g. for accurate adjustment of the inductance, the former could be provided with a screw thread for adjusting the core. When the coil is calculated it should then be borne in mind that the presence of the iron core generally increases the inductance. The extent to which this happens depends entirely on the core material and the construction. With some types the inductance is increased only 1.2 to 1.5 times, with others 10 to 20 times.

Use of screening

In many cases it is necessary to screen coils. Screening by means of a can or in any other way adversely affects both the inductance and the quality of the coil.

A sketch of a coil in a screening can is shown in Fig. 129. The reduction

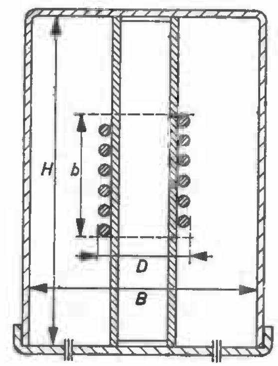


Fig. 129. Position of coil in screening can. The letters correspond to those in formula 5.

in the value of L expressed as a percentage is then given by:

$$1.47 \times \frac{D^2}{B^2} \times \frac{b}{H} \qquad (5)$$

Thus, with a very large screening can, say, $H = 3b$ and $B = 3D$, the inductance decreases by about 5 %. In our example, to obtain an inductance of 21 μH with the coil screened, the inductance used in the calculation (i.e. without screening can) must be 5 % higher, i.e. 22 μH. The number of turns then works out at 44.

The quality is not only affected by the dimensions of the can, but also by the material of which it is made. The exact amount is difficult to establish, but never exceeds more than a few per cent in the above example.

APPENDIX 3

TABLE OF ENAMELLED COPPER WIRE VALUES

Diameter (mm)		Cross section (mm^2)	Weight (g/m)	Resistance (Ω/m)	Turns per cm	Current at 2.5 A/mm^2 (mA)
bare	enam.					
0.03	0.035	0.0007	0.0065	24.4	250	1.7
0.04	0.050	0.0012	0.0118	13.75	165	3
0.05	0.060	0.0019	0.0183	8.78	135	5
0.06	0.072	0.0028	0.0262	6.10	115	7
0.08	0.095	0.0050	0.0464	3.43	90	12.5
0.10	0.12	0.0078	0.0723	2.19	74	19.5
0.12	0.14	0.0113	0.104	1.52	63	28
0.14	0.16	0.0154	0.141	1.12	54	38.5
0.16	0.18	0.0201	0.184	0.857	48	50
0.18	0.20	0.0254	0.232	0.677	43	177
0.20	0.22	0.0314	0.286	0.549	39	63.5
0.25	0.28	0.0491	0.446	0.351	32	78.5
0.30	0.33	0.0707	0.641	0.244	27	122.5
0.35	0.38	0.0962	0.872	0.244	24	240
0.40	0.44	0.1257	1.14	0.138	21	314
0.50	0.54	0.1964	1.78	0.088	17	492
0.60	0.65	0.2827	2.55	0.061	14	708
0.70	0.75	0.3848	3.47	0.045	12	965
0.80	0.85	0.5027	4.53	0.034	11	1260
0.90	0.95	0.6362	5.73	0.027	10	1590
1.00	1.05	0.7854	7.06	0.022	9	1970

Notes on the table

This table includes only the most commonly used wire diameters and is far from complete. As far as the amateur is concerned, however, this makes the table more comprehensive and thus much more useful.

The columns "weight" (expressed in pounds per 1000 yards) and "resistance" (expressed in ohms per yard) give average values and may vary according to the manufacturer and production tolerances.

The column headed "turns per inch" indicates the number of turns obtainable per inch length (single layer). This may vary fairly considerably, depending on the wire diameter and the care taken in winding.

The permissible current in mA applies to a transformer winding with a maximum load of 1000 A/in^2.

APPENDIX 4

COLOUR CODE

Although many components are still marked with their appropriate value in figures, the need for indicating them in a simpler and clearer manner becomes greater as the components become smaller. The colour code used for this purpose is laid down internationally. The value and tolerance on resistors are indicated by four coloured bands. Starting with the outer band, the first two bands denote the first two significant figures of the resistance and the third band denotes the number of noughts to be added. The fourth band is the resistance tolerance in per cent. The colour code table is as follows:

black	0	violet	7
brown	1	grey	8
red	2	white	9
orange	3		
yellow	4	gold	5 %
green	5	silver	10 %
blue	6		

Example: A resistor of 270,000 Ω and a tolerance of 5 % is colour coded as follows:

red	2
violet	7
yellow	4 noughts (0000)
gold	5 % tolerance

APPENDIX 5

THE AMATEUR BANDS

The bands of frequencies assigned to amateurs as laid down at the Geneva Administrative Radio Conference in 1959 are:
(These data apply to Zone 1, i.e. Europe, Africa and some parts of Asia).

Band		Range (Mc/s)	Subdivided as recommended by the amateur organisations	
Mc/s	(m)			
3.5	80	3.5— 3.8	3.5 — 3.6	CW
			3.6 — 3.8	phone
7	40	7.0— 7.1	7.0 — 7.05	CW
			7.05— 7.1	phone
14	20	14.0— 14.35	14.0 — 14.1	CW
			14.1 — 14.35	CW + phone
21	15	21.0— 21.45	21.0 — 21.15	CW
			21.15— 21.45	CW + phone
28	10	28.0— 29.7	28.0 — 28.2	CW
			28.2 — 29.7	CW + phone
144	2	144 —146	144 —145.8	CW + phone
			145.8 —146	CW
440	0.70	430 —440		CW + phone

In addition, the following bands are also allocated to amateurs: 1215, 2300, 3400, 5650, 10,000 and 21,000 Mc/s. These frequencies are of no practical use at present and are of no interest to newcomers. In several

European countries the use of the 160 metre band (1.715-2.0 Mc/s) is also permitted.

In view of the increasing use of single-sideband operation it is recommended by the amateur organisations that the upper frequencies of the bands are used for this purpose.

APPENDIX 6

ABRIDGED LIST OF COUNTRIES

A complete list of prefixes for amateur radio stations is compiled by the A.R.R.L. and published at regular intervals. The following is an abridged version of the official list.

AP	Pakistan	LZ	Bulgaria
BV	Formosa	OE	Austria
C	China	OK	Czechoslovakia
CM, CO	Cuba	ON 4	Belgium
CP	Bolivia	OZ	Denmark
CT1	Portugal	PAØ	Netherlands
CX	Uruguay	PJ	Neth. West Indies
EL	Liberia	PK	Indonesia
EQ	Iran	PY	Brazil
GW	Wales	PZ	Surinam
HH	Haiti	SL, SM	Sweden
HK	Columbia	SP	Poland
HL	Korea	SU	Egypt
HP	Panama	SV	Greece
HR	Honduras	TA	Turkey
HS	Siam	TF	Iceland
JA, KA	Japan	U	U.S.S.R.
KL 7	Alaska	VK	Australia
LX	Luxemburg	VO	see VE
OA	Peru	W	see K
OH	Finland	YK	Syria
VE, VO	Canada	YO	Rumania
VU 2	India	YU	Yugoslavia

XE, XF	Mexico	YV	Venezuela
YI	Iraq	ZC 6	Palestine
YV	Venezuela	ZL	New Zealand
ZP	Paraguay	ZS	Rep. of South Africa
4S 7	Ceylon	5A	Libya
4X 4	Israël	XZ 2	Burma
CE	Chile	ZB 1	Malta
DJ,DL,DM	Germany	ZB 2	Gibraltar
DU	Philippines	ZC 4	Cyprus
EA	Spain	ZD 1	Sierra Leone
EI	Republic of Ireland	ZD 6	Nyasaland
F	France	ZE	Southern Rhodesia
FA	Algeria	5NZ	Nigeria
G	England	9G 1	Ghana
GC	Channel Islands	9 M 2	Malaya
GD	Isle of Man	VP 3	British Guyana
GI	Northern Ireland	VP 4	Trinidad and Tobago
GM	Scotland	VP 5	Jamaica
HA	Hungary	VP 6	Barbados
HB1, HB9	Switzerland	VP 9	Bermuda
HC	Ecuador	VQ 2	Northern Rhodesia
HV	Vatican City	VQ 3	Tanganyika
I, IT	Italy	VQ 4	Kenya
JZØ	Neth. New Guinea	VQ 5	Uganda
K, W	U.S.A.	VS 1	Singapore
KA	see JA	VS 4	Serawak
LA	Norway	VS 6	Hongkong
LU	Argentina	VS 9	Aden

APPENDIX 7

MORSE CODE

A	.-
B	-...
C	-.-.
D	-..
E	.
F	..-.
G	--.
H	....
I	..
J	.---
K	-.-
L	.-..
M	--
N	-.
O	---
P	.--.
Q	--.-
R	.-.
S	...
T	-
U	..-
V	...-
W	.--
X	-..-
Y	-.--
Z	--..

	1	.----
	2	..---
	3	...--
	4	....-
	5	.....
	6	-....
	7	--...
	8	---..
	9	----.
	0	-----
	full stop	.-.-.-
	comma	--..--
	question mark	..--..
	stroke	-..-.
	error	....
	break sign	-...-
	wait	.-...
	invitation to transmit	-.-
AR	(= end of reply to CQ)	.-.-.
SK	(= end of work)	...-.-
KN	(= end of message)	-.--.

For use see Chapter 9.

APPENDIX 8

Q-CODE

Given below are the most important Q-abbreviations of the international Q-code. Q-abbreviations take the form of questions when sent followed by a question mark.

QRA	What is the name of your station? The name of my station is ....
QRB	How far approximately are you from my station? The approximate distance is .... miles.
QRG	Will you tell me my exact frequency in kc/s? Your exact frequency is .... kc/s.
QRH	Does my frequency vary? Your frequency varies ....
QRJ	Do you receive me badly? I cannot receive you.
QRM	Are you being interfered with? I am interfered with.
QRN	Are you troubled by atmospherics? I am troubled by atmospherics.
QRO	Shall I increase power? Increase power.
QRP	Shall I decrease power? Decrease power.
QRQ	Shall I send faster? Send faster (.... words per minute).
QRS	Shall I send more slowly? Send more slowly (.... words per minute).

QRT	Shall I stop sending?
	Stop sending.
QRV	Are you ready?
	I am ready.
QRX	When will you call me again?
	I will call you again at .... hours (on .... kc/s).
QRZ	Who is calling me?
	You are being called by .... (on .... kc/s).
QSA	What is the strength of my signals?
	The strength of your signals is .... (1-5).
QSB	Are my signals fading?
	Your signals are fading.
QSL	Can you acknowledge receipt?
	I am acknowledging receipt.
QSO	Can you communicate with .... direct? or by relay?
	I can communicate with .... direct (or by relay through ....).
QSU	Shall I send on .... kc/s? (or m)?
	Send on .... kc/s (or m).
QSV	Shall I send a series of Vs?
	Send a series of Vs.
QSW	Will you send on .... kc/s? (or m)?
	I am going to send on .... kc/s (or m).
QSX	Will you listen to .... on .... kc/s?
	I am listening to .... on .... kc/s.
QSY	Shall I change to transmission on another frequency?
	Change to transmission on another frequency (or on .... kc/s).
QSZ	Shall I send each word or group twice?
	Send each word or group twice.
QTH	What is your location?
	My location is ....
QTR	What is the exact time?
	The exact time is ....

APPENDIX 9

AMATEUR ABBREVIATIONS

In addition to the official Q-code, the following abbreviations are used in telegraphy traffic:

aa	all after
ab	all before
abt	about
ac	alternating current
af	audio frequency
agn	again
amp	ampere
ani	any
ant	antenna
bci	broadcast interference
bcl	broadcast listener
bcnu	be seeing you
bd	bad
bk	break, break in
btr	better
bug	vibroplex
b4	before
cfm	confirm
cheerio	
cl	call
	closing
cn	can
cnt	cannot
co	crystal oscillator
condx	conditions
cq	seek you
crd	card
cuagn	see you again
	call you again
cud	could
cul	see you later
	call you later
cw	continuous wave
dc	direct current
dnt	do not
duz	does
dx	distance
ere	here
es	and
fb	fine business
fil	filament
fm	from
fone	
fr	for
freq	frequency
ga	go ahead
gb	good bye
gg	going
gld	glad
gm	good morning
gn	good night
gnd	ground
gud	good
ham	amateur
hf	high frequency
hi	high

hi	telegraphic laugh
hpe	hope
hq	headquarters
hr	hear; here
hrd	heard; hard
hv	have
hvy	heavy
hw	how
if	intermediate frequency
key	key
lis	licensed
mi	my, mine
mike	microphone
mk	make
mni	many
mo	master oscillator
mtr	meter
nd	nothing doing
nil	nothing
nr	near; number
nw	now
ob	old boy
ok	all correct
om	old man
op, opr	operator
osc	oscillator
ot	old timer
ow	old woman
pa	power amplifier
pse	please
pwr	power
r	received solid
rcd	received
rf	radio frequency
rig	radio equipment
rpt	repeat
rx	receiver
sa	say
sed	said
sez	says
tu	thank you
tt	that
tvi	television interference
tx	transmitter
txt	text
sig	signal; signature
sked	schedule
sn	soon
sri	sorry
stdi	steady
stn	station
swl	short wave listener
tmw	to-morrow
tks, tnx	thanks
u, ur	you, your
unlis	unlicensed
vfo	variable frequency oscillator
vy	very
wid, wix	with
wkd	worked
wl	will
wud	would
wx	weather
xmtr	transmitter
xtal	crystal
xyl	ex young lady
yl	young lady
73	best regards
88	love and kisses
99	do not interfere

APPENDIX 10

RST-CODE

The RST-code has been devised in order to give a complete report on the reception of a station. This code is particularly useful in the case of contests, where speed is an all-important factor.

The report is given in a series of three numerals covering:

a. readability (= R).
b. signal strength (= S).
c. tone (= T).

a. Readability:

1. Unreadable.
2. Barely readable, occasional words distinguishable.
3. Readable with considerable difficulty.
4. Readable with practically no difficulty.
5. Perfectly readable.

b. Signal strength:

1. Faint signals, barely perceptible.
2. Very weak signals.
3. Weak signals.
4. Fair signals.
5. Fairly good signals.
6. Good signals.
7. Moderately strong signals.
8. Strong signals.
9. Extremely strong signals.

c. Tone:

1. Extremely rough hissing note.
2. Very rough a.c. note, no trace of musicality.
3. Fough, low-pitched a.c. note, slightly musical.
4. Rather rough a.c. note, moderately musical.
5. Musically modulated note.
6. Modulated note, slight trace of whistle.
7. Near d.c. note, smooth ripple.
8. Good d.c. note, just a trace of ripple.
9. Purest d.c. note.

The numerical group is given as a whole, e.g. RST 599. If the signal has the characteristic steadiness of crystal control, the letter X is added. If there is a chirp, the letter C, and if there is a click the letter K may be added.

The third figure is left out in the case of a telephony report; the modulation quality may then be added, if required.

APPENDIX 11

QSL-CARDS AND CERTIFICATES

As has already been mentioned in Chapter 9, each contact between two amateur stations, i.e. each QSO, is confirmed by exchanging cards on which the details of the communication are filled in. This applies only to the first time the two stations work each other.

The data consist of the RST-code, the frequency or frequency band, the date and the time, and also data about the type of transmitter, receiver and aerial used during the contact. These cards, the design of which often gives them a personal character, may be sent through "QSL-bureaus", operated by the national organisations, at very low cost.

Many amateurs value their QSL-cards greatly. They are a symbol of great achievement and are a visual and very attractive indication of the countries with which contact has been established. For this reason they very often decorate the wall of the shack.

As an extra encouragement many amateur organisations issue certificates for a given number of contacts, communication with a given number of countries, or some outstanding achievement.

It is outside the scope of this book to give a complete summary of all the certificates in existence. Details of these certificates may be obtained from the local amateur organisations.

1. Certificates issued by the A.R.R.L. include:

DXCC: DX Century Club. Issued to amateurs who have had QSO with 100 different countries.

OTC: Old Timers Club. Obtainable by all amateurs who have held a licence for 20 years.

RCC: Rag Chewers Club. Issued to amateurs who have had 100 % QSO with one of the members for 30 minutes in succession.

WAS: Worked All States. Issued to amateurs who have worked all the other states in the U.S.A.

2. Certificate issued by the I.A.R.U.:

WAC: Worked All Continents. Issued to amateurs who have had QSO with all six continents.

APPENDIX 12

FOR THOSE WHO WANT TO KNOW MORE

Since the subjects of electricity and radio have deliberately not been discussed in great detail and the operation of radio valves has been omitted altogether in this book, we advise readers who require further instruction in these fields, to consult suitable text books. For those who wish to study these subjects with a minimum of arithmetic, we recommend the following books:

— From the electron to the superhet, by J. Otte, Ph. Salverda and C. J. van Willigen, or
— Fundamentals of the radio valve technique, by J. Deketh.

Both these books are published by the Philips Technical Library.

The new semiconductors and their applications are described in:

— Germanium diodes, by Dr. S. D. Boon;
— Using transistors, by D. J. W. Sjobbema.

Both these books are also published in the popular series of the Philips Technical Library.

Further specialisation in the short-wave hobby is best obtained, as already stated in the introduction, by regularly reading the periodicals published by the associations, following special courses, etc.

In addition to the previously mentioned "Handbook" the following publications by the A.R.R.L. are also recommended:

— Single-sideband for the radio amateur;
— The ARRL antenna book;
— The Mobile manual for radio amateurs;
— Hints and Kinks.

These books contain a collection of articles published in QST, the monthly publication of the A.R.R.L., with reviews and practical descriptions of the relevant subjects and contains a wealth of information. The fourth book gives a great number of practical hints for the active amateur who prefers to build his own equipment.

The following book is recommended to those wishing to enter upon a theoretical study of transmitter problems in general and the operating conditions of transmitter valves in particular:

— Transmitter valves, by J. P. Heyboer, published by the Philips Technical Library.

For a theoretical description of semiconductors we mention:

— Diodes and Transistors, by G. Fontaine.

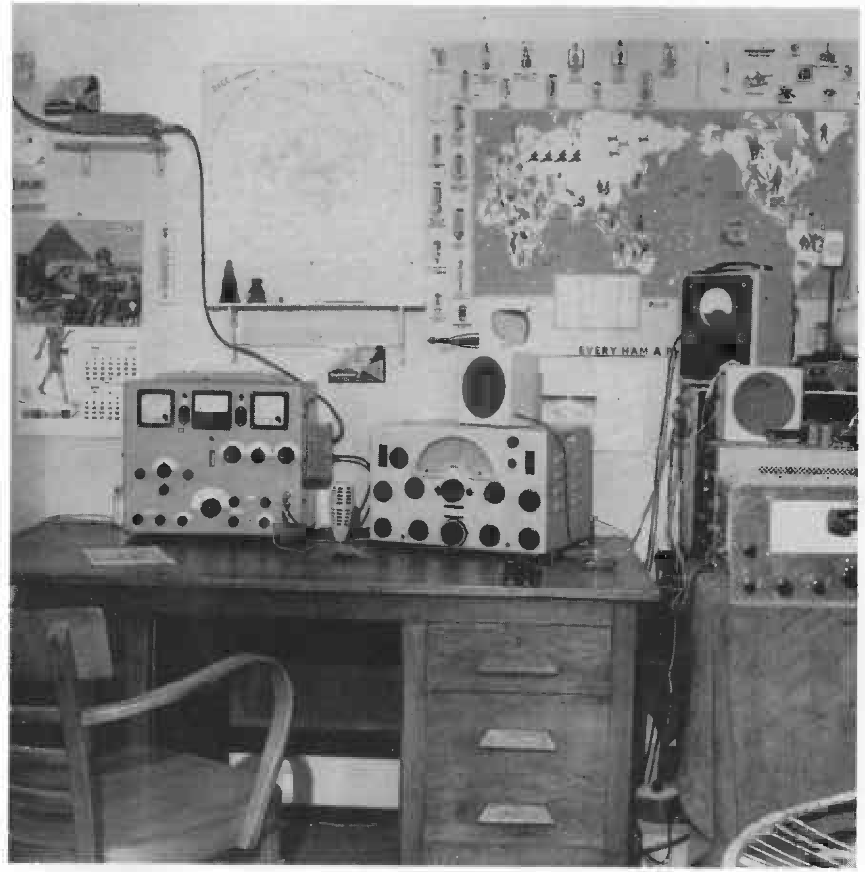


Photo 1. *Shack belonging to PAØIB.* The transmitter (left) and the receiver (right) are placed in convenient positions, plenty of space having been left for the morse key, microphone, log and other necessary attributes. On the right-hand side there is room for measuring instruments and for equipment which is being built. The aerial filter is seen in the left-hand top corner.

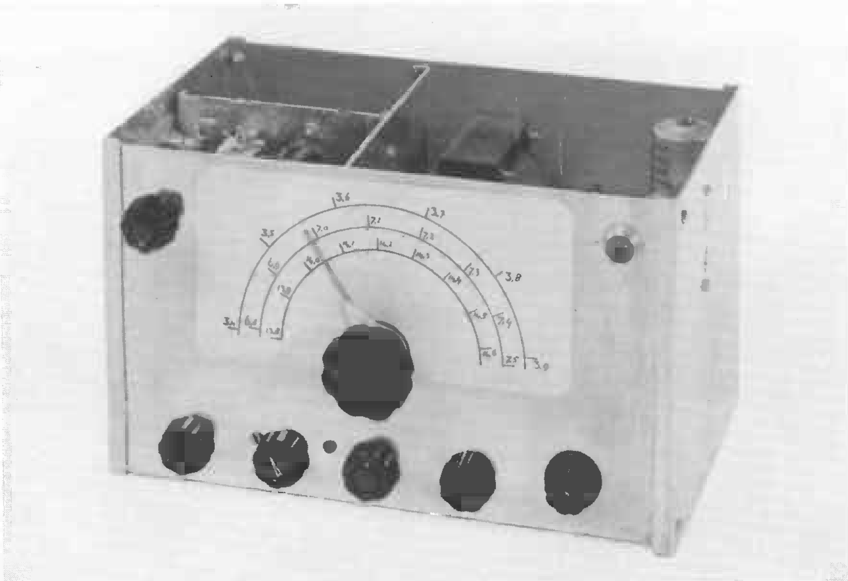


Photo 2. *The straight receiver* (described in Chapter 10). In the centre the large dial with the three ranges. The 5 knobs at the bottom are (from left to right): r.f. gain control, wave switch, feedback control, a.f. gain control + mains switch, fuse holder. The aerial capacitor is on the top l.h. side and the signal lamp on the top r.h. side.

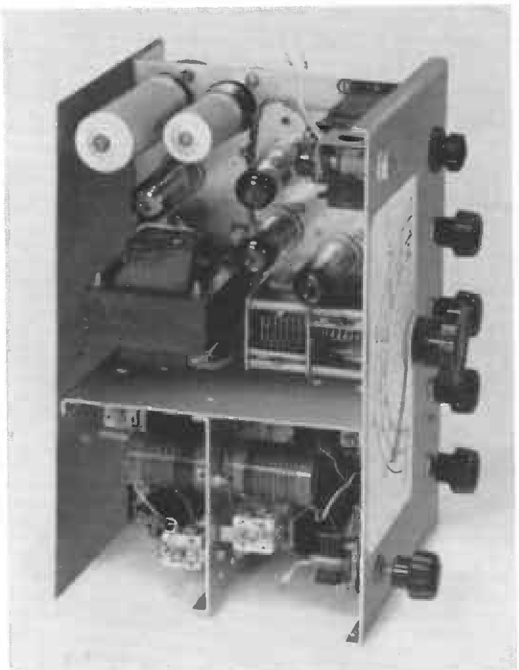


Photo 3. *Top view of straight receiver.* The two coil compartments are seen at the bottom of the photograph (detector on the left, aerial on the right). Each compartment contains three coils, one for each band, which are mounted perpendicularly to each other. Behind the twin capacitor is the mains transformer; the loudspeaker transformer is seen on the top r.h. side.

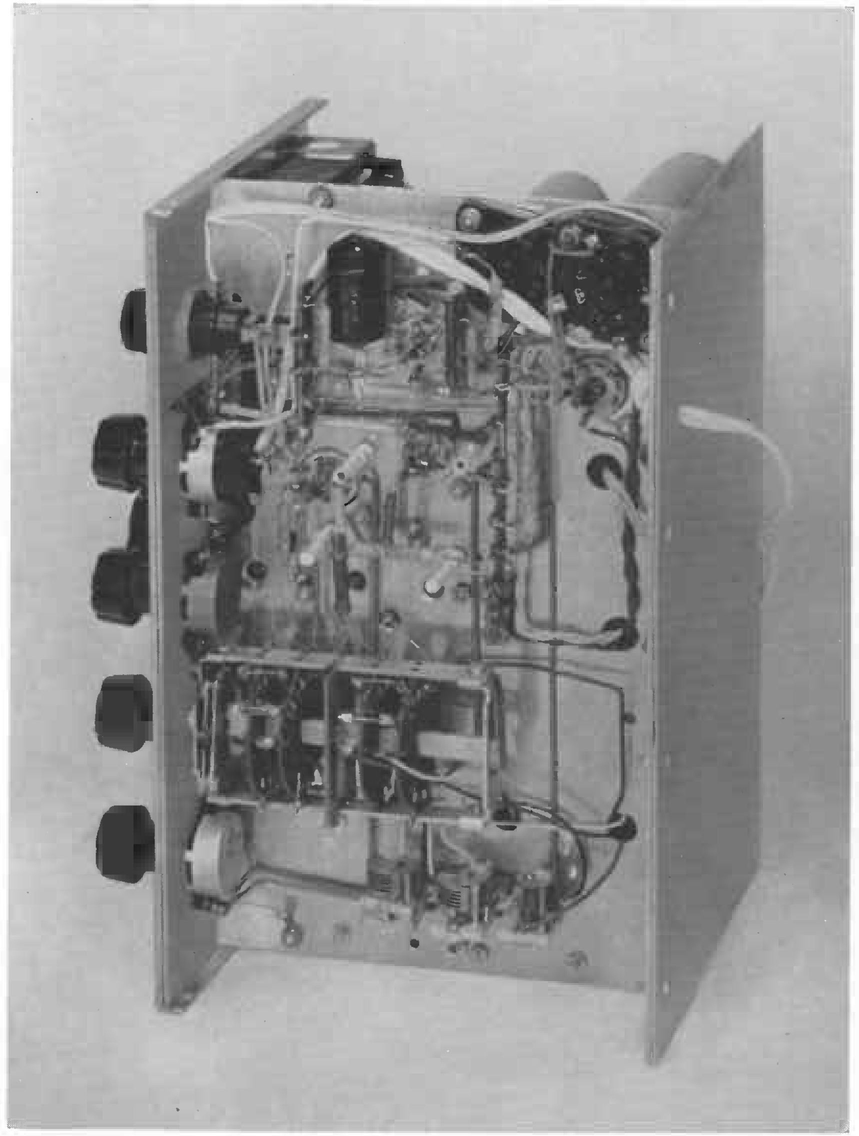


Photo 4. *Underneath view of straight receiver.* The wave-switch has four sections with a screen in the centre. This is in line with the screening on the top of the chassis between the aerial and detector circuits. The three trimmers for adjusting the feedback are seen at the bottom.

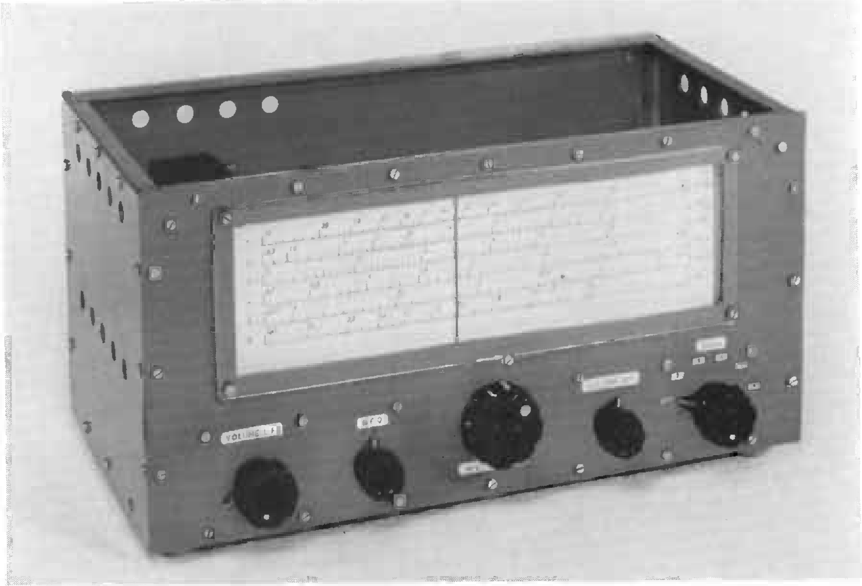


Photo 5. *Short-wave superheterodyne receiver* (described in Chapter 10). The large linear dial clearly shows the six bands. The knobs are (from left to right): a.f. gain control, b.f.o. switch, tuning knob, r.f. gain control, range switch.

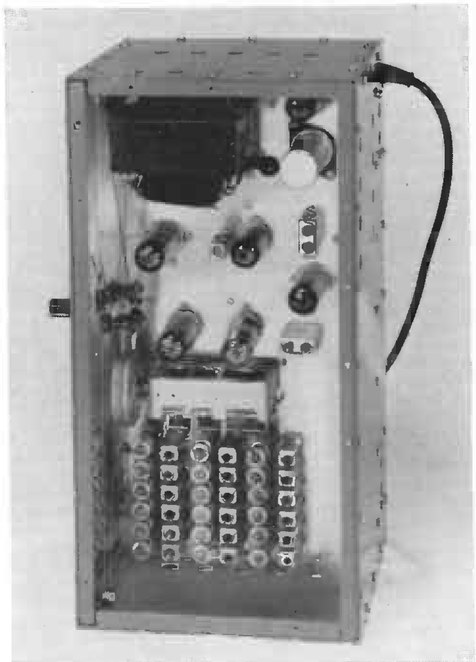


Photo 6. *Top view of short-wave superheterodyne receiver.* The set of coils is seen at the bottom. For each of the 6 ranges the aerial coil, second tuned circuit coil and oscillator coil (from left to right), each accompanied by a trimmer, are seen clearly. Above them are the triple variable capacitor with special oscillator section (right), the two i.f. transformers and the beat coil. The mains transformer is at the top.

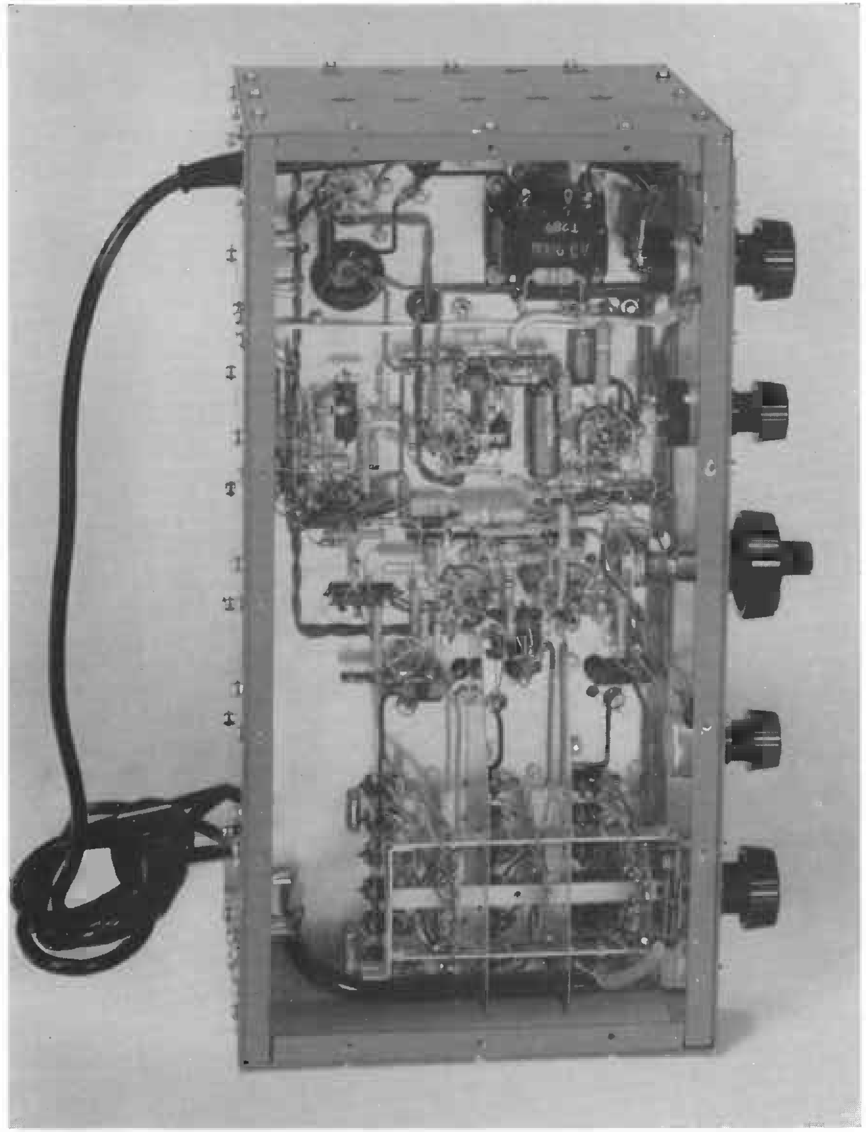


Photo 7. *Underneath view of short-wave superheterodyne receiver.* At the bottom the wave range switch with the two screens to separate the aerial circuit, the second tuned circuit and the oscillator circuit from each other. In the centre slightly to the left the screening over the valve holder of the i.f. valve. The loudspeaker transformer is at the top.

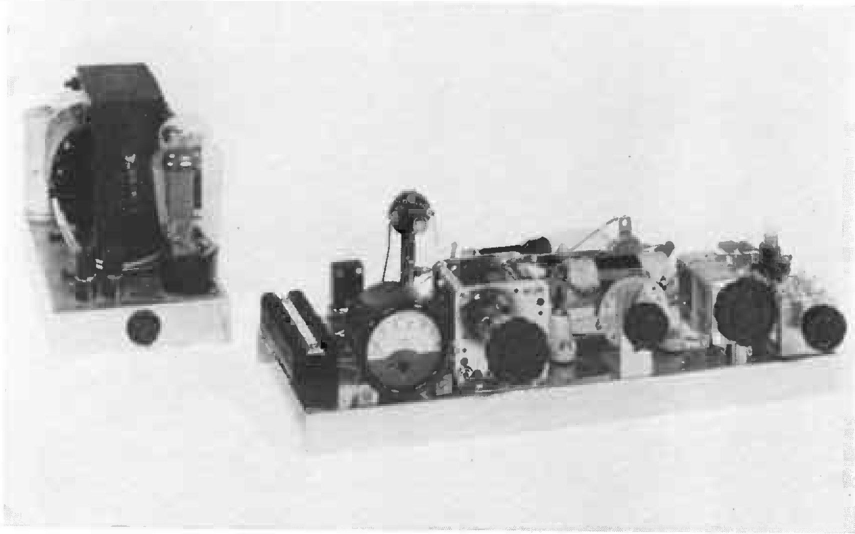


Photo 8. *Telegraphy transmitter* (described in Chapter 10). The open-chassis mounting is particularly suitable for experimental work. From left to right are the ammeter, the 250 pF tuning capacitor, 80—40 wave switch which short-circuits part of the coil and behind this the coil itself with next to this the tuning capacitor (150 + 480 pF) and finally the switch for aerial matching with beyond this the lamp indicating the aerial current. Behind the meter the crystal and lamp for indicating the crystal current.

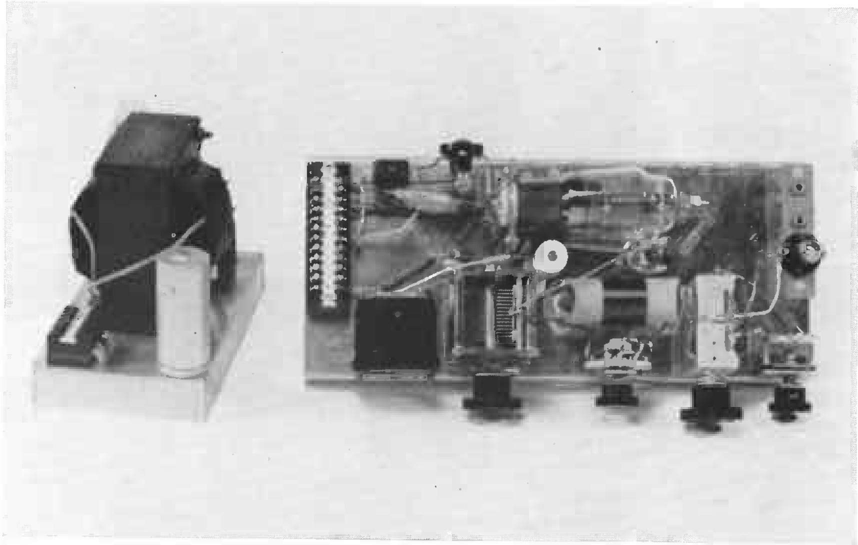


Photo 9. *Top view of the telegraphy transmitter.* The method of mounting the transmitter valve and associated chokes is clearly visible. The aerial connections are on the right.

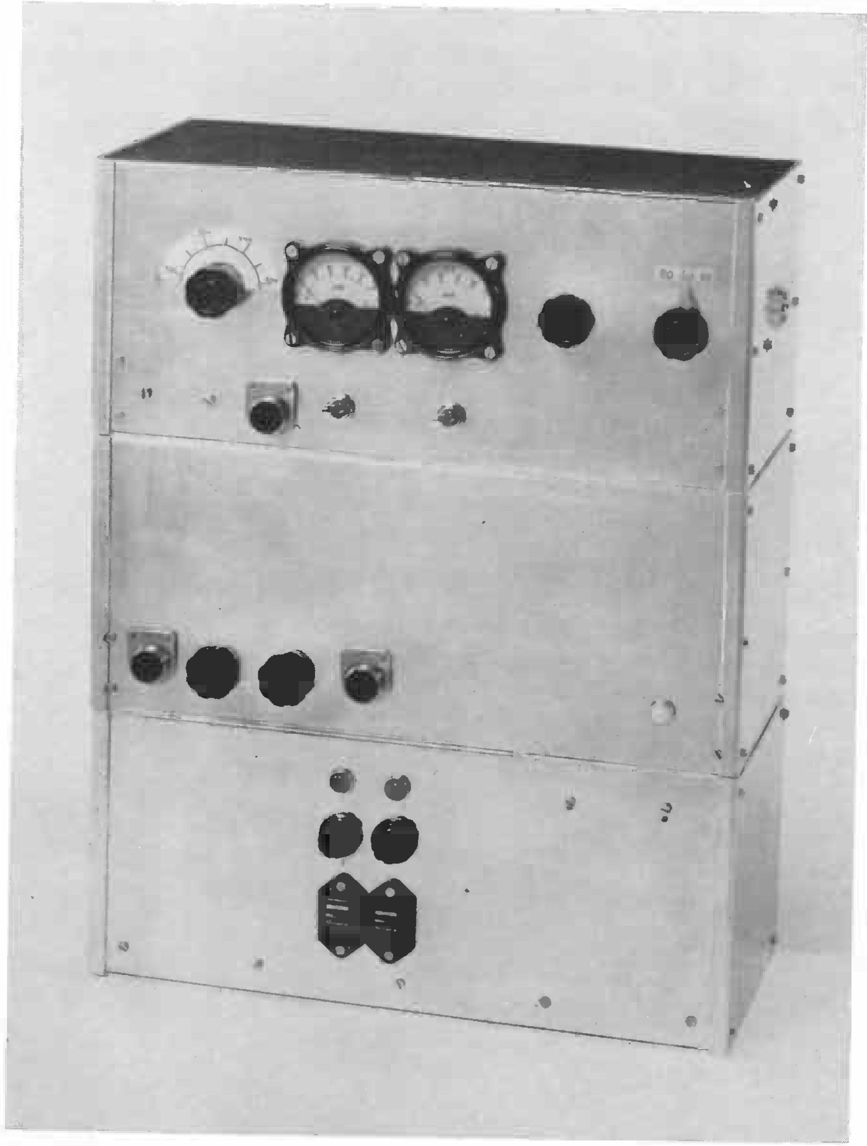


Photo 10. *Three-stage three-band transmitter* (described in Chapter 10). The transmitter is composed of three sections: the actual transmitter at the top, the modulator at the centre and the supply unit at the bottom. The transmitter has controls for the oscillator (left), the output stage (on the right next to the meters) and range switch of the output stage. Further socket for connecting the morse-key and the mains switches. The modulator includes connections for the microphone and pick-up with gain controls. The supply unit includes mains switches, fuses and signal lamps.

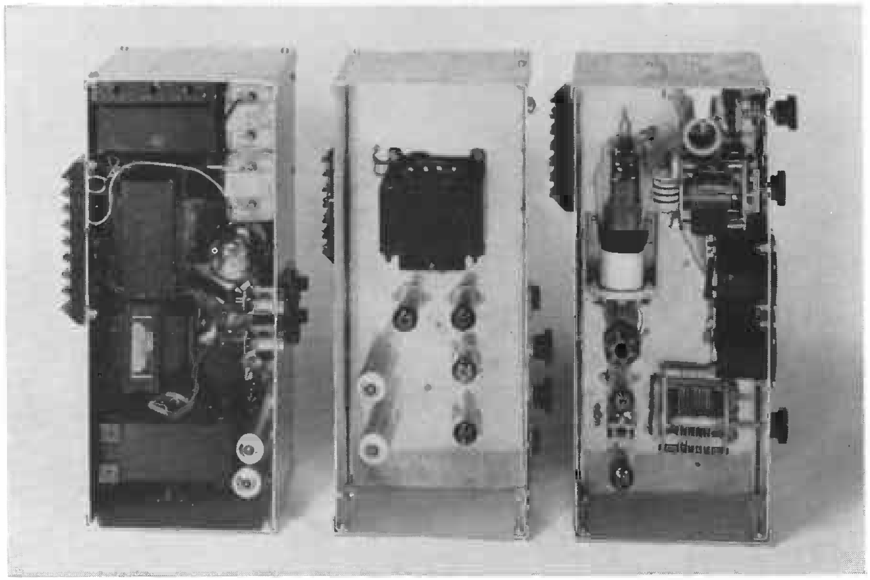


Photo 11. *Top view of the three sections.* On the left the supply unit with transformers, chokes, capacitors and rectifiers. In the centre the modulator with modulation transformer. On the right the transmitter with the variable capacitor of the oscillator at the bottom, the buffer stages beyond this and, right at the top, the output stage.

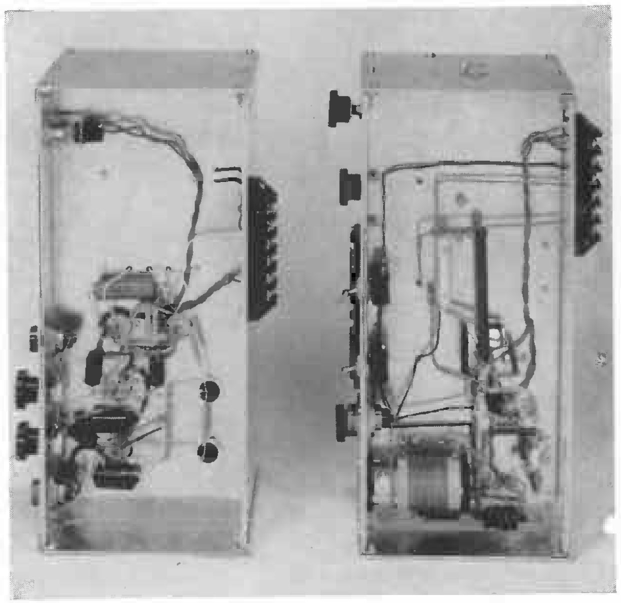
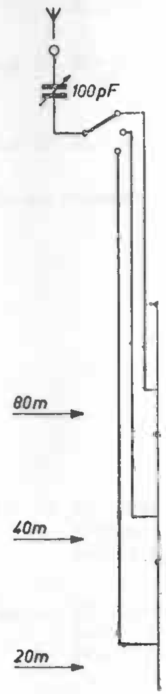
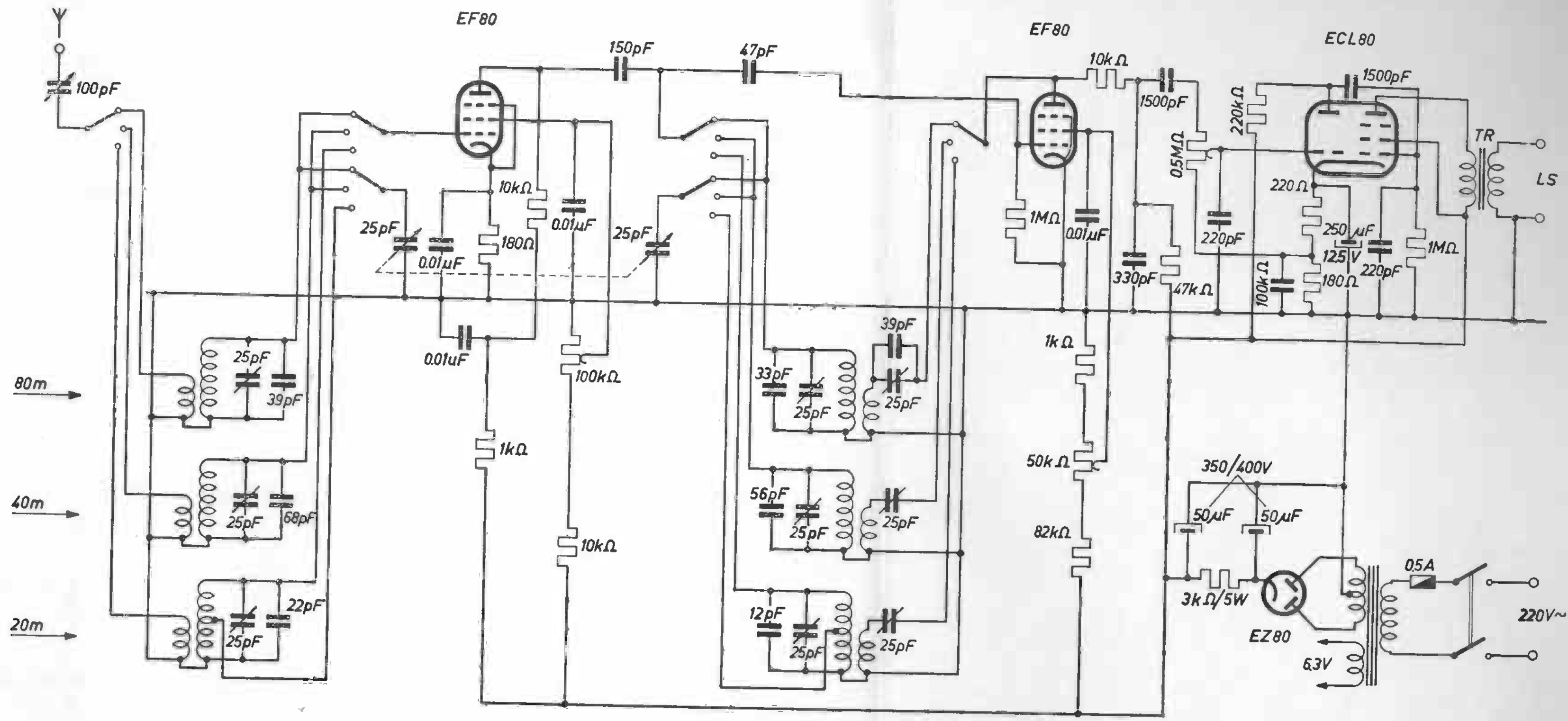


Photo 12. *Underneath view of the transmitter and modulator.* On the right the transmitter with the very robust oscillator coil visible at the bottom. To the right of this the trimmer of the permanently tuned 80-metre circuit. The wiring of the modulator (left) needs no further explanation.



STRAIGHT RECEIVER



Coil data : see text Chapter 10

Output transformer : primary : 10,000 Ω

secondary : 5 Ω

Mains transformer : primary : 220V

secondary : 2 × 250V by 50 mA

third winding : 6.3V

L = 24 turns 0.5 mm enamel wire on approx. 30 mm dia. ceramic former. Winding width 30 mm. L = 12 µH. Tapping at 7 turns from aerial end. When this is short-circuited, L = 6 µH.

L_{s1} = 10—12 turns 0.2 mm enamel wire wound on 1 W resistor of approx. 20 Ω.

L_{s2} = L_{s3} = choke, 1 mH or higher.

Mains transformer: 2 × 350V sec.—125mA
6.3V—1A
5 V—2A

L_1 = 15 turns 1 mm enamel wire on 38 mm dia. former, winding width 30 mm, with iron core and 21 turns without iron core. L = 14.5 µT.

L_2 = 45 turns 0.3 mm enamel wire on hexagonal former measuring 24 mm across corners. Winding width 20 mm. L = 32 µH.

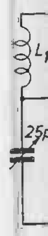
L_3 = 28 turns 0.5 mm enamel wire on hexagonal former measuring 30 mm across corners. Winding width 30 mm. L = 14 µH with iron core, and 12.5 µH without iron core.

L_4 = 24 turns 0.5 enamel wire on approx. 30 mm dia. ceramic former. Winding width 30 mm. L = 12 µH. Tappings at 7 and 12 turns from top end. L becomes 6 µH and 3 µH respectively when these parts of the winding are short-circuited.

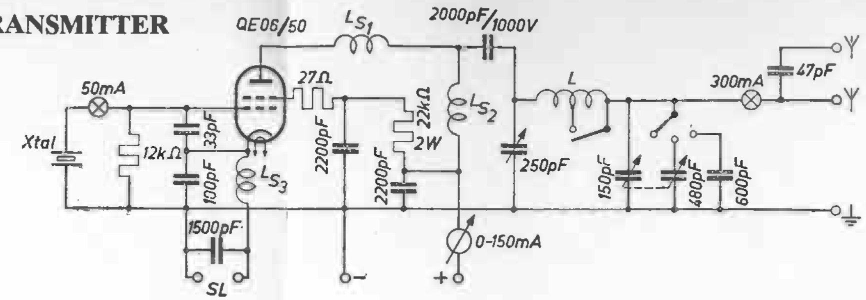
L_5 = 3 turns 0.5 mm dia. wound close together at earthy end of L_4.

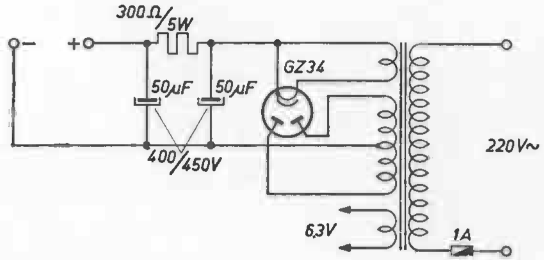
L_{s1} = 10—12 turns 0.2 enamel wire wound on a 1 W resistor of approx. 20 Ω.

L_{s2} = L_{s3} = choke, 1 mH or higher.



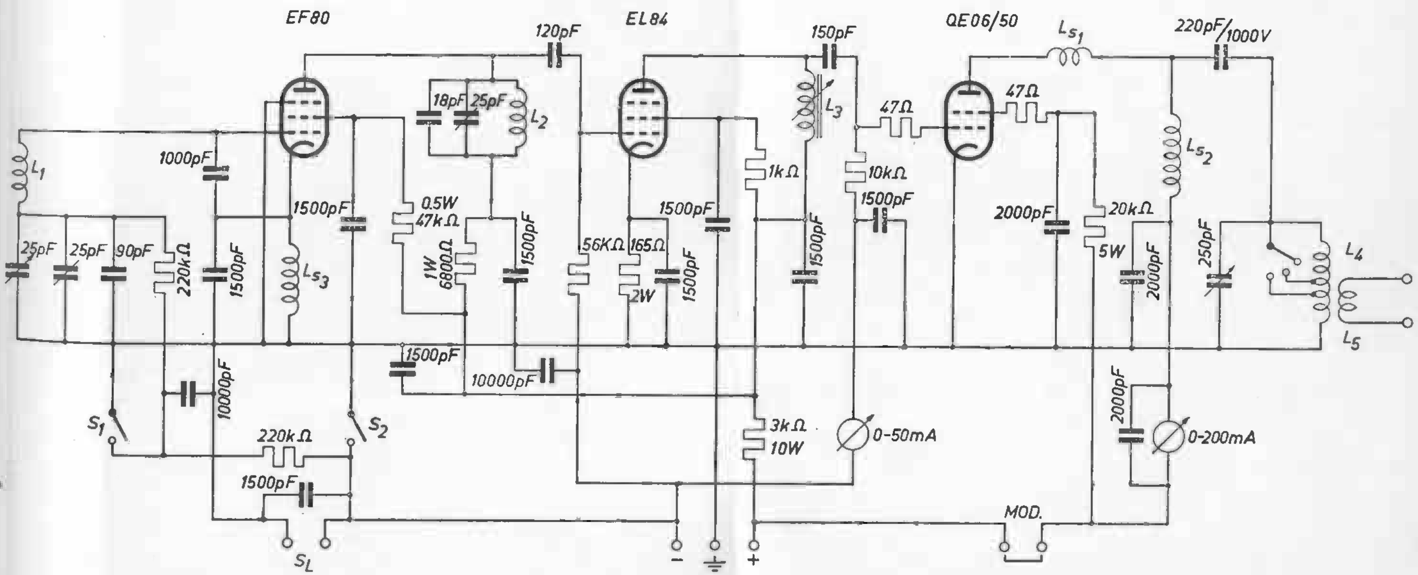
SINGLE-STAGE TELEGRAPHY TRANSMITTER





THREE-STAGE TRANSMITTER FOR 80, 40 and 20 m bands.

(transmitter section)



Modulation transformer:	core diameter	2.8 × 5 cm
	thickness of lamination	0.5 mm
	air gap	0.07 mm
	primary	2 × 1300 turns
		0.2 mm enamel wire
	secondary	1800 turns
		0.16 mm

Micro

T_1 = secondary 2 × 360V—150mA + 4V—2.5A + 6.3V—4A

T_2 = secondary 2 × 270V—100mA + 6.3V—4A + 200V—50mA

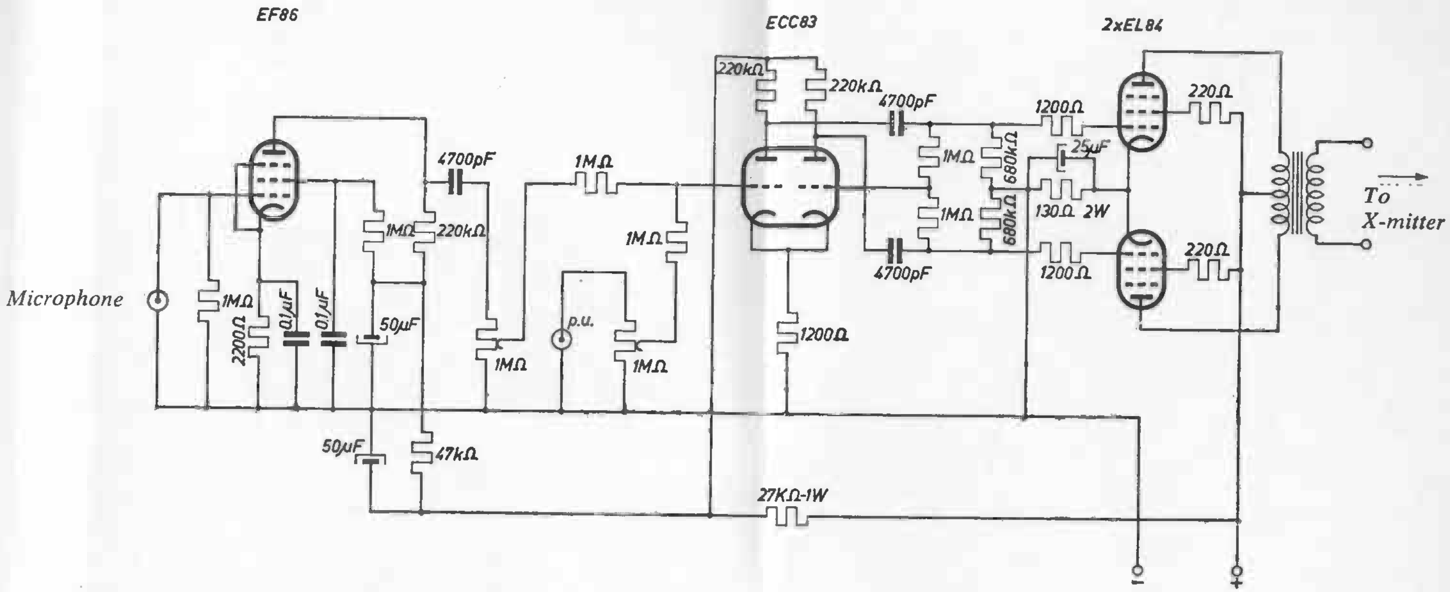
S = selenium rectifier 220V—50mA

L = signal lamps

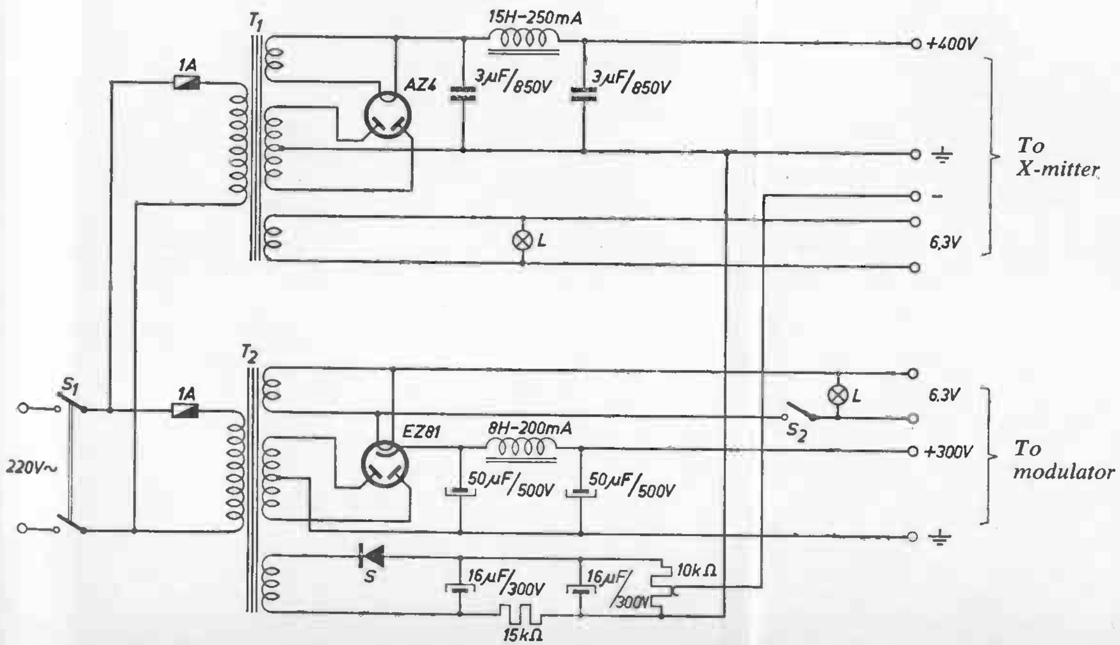
220

wire

THREE-STAGE TRANSMITTER (modulator)



THREE-STAGE TRANSMITTER (supply section)



All resistors ¼ W—10% unless otherwise indicated.

Coil data:

*S*1	circuit coil	0.55 μH	coupling coil	10 μH
*S*4	circuit coil	1.6 μH	coupling coil	10 μH
*S*7	circuit coil	4.7 μH	coupling coil	50 μH
*S*10	circuit coil	11 μH	coupling coil	100 μH
*S*13	circuit coil	38.5 μH	coupling coil	1000 μH
*S*16	circuit coil	200 μH	coupling coil	3000 μH

*S*2	circuit coil	0.5 μH
*S*5	circuit coil	1.25 μH
*S*8	circuit coil	3.6 μH
*S*11	circuit coil	11 μH
*S*14	circuit coil	32 μH
*S*17	circuit coil	108 μH

*S*3	circuit coil	0.56 μH	coupling coil 0.6 × No. of turns of circuit coil, extra coil 2 μH
*S*6	circuit coil	1.3 μH	coupling coil 0.4 × No. of turns of circuit coil, extra coil 8.5 μH
*S*9	circuit coil	4.3 μH	coupling coil 0.3 × No. of turns of circuit coil, extra coil 7.5 μH
*S*12	circuit coil	8.6 μH	coupling coil 0.25 × No. of turns of circuit coil
*S*15	circuit coil	16 μH	coupling coil 0.25 × No. of turns of circuit coil
*S*18	circuit coil	38.5 μH	coupling coil 0.25 × No. of turns of circuit coil

*S*22 = *S*23 = i.f. transformer 452 kc/s
*S*24 = S25 = choke 5 mH

Mains transformer:

secondary 2 × 270V—90mA, third winding 6.3V—3A

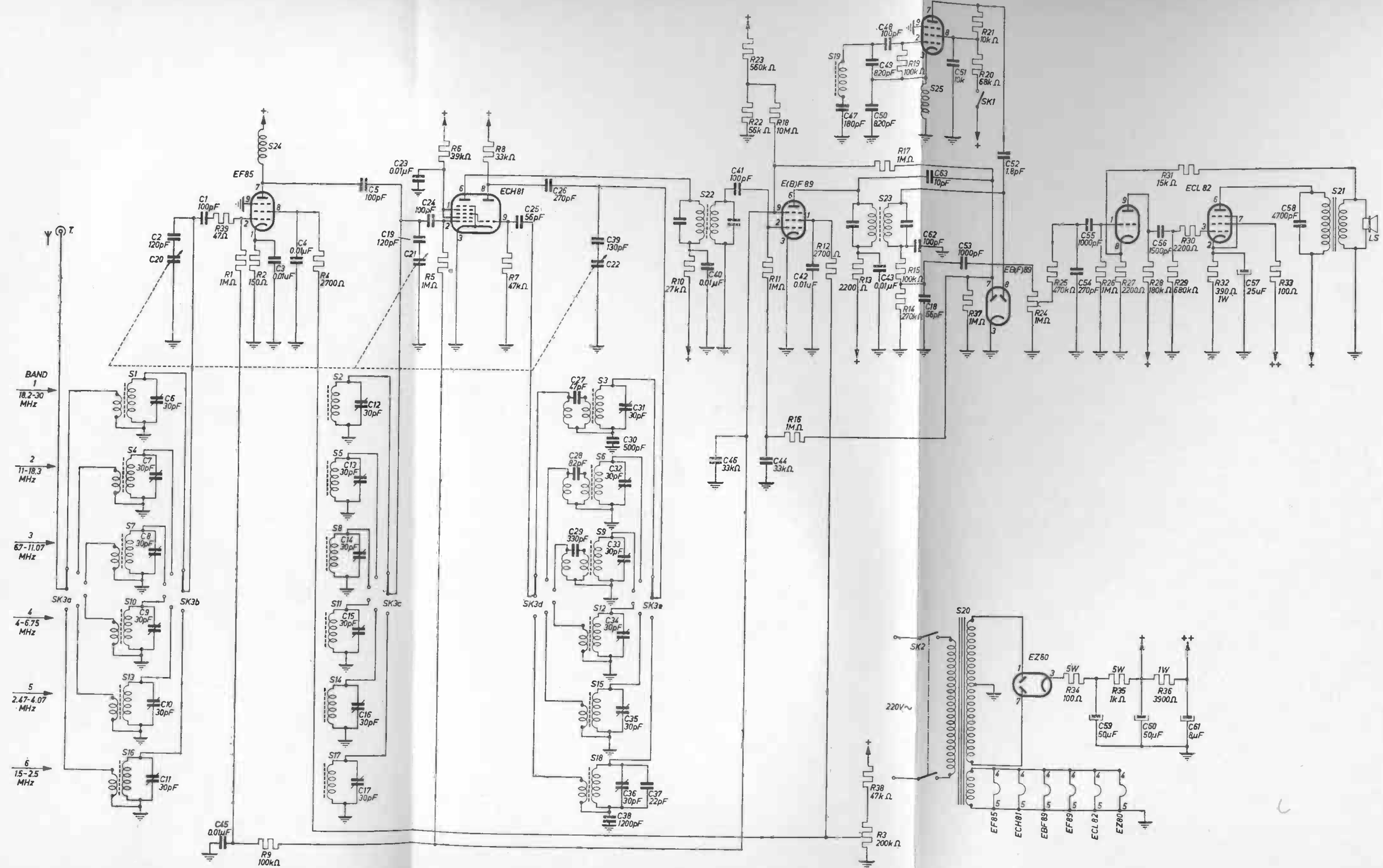
Output transformer:

primary 5400 Ω/secondary 5 Ω

C_{20} C_{21} = 2 × 500 pF

C_{22} = 520 pF

SHORT WAVE SUPEREHET. RECEIVER



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