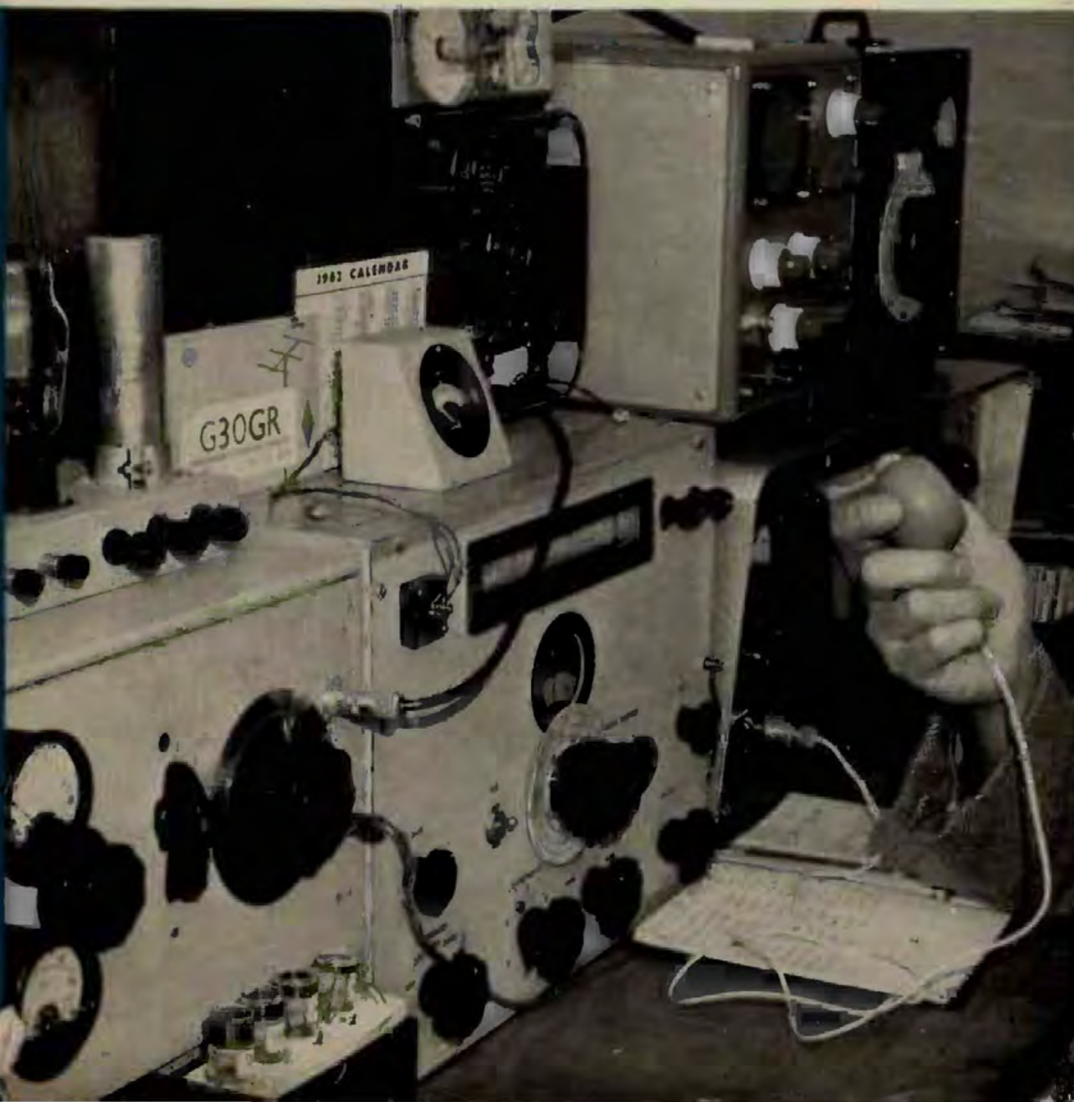
# Amateur Radio

F. G. RAYER




F. G. RAYER

Amateur Radio

ARCO

This book covers the field of short-wave listening and amateur transmitting, and includes sections on receivers, aerials, amplifiers and modulators, propagation, test equipment and transmitters.
Since many short-wave listeners eventually have transmitting equipment, the Morse Code, station operating, and similar items are also dealt with, and the book is intended as a guide for anyone wishing to have a transmitting licence.
The 'listener only' enthusiast is well provided for in the sections on QSL card collecting, codes, receivers, microphones and amplifiers, while much of the information on circuit elements and components, power packs, receivers, measurements and instruments, has a wide scope for all radio constructors and enthusiasts. Practical working circuits are provided throughout.

30s. net

Illustrated
Second Edition

£2-50

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LONDON
ARCO PUBLICATIONS
1967

FIRST PUBLISHED BY ARCO PUBLICATIONS 1964
REPRINTED 1967

PRINTED IN GREAT BRITAIN BY
COX AND WYMAN LTD.
LONDON, FAKENHAM AND READING

# Contents

# List of Plates

CHAPTER ONE

# Amateur Radio and Morse

TRANSMITTING Radio Amateurs have a transmitting licence, and use short wave radio to communicate with other Amateurs all over the world, finding this an absorbing hobby. Many thousands of 'listening' amateurs, or Short Wave Listeners are also active. They do not use transmitting equipment, but specialize in receiving distant stations, and may collect QSL cards – a form of acknowledgement used by Amateurs the world over.

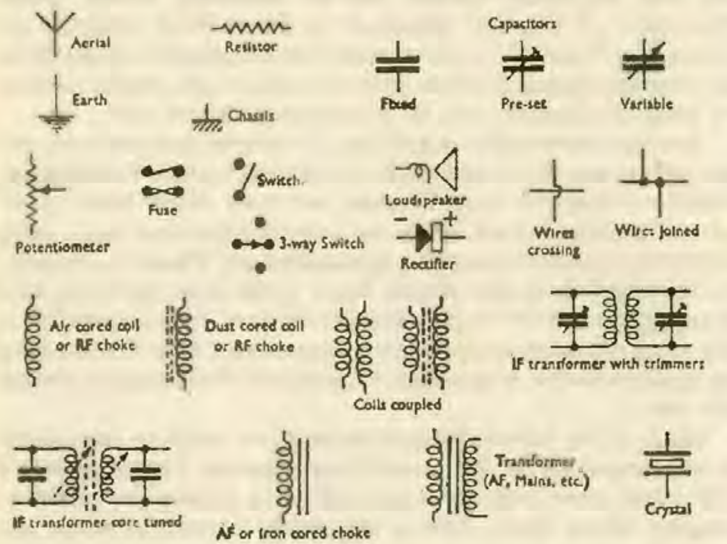
Amateurs have radio as a hobby, for interest and pleasure, and do not operate for commercial or similar purposes. Transmitting Amateurs begin by being listeners, and later obtain their 'ticket' or transmitting licence. They can operate when they wish, using any of the Amateur Bands. Large numbers use 'Phone' (telephony, or speech). Others like Morse. Some spend most operating time chatting to other 'G' (Great Britain) stations. Others specialize in Dx (long distance) working, or operate with a view to contacting as many countries as possible, to gain one of the various awards for this.

Much of the knowledge and information useful to the listener is also important to the transmitting Amateur. Listening with a SW (short wave) receiver is also helpful in gaining proficiency at reading Morse Code. This is important, because a Morse test must be passed before a transmitting licence is obtained. Fortunately these tests are not too difficult, and can be taken at many centres over the country.

Clearly the improper use of transmitting equipment could cause interference to ordinary radio or television programmes. This is a good reason why transmitting Amateurs should have sufficient knowledge of their apparatus and the correct way to operate it. So to get a licence there is a further examination which must be taken, dealing with the theory and use of small transmitting equipment. This test, also, is not particularly difficult, and many candidates pass it every year.

The actual conditions which apply to Amateur transmitting may vary slightly from time to time, so a copy of these regulations should be obtained well in advance of sitting for the examination. This can be got by post from the Amateur Radio Licensing Department, G.P.O. Headquarters, St. Martin's Le Grand, London, E.C.1.

It is only intended to deal briefly with licence conditions here, because they appear in full in the copy mentioned. The first part of the theory examination is replies to questions based largely on these regulations, so it is clear that they must be studied. Particular importance is attached to the candidate's knowledge of them.




Symbols

These licence conditions, to which the Amateur must adhere when he obtains his transmitting licence, avoid misuse of the station. For example, messages must not be sent in secret code, and the transmitting equipment must be used by the licence holder only. There is also a power limitation, this being 150 watts for the 3·5mc/s to 28mc/s bands, so the licence holder may not have extremely high power equipment. The transmitter must always be used within the permitted frequency bands (given in detail later), and incorrect methods of working which could interfere with other transmissions must be avoided. A Log is to be kept,



showing dates, times, call signs of stations contacted, and similar information. The call sign issued must always be given over the air for identification, and commercial messages, transmitted for gain, are forbidden.

These and the other conditions assure that the station is operated sensibly, for Amateur purposes only. They must be studied in advance, as mentioned, because some examination questions are about them.

The remaining part of the written examination is upon radio and transmitting theory, covering simple calculations, use of equipment, propagation of radio waves, and other subjects. The person sitting the examination can generally choose a certain number of questions himself, from those set in this part. He can thus select questions he feels best able to answer well. The candidate is normally allowed three hours for the examination, which is wholly written.

The 'Radio Amateurs' Examination' is conducted by the City and Guilds of London Institute, and it can be entered at technical colleges. Some colleges have preparatory classes, but colleges without classes can usually enter candidates. Previous question papers may be obtained from the City and Guilds of London Institute, Department of Technology, 31 Brechin Place, South Kensington, London, S.W.7, and it is a good plan to get some of these in advance. The subject is No. 55 – Radio Amateurs' Examination.

When the examination is passed, a certificate can be obtained. This certificate and a pass in the Morse test are needed before applying for the transmitting licence.

Fig. 1 shows the Amateur Bands between 1·8mc/s and 30mc/s, and they are used for world-wide and local communication. Other bands are also available. The table also shows the correspondence between frequency and wavelength, over the range 200–10 metres. Any frequency is readily converted to wavelength, or vice versa, as described later.

It is important to note that the Morse test can be taken at any time after obtaining the pass for the Radio Amateurs' Examination. But if the Morse test is passed first, the Radio Amateurs' Examination must be passed within twelve months. If not, the Morse test has to be taken again.

It is thus best to pass the Radio Amateurs' Examination first, unless the risk of perhaps taking the Morse test again is felt justified. Despite this, it is wise to start studying Morse at an early stage, because learning takes time.

For this reason, Morse is dealt with first, here. If an oscillator is constructed a start can be made on the code, and this is a diversion from technical study. If Morse is already known, from Scout or other activities, more practice in reading by ear may well be needed.

The actual Morse test consists of reading and sending plain language and figures. In the test, 36 words are to be sent in 3

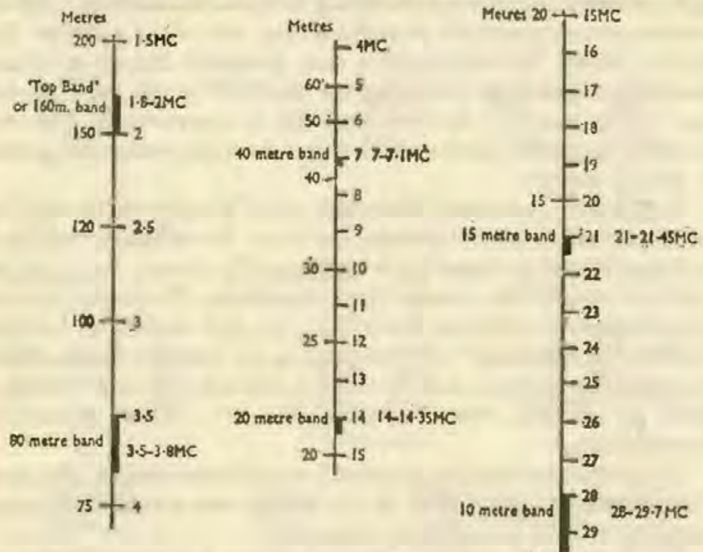



FIG. 1. Showing wavelengths with corresponding frequencies and Amateur Bands

minutes, with a maximum of 4 erasures or corrections, and no uncorrected errors. Similarly, 36 words are copied in 3 minutes, without more than 4 errors. This completes the plain language test. For figures, 10 groups of 5 figures are to be sent in 1½ minutes, with no uncorrected errors and not more than 2 erasures, while 10 groups of 5 figures are to be received in 1½ minutes, with a maximum of 2 errors.

The plain language test is 12 words per minute. This is low, compared with commercial operation. It is, nevertheless, necessary to work up to the needed 12wpm slowly, and to achieve a



reliable copying and sending speed of a little above this, to assure easy copying at 12wpm in the actual test.

Many Amateurs employ Morse, and very simple equipment may be used, giving long distance communication even in adverse conditions. Others, however, frequently use telephony (speech) generally termed 'phone'. The Morse test must be passed even if phone working is in view, because the licence cannot otherwise be obtained.

### *Equipment*

Details of the equipment required will become apparent from later chapters, but a brief summary should be of interest.

The receiver is naturally very important, and is generally a highly sensitive and efficient type of set – a 'Communications Receiver'. These can tune all the required short wave bands, and have special features, such as may be needed to receive Morse. New, high-class communications sets are expensive, but second-hand and surplus or ex-service receivers of excellent performance are readily available. Such sets are very much used by both listening and transmitting Amateurs.

There are, of course, no regulations about setting up an amateur station for receiving only. So many amateurs purchase a receiver, as the first piece of equipment, keeping this for use with the transmitter later. To start as a Short Wave Listener it is only necessary to have a receiver, an aerial such as described later, and some knowledge of short wave conditions.

The transmitting Amateur also has one or more transmitters. These are built from kits of parts, or obtained ready-made, or may be purchased second-hand, or made to the user's own design. Simple Morse transmitters can be very inexpensive. A small-power phone (speech) transmitter may cost about the same as a surplus or ex-service receiver of good type. A transmitter using near the maximum permitted power (150 watts) and purchased ready-made or as a kit of parts, would cost about the same as an expensive new communications receiver, but less than the most expensive type of communications receiver. 'Table top' transmitters, of compact design, in a single cabinet, are popular.

Many stations use home-built transmitters, and ready-made receivers. Quite a number use ready-made equipment for both receiving and transmitting. Again, others enjoy making equipment and may have no ready-made apparatus. Some Amateurs begin transmitting with low power equipment, or begin on 'Top Band' (1·8mc/s to 2mc/s) where the power limitation is 10 watts, so that transmitting equipment is particularly inexpensive.

Another important item is the aerial, but this need cost little. Long distance working is possible with wire aerials, costing shillings, rather than pounds. Aerials are dealt with later. Simple aerials may have one end going to the transmitter, and are termed 'end fed'. Or the aerial is cut in the middle, and has a twin feeder. The same aerial is generally used for both transmitter and receiver. Various aerials are available for people with small gardens or otherwise limited space.

Specialists in D× (distant) working often favour more complex aerials, such as rotary beams. Operating the station is described in Chapter Eight.

Other equipment kept will include means of checking frequency, meters, and similar radio gear. Many years of active operating are possible with modest equipment, though enthusiastic Amateurs often have a number of transmitters and receivers, a range of aerials, and all sorts of other apparatus.

Once the station is working, there need never be lack of contact with other Amateurs. Any Amateur may call any other Amateur who is 'calling CQ' and looking for a contact, or he may himself give a call requesting a contact, as described later. It is almost impossible to tune the Amateur Bands (those frequencies allocated for Amateur use) at any hour of the day or night without hearing other stations working.

There is further interest in portable or alternative address working, such as can be adopted when taking a small transmitter elsewhere, as on holiday. Mobile working is also possible, and here communication can be from a car or other vehicle, to a fixed station, or another mobile station.

Some Amateur Bands are shared with coastal and other services. The shared bands are given in the information issued by the G.P.O. covering Amateur transmitting licences.

### Learning Morse

The Morse Code consists of short and long sounds, often called dots and dashes. Each letter, figure, or other character is represented by a particular group. When receiving Morse with a radio set, reading is by ear. So from the very beginning the code should



be memorized as short and long sounds, not as dots and dashes on a printed page. As an aid to this, dots can be memorized as 'dit' (a short sound) and dashes as 'daaah' (or a long sound). For example, . . . – – – . . . (S O S) would be dit-dit-dit daaah-daaah-daaah dit-dit-dit.

It is impossible to have a written equivalent of the sound, of course, but as practice is by ear, with an oscillator or receiver, this is not too important. Each dash should equal the length of

Fig. 2. Morse Code

3 dots. The space between letters in a word should also equal 3 dots. A longer space, equal to 5 dots, is left between words. The actual spaces between the individual dots and dashes of a letter are about 1 dot in length. Fig. 2 shows the timing and the intervals.

A lot of code sending departs somewhat from this ideal, but the nearer it can be approached, the better. Good code is more easily read than bad code, and poor sending may cause errors.

For example, . . – is 'I' 'T' – 'it', but if the space is missed, producing . . –, this is 'U'.

The sounds may be hummed, whistled, or merely *thought* of as short and long. For example, 'A' is not memorized as 'dot-dash', but as dit-daaah, or pip-peeet, or dit-diiir, or as a short audible tone, followed by a tone 3 times longer.

The whole alphabet, and figures, will be seen in Fig. 2. Punctuation and other symbols are not given here, as they are not required in the test. They will be found in the section on station operating.

The figures are systematic, and are quite easily remembered. The sending and receiving speed required for figures is not very great. It is thus as well to omit the figures until a fair speed has been achieved with the alphabet. Practice with figures will then be a change, avoiding boredom, and it will probably not be necessary to spend too much time on them.

The code is generally learnt by taking a few letters each day. These can be repeated at any odd intervals, until they are thoroughly known. It is not unusual to learn the simple sounds first. For example, . E, . . I, . . . S, and . . . . H, then – T, – – M, and – – – O. Systems such as remembering that N ( – . ) is the reverse of A ( . – ) or U ( . . – ) the opposite of D ( – . . ) and so on, may occasionally help in recalling a letter, but tend to slow down reading. Nor should the alphabet be learnt in such a way that it can only be repeated from A to Z, in correct order. Instead, sufficient practice is needed until each letter and its sound are associated, without reference to other letters. This can only be achieved by practice. In all code learning, ten or fifteen minutes a day, several days a week, will be much better than trying to memorize large numbers of letters in one long session.

Once the code is known, a certain sending and receiving speed will be obtained, but will be low. It naturally depends on how well the code is known, but may be only a word or so a minute. Practice brings this speed up to that needed.

For practising, a Morse key is needed, and an oscillator, with phones or other means of listening. Buzzers are sometimes used, but an oscillator produces a tone more nearly like that which will be obtained from a radio receiver, so it is recommended.

Fig. 3 shows a simple valve oscillator, and practically any valve will work in this circuit. If no oscillation is obtained, connections to one transformer winding must be reversed.



If a transistor oscillator is preferred, the other circuit in Fig. 3 may be used. Any small audio amplifier transistor is satisfactory. The tone may be modified by changing the battery voltage, or the value of the 0·05μF capacitors. It is necessary to use medium impedance or similar phones, as the oscillator circuit is completed by them.

Initially, the key can be adjusted so that its contacts are separated by about $\frac{1}{16}$-in or a little less. Later, and for higher speeds, a closer adjustment can be used. But a very close adjustment is not wise for early practice. Nor should any type of 'bug' or automatic key be used, as the test will be on an ordinary key.

Sending can be easier than reading, but when sending, great

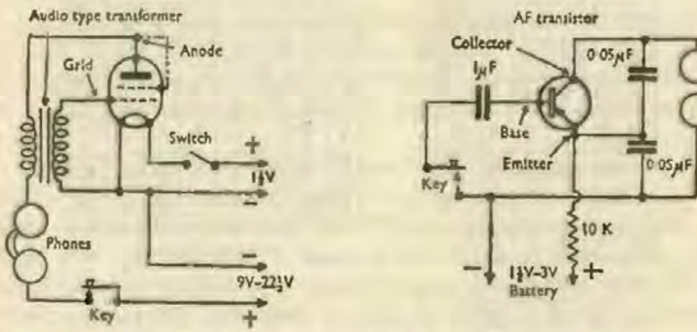



FIG. 3. Two oscillators suitable for Morse practice

care should be taken to avoid bad habits, incorrect spacing, or other errors. In particular, individual letters must be correctly separated, while each letter should form virtually a single, combined sound. For example, C is not daaah, dit, daaah, dit, nor daaah-dit, daaah-dit, but rather daaah-di-daaah-dit. When speed has been gained, letters will be read as complete sounds. Later, short words will be recognized as a whole – especially frequent words like 'the'.

If a friend or group is learning the code, practice can be together, turns being taken at sending and copying. Accuracy in sending and reading should always be in view. Sloppy, fast sending, which even an experienced code operator might find difficult to read, is useless.

First practice needs to be at low speed, so that everything is copied correctly. Sending may then be speeded up slightly, at intervals. Maximum learning is considered to be at such a speed as will allow the code to be read only with concentration and some difficulty. Only short periods should be spent, and the existing speed should be read accurately, before going on to a higher speed. Periods may arise when no increase in speed seems to be coming. If so, the code can be dropped for a few days or a week or so. After this, results will probably improve.

With straight text, it is not difficult to guess some letters. To avoid this, random letters can be used from time to time. Fig. 4

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

36 Letters (7 words)

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

64 Letters (12 words)

| | | | | |
|---|---|---|---|---|
| 4 | 7 | 5 | 2 | 8 |
| 4 | 1 | 9 | 3 | 1 |
| 9 | 6 | 1 | 3 | 6 |
| 5 | 2 | 4 | 0 | 8 |
| 3 | 2 | 7 | 5 | 0 |

Number square (5 groups of 5)

FIG. 4. Letter squares with letters per minute and approximate words per minute. Each block sent in one minute

shows groups of random letters, which can be read horizontally, vertically, and diagonally, to avoid repetition making them too familiar. The 6 by 6 square contains 36 letters, and this is about 7wpm, if the block is sent in a minute. In the same way, the square with 64 letters equals nearly 13wpm. Other squares can easily be drawn up. If there is any difficulty with particular or difficult letters, these can be added fairly frequently in the practice squares, and easy letters can be temporarily dropped.

Practice must also include straightforward text, naturally of



matter not already known. If practice is with a beginner friend only, with a key and oscillator, a more experienced operator should occasionally check progress and keying, if possible.

A short wave radio will provide many Morse signals. Most Morse is unmodulated carrier wave (CW) and to render it audible as a tone, a beat frequency oscillator (BFO) is required. A communications set will have this BFO. An ordinary, domestic type set with one or more SW bands may be fitted with a BFO, as described later.

Morse, as tuned in on the radio, will be too fast to read, if the code has only been memorized. But after some practice, with an oscillator or other means, some of the easy letters will be recognized. Repeated signals, such as call signs, may also be read occasionally.

The Radio Society of Great Britain, New Ruskin House, Little Russell Street, London, W.C.1, can provide a list of their Slow Morse Transmissions, which are for those learning the code. Some of these transmissions should be heard in most parts of the country.

Intervals spent on reading Morse from the radio will be well worth while, and can be added to other practice methods. As more and more can be read from actual transmissions, it will be clear that real progress is being made. At week-ends and other times quite a number of Amateurs, some newly licensed, will be heard using code, and their sending is often at no great speed. But no one can read code straight from the radio, and complete, at first.

Morse records form another method of learning to read the code. These are available in various types, many incorporated with a course on code reading and sending. They usually begin at low speed, becoming progressively faster.

If a tape recorder is available, it can be used to gain reading practice. To do this, record at the required speed, and then copy the code as the recording is played back. To avoid guessing and aid by memory, random letters or squares, like those in Fig. 4, will have to be largely used. The simplest way to record will be to place the tape recorder microphone on or near one earphone of the oscillator, keeping the key clear of the microphone to avoid mechanical clicks. Adjust for volume in the usual way.

Sending can be kept ahead of reading, so that this method permits practice by a single person, alone. Initially, the recording can be made at 3 or 4wpm. If some 15 minutes or so of this is recorded, the same recording can be used over and over again. If keying mistakes become apparent, they should be corrected. Speeds can be increased at about 2wpm (extra 10 letters per minute) or so, each time.

Various short, frequently-appearing words can be recorded, in no particular order. Recording and then reading sentences or similar material will not be too successful as practice, due to the aid furnished by memory.

When practising sending, use the erasure sign (8 dots) to correct any error. Do not let sending errors pass. If errors are made in the Morse test, they will have to be corrected, so the habit should begin at once.

If circumstances permit, it is wise to gain a reasonable reading speed before bothering too much about sending practice. If sending is necessary from the very beginning, due to the method of practice used, particular care should be taken to avoid forming bad sending habits, such as incorrect spacing or timing.

When reading the code, the text should be written down as it is received, not being merely read mentally. Longhand is perhaps more satisfactory than printing or capitals, as it will be much easier to write at higher speeds. Words and groups of figures need to be properly separated.

More skilled operators read and write whole words at a time, and may be writing behind the actual code, in order to give neat, punctuated copy. Such reading behind is actually easier after long practice, and for faster speeds.

If a letter is missed, while reading, a space must be left, as prolonged thought will result in many more letters being lost. Sending, of course, should not be at a higher speed than can be dealt with correctly. Occasional practice with random letter squares or unusual words will help to avoid the habit of filling in missed letters by guessing.

When all the letters of the alphabet can be recognized, it is a good plan to have each letter sent fairly rapidly, the lower rate of words per minute being obtained by temporarily increasing the interval between letters and between words. It will then be easier to reach higher speeds. If the characters forming a letter are sent in a slow, drawn-out form the letter will sound different when speed is increased. But if the lower rate of words per minute is obtained by increased spacing, the sound of each letter will be



about the same, even when speed is increased by reducing the interval between letters. It should, however, be remembered that this extra spacing is only adopted so that each letter can be sent fast, and is really incorrect.

There is no quick, short-cut method of gaining speed. Some people learn more easily than others. If most practice is with an oscillator, it is wise to vary the tone sometimes, and also the writing position, or room. Or a change, such as will arise at the Morse test, may result in everything seeming so unfamiliar that the accustomed speed is impossible.

Short learning periods, several times a week, will be best, as mentioned. Learning methods should be varied. Any opportunity to gain practice with a licensed Amateur, or other proficient code operator, should be taken. Listening to code on the radio will be extremely useful, especially at the later stages. If virtually nothing at all can be read off a broadcast message, at first, this is no cause whatever for alarm. If a message is copied, and does not seem to be intelligible, this may be because it is not in English! Or, if the station does chance to be English, abbreviations and other special signals may be frequently employed. Some of these appear in the section on operating, and there is no need to bother with them much at this stage.

The actual test may be taken at certain post offices, and coast-guard stations, and details can be obtained when getting a copy of the licence conditions. A little safety margin is recommended, such as the ability to send and receive accurately at 14 or 15wpm, instead of the minimum 12wpm required by the test. If possible, a 'dummy' test can be taken with a licensed Amateur. If this is successful, it will give confidence; if errors or weaknesses are revealed, extra practice is indicated.

Should the test be failed, it can be taken again, later. If it is passed, a pass slip will be issued, and this is sent within 12 months with the application for a transmitting licence.

CHAPTER TWO

# Circuit Elements and Components

A MOLECULE is the smallest particle of a substance, and may be regarded as a small group of atoms. Various atom combinations produce different substances. An atom may be regarded as consisting of a central proton nucleus, with one or more electrons rotating round it. The nucleus is positive, and the electrons are negative, so that attraction between these dissimilar charges keeps the electrons in orbit round the nucleus.

An electric current is a flow of electrons. As these are negative, an increase in the number of electrons constitutes a negative charge. Conversely, a shortage of electrons may be regarded as a positive charge.

A conductor is a substance (such as copper wire) which will allow a ready passage of electrons. Conductors offer some resistance to the current, and this varies according to the type of material. Copper is widely used, because it is cheap and is a good conductor. Some alloys have appreciable resistance, and are not such good conductors. Wires made from these alloys are therefore used for wire-wound resistors. Other materials, such as carbon compounds, have resistance, and can be used to make carbon (e.g. not wire-wound) resistors. The resistivity, in microhms (millionths of an ohm) for a centimetre cube of some well-known metals is approximately as follows:

| | | | |
|---|---|---|---|
| Silver | 1·55 | Brass | 6 to 9 |
| Copper | 1·65 | Nickel | 7·5 |
| Aluminium | 2·65 | Iron | 9·5 |

When the resistance of a kind of wire is known, for a given length, the resistance of any length of the wire may easily be found. For example, assume 34 SWG copper wire with a resistance of 361 ohms per 1,000yds is used. What is the resistance of





30yds of the wire? Resistance per yard $= \frac{361}{1{,}000}$ so for 30yds resistance is:

$$\frac{361 \times 30}{1{,}000} = 10{\cdot}83 \text{ ohms}$$

Or suppose 34 SWG resistance wire with a resistance of 10,128 ohms per 1,000yds were substituted:

$$\frac{10{,}128 \times 30}{1{,}000} = 303{\cdot}84 \text{ ohms}$$

Or suppose a 4 ohm meter shunt resistor is required, and the wire used has a resistance of 2·5 ohms per foot. Length needed:

$$\frac{4}{2{\cdot}5} = 1{\cdot}6\text{ft}$$

Insulators have an extremely high resistance and a perfect insulator would have infinitely high resistance. Many plastic substances are used as insulators in radio. Enamel, cotton, silk, rayon, rubber, and similar materials are used as insulated coverings for wires. Glass, mica, ceramics, impregnated paper, and similar materials are also used in valves, capacitors, transformers, and other components.

Resistivities of insulators are very high, and some typical substances and resistivities are as follows, for a cm cube:

| | | | |
|---|---|---|---|
| Mica | $10^{16}$ ohms | Ceramics | $10^{14}$ ohms |
| Glass | $10^{14}$ ohms | Bakelite | $10^{11}$ ohms |

In the usual way, $10^{16}$ equals the figure 1 with 16 noughts, and so on. For example, $10^2 = 100$, $10^3 = 1{,}000$, $10^4 = 10{,}000$, etc. This method of showing very large numbers is conveniently employed in radio, when the numbers are very great.

*Magnets*

If a number of turns of insulated wire are wound round an iron rod or other core of ferrous metal, and a current is passed through the wire, the core will become magnetized. This is an electromagnet.

If the core is of some material which retains magnetism, the magnetism will remain, when the current ceases. If so, a permanent magnet has been formed. Permanent magnets are constructed from special alloys, which retain their magnetic power well.

Permanent magnets are used in PM (permanent magnet) speakers. Here, the magnet is specially shaped so that a gap is left, with a strong magnetic field, to receive the speech coil, as in Fig. 5 and Fig. 37. Audio-frequency current flowing in this coil makes the coil vibrate, and the coil is fixed to a cone from which sound is distributed.

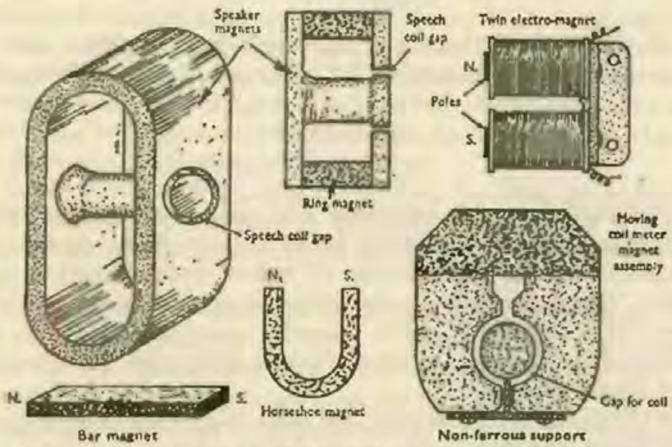



FIG. 5. Types of permanent magnets and a twin electro-magnet

Permanent magnets are also used in moving-coil meters, the moving coil being pivoted to swing in a magnetic gap. Moving-coil microphones have a permanent magnet, similar to that in a PM speaker. Permanent magnets are also used in headphones.

Electro-magnetic assemblies are used in some types of AC/DC current voltmeters. The field coil of an energized speaker is an electro-magnet, usually receiving current from the receiver HT supply, and replacing the permanent magnet of the PM speaker. Electro-magnets are also used to operate the mechanism of relays, which may be regarded as switches in which the contacts are moved electrically.

*Voltage, Resistance, Current, Wattage*

A battery, generator, or other source of electricity will cause



a current to flow through an external circuit. The greater the electromotive force or voltage, the larger will the current tend to be. But the external circuit has some resistance, which hinders the flow of current. Lowering this resistance, for a given voltage, will increase the current flowing. Increasing the resistance will decrease the current flowing.

Electromotive force (emf) or voltage is usually indicated by E or V. Current is denoted by I, and resistance in Ohms by R.

If two factors are known, the other factor can be found from:

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}} \text{ or } I = \frac{V}{R}$$

$$\text{Resistance} = \frac{\text{Voltage}}{\text{Current}} \text{ or } R = \frac{V}{I}$$

$$\text{Voltage} = \text{Current} \times \text{Resistance, or } V = I \times R, \text{ or } IR$$

These are ways of expressing Ohm's Law. Resistance is in Ohms ($\Omega$) and current in Amperes (amp or A). If any two factors are known, the third is found as shown. Ohm's Law is for direct current (DC) or when DC conditions apply.

*Examples:* A 12V battery is connected to a 6 ohm resistor. What current flows? 12/6 = 2 amperes.

An emf of 50V is applied to a circuit and it is found ½A flows. What is the circuit resistance? 50/0·5 = 100 ohms.

A valve heater drawing 0·2A and requiring 13V is to be run from a 25V supply. What resistance is needed? Voltage to be dropped in resistance = 25 − 13 = 12V. So resistance required = 12/0·2 = 60 ohms.

0·25A is flowing through a 1,000 ohm resistor. What voltage is present across the resistor? 0·25 × 1,000 = 250V.

Small currents are present in many radio circuits. These are given in milliamperes (mA) or microamperes ($\mu$A).

1,000mA = 1A. Or 1mA = 1/1,000A, or 0·001A, or $10^{-3}$A

1,000$\mu$A = 1mA. Or 1$\mu$A = 1/1,000mA, or 0·001mA, or $10^{-3}$mA

1,000,000$\mu$A = 1A. Or 1$\mu$A = 1/1,000,000A, or $10^{-6}$A

Resistances are often high, and K is used to indicate kilohms, or 1,000 ohms, while M$\Omega$ indicates megohms, or 1,000,000 ohms. So 2K is 2,000 ohms. Similarly, 500K is 0·5 megohms, or 500,000 ohms, and so on.

If the terms in Ohm's Law are given in mA and kilohms, direct calculation is possible. This is often convenient. For example, 300V is applied to a circuit and 2mA flows. What is the circuit resistance? 300/2=150K.

But if current is in amperes, resistance must be in ohms, as in earlier examples. If the previous example were worked in this way, 2mA=0·002A, so resistance=300/0·002=150,000 ohms.

In some circuits, the voltage may be extremely small. It may then be given in millivolts (mV) or microvolts ($\mu$V). 1,000mV=1V, and 1,000,000$\mu$V=1V.

The power dissipated in a circuit is expressed in Watts. Or, if the power is small, it may be given in Milliwatts. 1,000mW=1W.

$$W = I \times V \text{ or } IV, \text{ or } W = V^2/R, \text{ or } W = I^2 \times R \text{ or } I^2R.$$

As example, a valve with a cathode current of 50 mA uses a 400 ohm cathode bias resistor. What is the minimum wattage resistor which can be fitted? 0·05×0·05×400=1 watt.

Again, the power amplifier valve of a transmitter draws 150mA and receives 400V. What is the power input to the stage? 0·15×400=60 watts.

*Resistors in Series*

When resistances or resistors are in series, their values are added. For example, in Fig. 6A, if R1 is 250 ohms and R2 is 300 ohms, the total is 550 ohms. Similarly, 500 ohms, 1K and 2·5K in series total 4K. The current in all resistors thus in series must be equal.

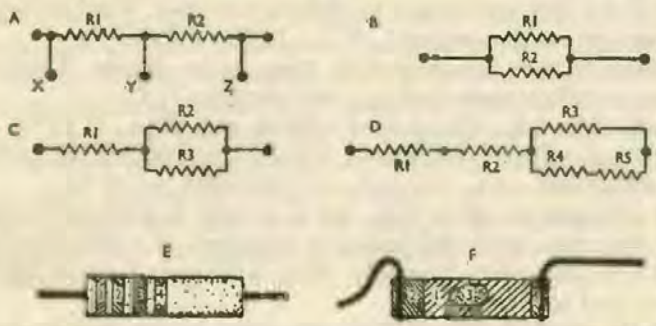



FIG. 6. Resistors in series and parallel, and resistor colour code



For example, 500 ohms, 1K and 2·5K resistors, in series, are wired to an 80V supply. Current in each resistor:

$$\frac{\text{Voltage}}{\text{Total Resistance}} = \frac{80}{4,000} = 0{\cdot}02\text{A or } 20\text{mA}$$

Voltage across each resistor = I × R. E.g.:
Across 500 ohms = 500 × 0·02 = 10V
Across 1K = 1,000 × 0·02 = 20V
Across 2·5K = 2,500 × 0·02 = 50V
And 10+20+50 = 80V

In the same way, the wattage dissipated in any resistor can be found.

*Resistors in Parallel*

When two resistors are wired in parallel, as in Fig. 6B, the overall resistance may be found from:

$$\frac{R1 \times R2}{R1 + R2}$$

For example, 10K and 20K resistors are wired in parallel. Resistance:

$$\frac{10,000 \times 20,000}{10,000 + 20,000} = 6,666 \text{ ohms}$$

For more than two resistors:

$$\frac{1}{R} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3}, \text{ etc.}$$

The overall resistance of simple networks can be found from series and parallel calculations. Fig. 6C shows a simple network. R2 and R3 in parallel equal:

$$\frac{R2 \times R3}{R2 + R3}$$ and adding R1 gives the total value.

Again, in Fig. 6D, R4+R5=R6, so total resistance:

$$\frac{R3 \times R6}{R3 + R6} + R1 + R2$$

It is sometimes possible to work such problems in several ways with the same result.

*Resistors*

These are frequently made from carbon compounds, in wattages from one-tenth to 2 watts, and occasionally higher. Resistors over about 5W are generally wire-wound; that is, wound with resistance wire on an insulated, heat-resistant body.

Small resistors are usually colour-coded. The colour code is as follows:

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

Resistors have colour bands, as at E in Fig. 6, or body, tip and dot colours, as at F. With E, colours are read from the end, as shown. With F, body, tip and dot colours are read in that order. The 'dot' may be a band round the resistor.

The first colour gives the first figure, the second colour the second figure, and the third colour the number of noughts. E.g. orange/orange/orange=33,000 ohms (33K). Similarly, yellow/violet/orange=47K. In the same way, red/green/brown=250 ohms, and red/red/green=2,200,000 ohms, or 2·2 megohms.

Resistors marked with three colours in this way are within 20 per cent of the marked value. That is, they have a 20 per cent tolerance. The errors in exact value arise in manufacture. They are suitable when exact resistance values are not necessary.

If the circuit calls for a more correct value, 10 per cent tolerance resistors may be used, and these are marked with a silver tip or ring in addition to the previous colours. In the same way, 5 per cent tolerance resistors have a gold tip or ring. Resistors accurate to 1 per cent or 2 per cent may be obtained for use in test meters, etc. In most radio circuits, an error of 10 per cent in the values of small carbon resistors of this kind will not be of importance. In E and F, colour 4 is silver or gold, for 10 per cent or 5 per cent.

The wattage rating of a resistor should be at least equal to the wattage dissipated in it. For example, if a circuit called for a ·3W resistor, a ½W component (nearest standard larger wattage) could be fitted. Small resistors are often $\frac{1}{10}$, ¼, ½, and 1 watt, with larger resistors being 2, 5, 10 watt, and more. Large resistors



such as mains droppers may be rated at the current they can carry – say, 300mA, or 0·3A.

Fig. 7 shows a circuit requiring a mains dropper. A 7-valve receiver has five 6·3V 0·3A valves, and two 25V 0·3A valves, and is to be run from 240V mains. What resistance is needed for the mains dropper R?

Valve heaters total 81·5V. Mains voltage is 240V, so R must drop 240−81·5V=158·5V. Current is 0·3A, so:

$$R=\frac{158 \cdot 5}{0 \cdot 3}=528 \text{ ohms}$$

It would be considered satisfactory, in practice, if the actual current through the heater chain were with 2½ per cent of 0·3A.

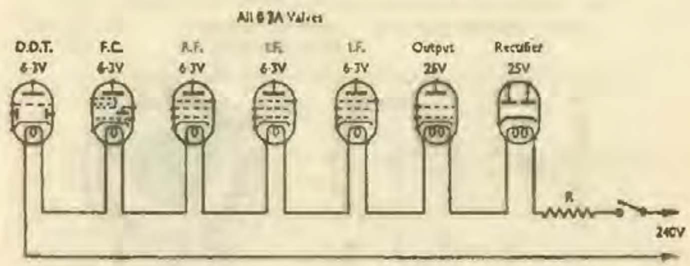



FIG. 7. Series heater circuit with mains dropper

*Conductance*

This is given in mhos ('ohms' backwards) and is the reciprocal. That is, 1/R is the conductance of R. With resistors in parallel, the conductances of each resistor may be added, to give the conductance of the whole. This has already been encountered in:

$$\frac{1}{R}=\frac{1}{R1}+\frac{1}{R2}+\frac{1}{R3}, \text{ etc.}$$

This can also be given as:

$$R=\frac{1}{\frac{1}{R1}+\frac{1}{R2}+\frac{1}{R3}}$$

The term is most often encountered in the case of valves, where the Mutual Conductance may be given, as described later.

*Potentiometers*

The potentiometer, as usually employed, is a resistor with a circular track. One terminal or tag is connected to each end of this track, and a rotating contact bears on the track. This contact is often electrically isolated from the control spindle, and a third terminal provides a connection for it. A potentiometer is the same as a variable resistor with connections for both ends of the resistance element, as shown in Fig. 8.

A potentiometer is frequently used as an audio gain control. The audio signal is developed across the whole of the element, and the slider is taken to the control grid of the next stage. The slider can then be adjusted to take off any desired level of audio voltage. The resistance element may be linear, with a linear variation in

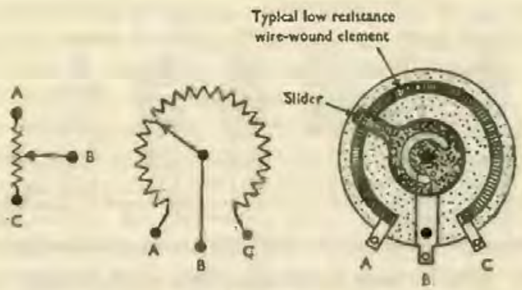



FIG. 8

value as the spindle is rotated. Or it may be logarithmic, with a logarithmic variation in value. These components are termed 'linear' and 'log' potentiometers respectively.

Two resistors in series will form a fixed potential divider. In Fig. 6A, X could be taken to HT negative, and Z to HT positive. A reduced voltage would then be available between X and Y. The voltage here would depend on the HT voltage, resistor values, and current drawn, and can be calculated from Ohm's Law. A fixed potential divider of this kind could be used to supply the screen grid of a valve.

*DC and AC*

Direct Current is a steady flow of current in one direction, and this arises when a steady voltage is applied to a circuit having



resistance. The steady potential (or current) may be represented as at A in Fig. 9.

The terminals of an Alternating Current supply are alternatively positive and negative, so current flows back and forth. This can be represented by B, where the positive and negative peaks are equal in magnitude, though opposite in polarity. There is one positive half-cycle, and one negative half-cycle.

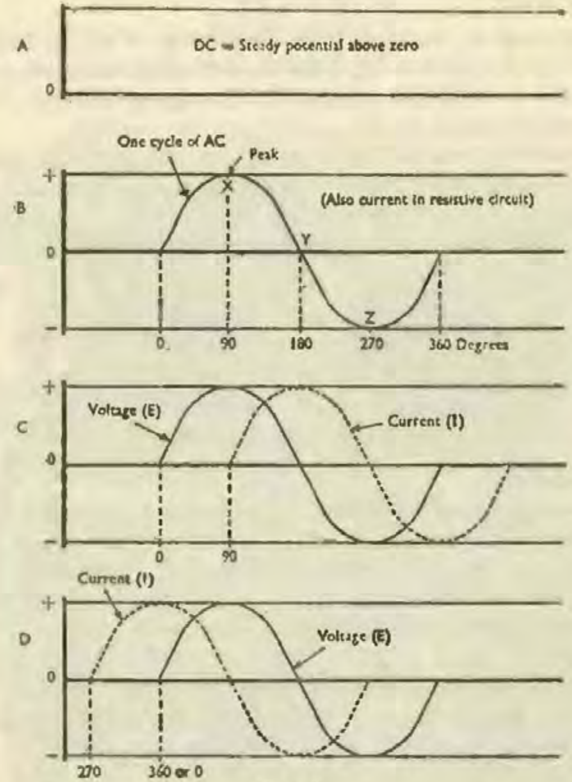



FIG. 9

During a complete half-cycle, the voltage rises from zero, reaches maximum, and falls again to zero. The highest voltage reached is termed the 'peak' voltage.

The actual heating effect (or 'power') of the half-cycle is clearly less than that of the maximum or peak voltage continued for the duration of the whole half-cycle, because for parts of the cycle the voltage is near to zero. For this reason, AC voltages are commonly given and measured as the Root Mean Square, or RMS, value. This is actually the value which would have the same heating effect as DC of that voltage. When AC voltages are given, these are RMS values, unless otherwise stated. The peak voltage is 1·414 times the RMS voltage. A '100V AC supply' would thus actually be 100V RMS.

The average or mean value is the average of all the half-cycle, and is 0·636 the peak value, if the wave is a sine wave, as in Fig. 9. If the wave is of different shape, the average is different. Average values are not much used.

The instantaneous voltage is the actual voltage at any particular chosen instant, and it could thus be anything from zero to the peak voltage. It is seldom required.

The relationships can be summarized as follows:

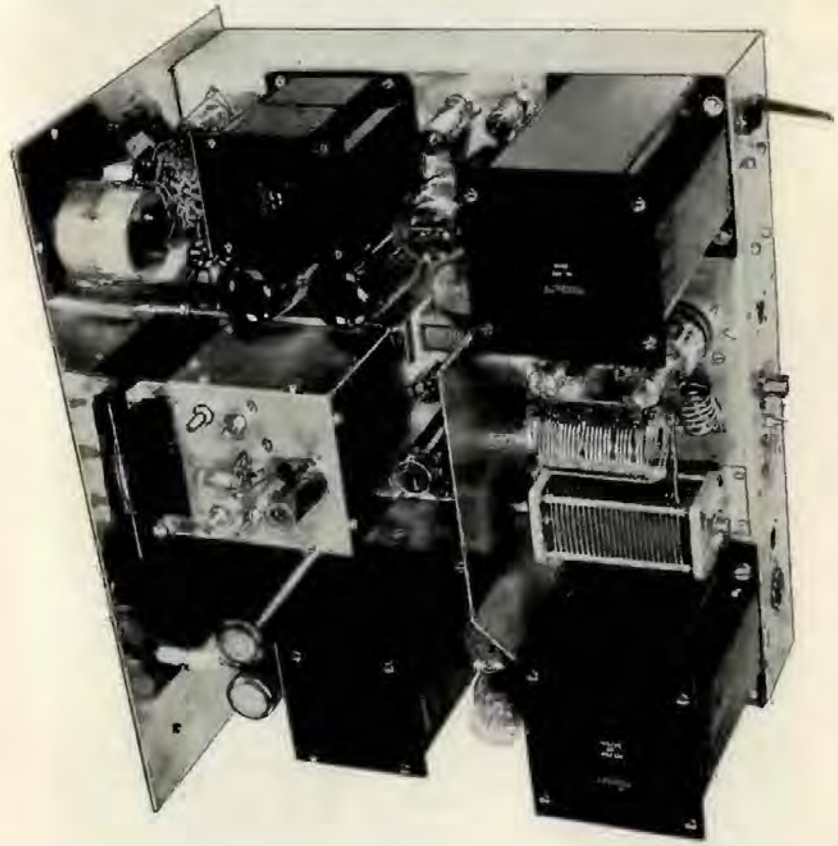
Peak × 0·707 = RMS
Peak × 0·636 = Average
Average × 1·11 = RMS
RMS × 0·9 = Average
RMS × 1·414 = Peak
Average × 1·57 = Peak

*Lag and Lead*

One complete cycle of an alternating voltage is shown in Fig. 9B. This cycle begins at zero potential, and rises from this point to the maximum positive potential, or peak X. From here, it falls away to zero, at Y. It continues from this point to Z, which is the maximum negative potential, then again returns to zero. This is one complete cycle.

If this alternating voltage is applied to a resistor, current in the resistor reaches a maximum at the same time as the voltage peak X, then decreases to zero, and reaches another maximum at the peak Z. That is, the rise and fall of current takes place at the same time as the rise and fall of voltage: the current I is in phase with the voltage E. This is always so with a purely resistive load.

If an inductance is connected to the supply the flow of current is different. An inductance produces a back emf, which tries to oppose any change in the current in the inductance. As a result, the actual flow of current is one quarter of a cycle behind the



1. DX–100U 150 watt transmitter covering 160 to 10 metres. Left, power transformers, centre, screened VFO, right, push-pull modulator, PA two 6146's. (Heathkit, Daystrom Ltd., Gloucester.)

2. *Above* DX-100U table top transmitter, for speech and CW, 150 watts. 3. *Below* Morse practice outfit – transistor oscillator built to circuit in Chapter 1, and key.



voltage, as shown at C. As one complete cycle is 360 degrees, this is the same as saying that the current I is 90 degrees behind the voltage E. That is, the current I lags behind the voltage E by 90 degrees. This is always so in circuits with inductance only.

If a capacitor is connected instead, it is charging most rapidly when the change in applied voltage is beginning to sweep to a peak, but the charging current begins to fall off as the capacitor becomes nearly fully charged. As a result, the current flowing into the capacitor is at a maximum one quarter cycle before the voltage peak. That is, the current I is one-quarter cycle, or 90 degrees, ahead of the voltage E, or leads the voltage E by 90 degrees. (Fig. 9D.) This is always so in a capacitor, which charges and discharges each time polarity changes.

In brief, when an AC voltage is applied to a resistor, the current I is in phase with the voltage E. When an AC voltage is applied to an inductance, current lags voltage by 90 degrees. When an AC voltage is applied to a capacitor, current leads voltage by 90 degrees.

The resistance of a resistor is expressed in Ohms, and with AC calculations results are the same as for DC. But in a circuit with inductance only, the ratio between voltage and current is termed the reactance, and inductive reactance is denoted by $X_L$. For the capacitor, the ratio between voltage and current is the capacitive reactance, denoted by $X_C$.

If steady DC were applied to an inductance, the inductance would simply act as a resistor of equivalent resistance to the wire with which the inductance is wound. If steady DC were applied to a perfect capacitor, no current at all would flow, because the capacitor consists of plates insulated from each other.

*Capacitance*

Two conductive plates placed by each other, as in Fig. 10, form a capacitor (or condenser). If a voltage is applied, a momentary current flows, charging the plates to the potential of the applied voltage. This electrostatic charge can be discharged by removing the voltage, and shorting the plates by means of a conductor, when the stored charge will produce a momentary current back through the conductor.

The unit of capacity is the Farad, but this is too large for radio work, so the microfarad ($\mu$F) and micro-microfarad ($\mu\mu$F)

B

or picofarad (pF) are used instead. The units $\mu\mu F$ and pF are the same.

$1\mu F = 1/1{,}000{,}000$ Farad, or $10^{-6}$, or 0·000,001 Farad

$1pF = 1/1{,}000{,}000\ \mu F$, or $10^{-6}$, or 0·000,001 $\mu F$

1pF or $1\mu\mu F = 10^{-12}$ Farad

Values are usually given in such a way as to be convenient, or to avoid too many noughts. For example: 0·1$\mu$F (100,000pF); 0·01$\mu$F and 10,000pF; 1,000pF (0·001$\mu$F); 100pF (0·0001$\mu$F); 10pF (0·00001$\mu$F), etc.

Tuning capacitors for broadcast bands (medium and long waves) are frequently up to about 500pF maximum capacity,

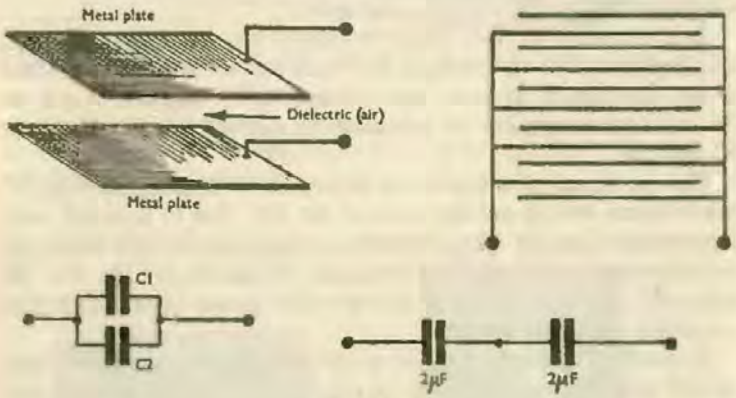



Fig. 10

while in receivers for short waves only 100pF to 250pF will be more usual. The minimum capacity of these components is not zero, but will be around 5pF to 25pF or so. Mica capacitors are often up to about 1,000pF. Many paper capacitors are about 1,000pF to 1$\mu$F, while electrolytic capacitors are often 2$\mu$F to 100$\mu$F, and higher.

The capacitor has insulation between its plates. This is termed the dielectric. An air-spaced tuning capacitor is an example of an air dielectric capacitor. If some material other than air were between the plates, the capacity would be increased. This effect depends on the 'dielectric constant' of the material, or its specific



inductive capacity. Frequently used dielectrics and insulators, and their approximate dielectric constants, are:

| | | | |
|---|---|---|---|
| Air | 1 | Ebonite | 2·75 |
| Mica | 5·4 | Shellac | 3 |
| Paper | 1·5 | Glass | 4 to 6 |

Energy actually stored is in joules, or watt-seconds, and equals $\frac{C \times E^2}{2}$ where C is capacitance in Farads, and E the voltage. For microfarads, this equals:

$$\frac{C \times E^2}{2 \times 1{,}000{,}000}$$

The capacitance of two plates can be calculated from:

$$0{\cdot}2248 \times K \times \frac{A}{t}$$

where A is the area of overlap of the plates, t is the thickness of the dielectric (or distance between the plates), and K is the dielectric constant of the dielectric (1 for air, etc.). A and t are in inches, and the capacitance is obtained in pF.

As mentioned, actual capacitors consist of conductors (such as plates or foil) separated by an insulator (air, mica, paper, etc.). Variable tuning capacitors are usually air-spaced, but fixed capacitors generally have a solid dielectric. Capacitors with mica and ceramic insulation are stable, have high resistance, and are often used in fairly small values. Paper capacitors are made by rolling foil and paper together, and can be of quite high capacity.

Electrolytic capacitors employ an electrolyte between plates, which increases capacity. They must always be connected in the correct polarity. The polarity applied to mica, paper and similar capacitors is unimportant, but the outside foil may be indicated by a band, or OF, when it may be necessary to know which end to take to earth or chassis.

Electrolytic and paper capacitors have a maximum working voltage marked on them, and may be expected to break down if they are used with a higher voltage.

When capacitors are connected in parallel, their values are added (as for resistors in series). When capacitors are in series, the method of calculation is the same as for resistors in parallel.

E.g. in Fig. 10 C1 and C2 are 1$\mu$F and 4$\mu$F capacitors wired in parallel. What is the overall total? 1+4=5$\mu$F. Again, 100pF and 300pF capacitors are in parallel. Total: 100+300=400pF.

Again, two 2$\mu$F capacitors are in series, in Fig. 10. What is the resultant capacity?

$$\frac{2\times 2}{2+2}=1\mu F.$$

Similarly, a 50pF capacitor is wired in series with a further 50pF capacitor. What is the total?

$$\frac{50\times 50}{50+50}=25pF.$$

For two capacitors in series:

$$C=\frac{C1\times C2}{C1+C2}$$

For three or more capacitors in series:

$$\frac{1}{C}=\frac{1}{C1}+\frac{1}{C2}+\frac{1}{C3}, \text{ etc.}$$

*Capacitive Reactance*

If a capacitor has perfect insulation, it will not allow any DC to pass. Good practical capacitors approach this ideal, and offer no path for DC.

If a capacitor is used in a curcuit where AC is present, the plates charge and discharge at each reversal of the AC supply, and this is the same in effect as if a current flowed through the capacitor. The capacitor will, however, have some 'resistance' to the AC supply. This is termed capacitive reactance, and is denoted by Xc. It is applied to capacitors and the capacitive reactance falls as frequency is increased, or when the capacity is increased. Xc, or capacitive reactance in Ohms, equals:

$$\frac{1}{2\pi f C}$$

Here, 2 $\pi$ may generally be taken as 6·28, and the frequency f is in cycles per second, the capacity C being expressed in Farads. As large capacities are not used in radio, and capacitive reactance



is often required at radio frequencies, it may be convenient to find Xc from:

$$\frac{1,000,000}{2\pi f C}$$ or $\frac{159200}{fC}$

with f in mc/s and C in pF.

For example, a 50pF capacitor is wired in a 3 mc/s circuit. What is its capacitive reactance?

$$Xc=\frac{1,000,000}{6{\cdot}28\times 3\times 50}=1,061 \text{ ohms}$$

*Capacitor Construction*

*Variable capacitors.* A single variable capacitor has one set of fixed plates, and one set of moving plates. The latter are secured to the control spindle. Moving and fixed plates do not touch each other. With an air-dielectric capacitor, this is achieved by accurate construction. In the case of a small solid dielectric variable capacitor, thin sheets of insulating material are placed between fixed and moving plates. Solid dielectric variable capacitors are very seldom used in SW equipment.

Fixed and moving plates are insulated from each other, and this may be arranged by building the capacitor on insulated end plates, or by using metal plates with ceramic or other insulators to support the fixed plates of the capacitor. Connection to the moving plates is frequently by friction springs, bearing on the spindle.

*Fixed Capacitors.* These may be small, moulded components, with wire ends, or they may be tubular, usually made from rolled foil and paper, with a card cover, impregnated with wax or other material to keep out moisture. Such small capacitors are supported by their wire ends.

Larger fixed capacitors may be in block form, with lugs so that they can be bolted in position. Or they may be tubular, secured with a circular clip. Metal cased capacitors may have the case common to the negative terminal.

*Electrolytic capacitors.* In an electrolytic capacitor, a very thin layer of aluminium oxide acts as the dielectric. Very high capacities are obtainable, in small size components. The plates may be of aluminium foil, and the electrolyte may be in paste form on paper or similar material. Foil and paper may be rolled into tubular capacitors, in a similar way to tubular paper dielectric capacitors. It is quite common to include two or even more capacitors in a single component, and to use a metal can for the negative terminal.

Any electrolytic capacitor will have positive and negative ends, and it must always be wired in circuit correctly. A small leakage current flows through the electrolyte, and maintains the capacitor in proper condition. The voltage applied to it must never be of reversed polarity. The capacitor will also have a maximum voltage rating, which must not be exceeded. In bias and low voltage valve circuits, electrolytic capacitors of 25$\mu$F to 50$\mu$F or so, 12V, 25V and 50V working, are often used, with 8$\mu$F, 16$\mu$F, 32$\mu$F and other capacitors, of 350V to 500V working, for HT circuits.

*Inductance*

If a conductor moves in a magnetic field, this induces a current in the conductor. Similarly, if the conductor is fixed, and the magnetic field moves, a current is also induced in the conductor. Fig. 11 shows a simple air-cored solenoid, or winding without any metal or similar core. When current is flowing, a magnetic field is generated, as shown. If the current is always of the same strength, there is no change in the magnetic field. But if the current is increased, or decreased, the magnetic field changes, and this in turn induces current in the winding.

This effect is 'self-inductance'. If a change in current of 1 ampere per second induces 1V the winding has an inductance of 1 Henry. Large windings, such as smoothing chokes, may have an inductance of several Henrys, but radio frequency coils and smaller windings have a much smaller inductance, and this is generally given in microhenrys, or millihenrys:

1 Henry = 1,000 millihenrys (mH) = 1,000,000 microhenrys ($\mu$H)
1 millihenry (mH) = 1,000 microhenrys ($\mu$H)

Similarly:

$1\mu H = 0{\cdot}001 mH$ (or $10^{-3} mH$) $= 0{\cdot}000{,}001 H$ (or $10^{-6} H$)

When a voltage is applied to the inductor, current will flow, creating lines of magnetic force, which in turn tend to oppose the flow of current, or produce a 'back electromotive force' (back emf). This is a property of all inductances or inductors. When the voltage is removed the lines of magnetic force begin to collapse,



and an emf is induced which tends to maintain the current flowing. An inductor thus opposes an increase in current, and also a fall in current.

If two solenoids or other windings are so placed that some of the magnetic lines produced by one coil link with the turns of the other coil, 'mutual inductance' exists between the coils. A current is only induced in the second coil when there is a rise or fall of current in the first coil.

If the two coils are close to each other, the degree of coupling is high. As the coils are separated, the coupling falls. Coils close together are said to be closely coupled, while well separated coils are loosely coupled. If one coil is rotated so that its axis is at right angles to the other, this also reduces coupling to a very low level.

If inductors are wired in series, the total inductance is the sum of the inductance of the various coils. That is: Total = L1 + L2 + L3, etc. This only applies if the coils are so arranged that there is no mutual inductance between one and another.

If inductors are wired in parallel, the overall inductance is found in the same way as described for resistors in parallel, if there is no coupling between individual inductors.

*Inductors*

Small inductors, such as used in VHF circuits, are sometimes self-supporting, consisting of a few turns of stout wire. Rather larger inductors, such as tuning coils for short, medium and long wave bands, may be air-cored, and are then wound on an insulated tube or former which has no core. SW coils with few turns frequently have spaced turns, to reduce self-capacity. Larger coils may have turns in a single layer, closely side by side; even larger coils have turns wound in compact piles. HF chokes can be of somewhat similar construction, though generally with quite a large number of turns, sectionalized to reduce capacity. (Fig. 11.)

In transmitting equipment, the coils and RF chokes used in early stages can resemble those in receivers, and receiver components of suitable type could be employed. But where larger power is used, as in the power amplifier stage, the choke may be required to carry a fairly high current (perhaps 150mA to 250mA or so). Such chokes are wound with stouter wire than a receiving choke. There may also be high RF voltages across the choke, so the winding may be on a longer former.

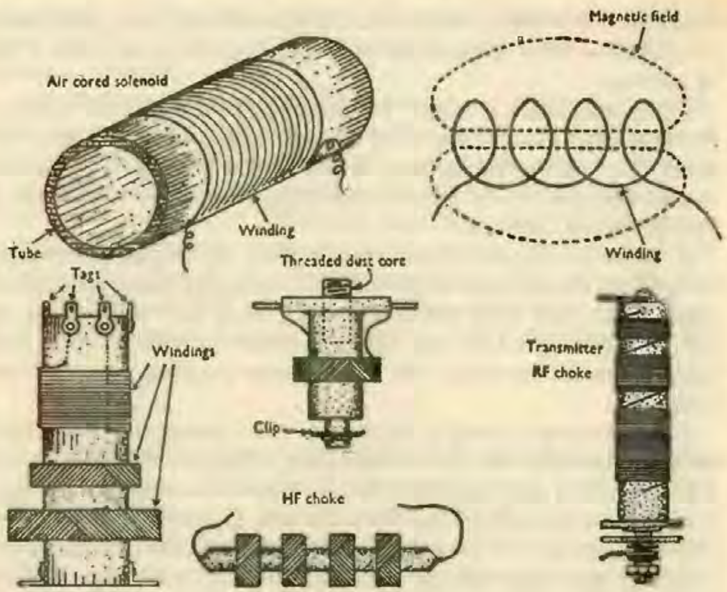



FIG. 41

Interference suppressor chokes are also sometimes used in mains circuits, and these may also have to carry a fairly heavy current. Some typical RF chokes, with applications, are as follows:

| *Inductance* | *DC resistance* | *Application* |
|---|---|---|
| 2·5mH | 25 ohms | Receivers; small transmitters |
| 2·5mH | 10 ohms | Transmitters, current up to 250mA |
| 5μH | 1·5 ohms | VHF circuits |
| 25mH | 160 ohms | Receivers |
| 80μH | 1 ohm | Mains suppression |

Coils may have dust iron cores, which increase the inductance. That is, a given inductance is obtained with fewer turns, when a dust core is present. The resistance of the winding is thus reduced, and the Q (goodness factor) of the coil is improved, as described later. Dust cores are often movable, so that the inductance can be adjusted, for alignment purposes. Litz wire, which has several



strands individually insulated from each other, is also often used, to increase Q.

Typical coil inductance values are as follows:

| *Inductance* | *Approximate range with 500pF tuning capacitor* | |
|---|---|---|
| | *Metres* | *Frequency* |
| 2,200μH | 700–2,000 | 425–150 kc/s |
| 170μH | 200–550 | 1,500–550 kc/s |
| 1·5μH | 16–50 | 19–6 mc/s |

When a much larger inductance is needed, for audio or smoothing circuits, the inductor has an iron core. This is usually made up from stampings, in a somewhat similar way to that described for mains transformers. If a large direct current passes through the winding, the core could become magnetically saturated. This would hinder the rise and fall of magnetic lines, which are required to maintain self-inductance. So power choke cores may have a magnetic gap. This can be obtained by placing all U stampings and all T stampings together, and inserting thin insulating material, to provide a small magnetic gap.

Many common smoothing chokes have an inductance in the region of 5H to 10H, and are commonly rated at being able to carry currents of 60mA, 100mA, 150mA, 250mA, etc., according to the gauge of wire employed for the winding. The DC resistance of such chokes is commonly some 100 to 400 ohms or so. Chokes of much higher inductance are also made. These and similar chokes are often called 'audio' or AF (audio-frequency) chokes, because they are generally used in the range of perhaps 25 to 10,000 cycles per second.

*Inductive Reactance*

Inductors oppose the flow of AC, because they try to avoid any rise or fall in current, as explained. The degree to which they do this depends on their 'inductive reactance'. Inductive reactance is possessed by all coils, windings, etc., and is denoted by $X_L$. Inductive reactance increases as the frequency is increased, or as the inductance is increased in value. The inductive reactance $X_L$, in ohms, may be found from:

$$2 \pi f L$$

Here, the frequency f is in cycles per second and the inductance L is in Henrys. 2 $\pi$ may be taken as 6·28.

For example, a 2H choke is wired in a circuit where a 100 cycle per second current flows. What is the inductive reactance of the choke?

$$X_L = 6{\cdot}28 \times 100 \times 2 = 1{,}256 \text{ ohms}$$

For radio frequencies, $X_L$ can similarly be expressed, with frequency f in mc/s, and inductance L in $\mu$H.

As example, a coil of $55\mu$H is wired in a radio frequency circuit operating at 2·5 mc/s. What is the coil reactance?

$$X_L = 6{\cdot}28 \times 2{\cdot}5 \times 55 = 863{\cdot}5 \text{ ohms}$$

*Note* that the inductive reactance ($X_L$) of a coil rises as frequency is increased, while the capacitive reactance ($X_C$) of a capacitor falls as frequency is increased.

*Reactances and Impedance*

Inductive reactance is denoted by $X_L$ and capacitive reactance by $X_C$, as explained. Current in an inductive circuit lags behind the voltage by 90 degrees. Current in a capacitive circuit leads the voltage by 90 degrees. Hence inductive and capacitive reactance currents are in a phase relationship of 180 degrees, or phase opposition. Many circuits have significant values of inductive and capacitive reactance.

Some resistance will be present in actual circuits and components. With a pure resistance, the current is in phase with the voltage. The current due to resistance will thus lead the inductive current (which lags behind voltage by 90 degrees), and lag behind the capacitive current (which leads voltage by 90 degrees). In Fig. 9, C showed the current I (inductive) lagging 90 degrees behind the voltage, and at D current I (capacitive current) leading the voltage by 90 degrees, while B is the current I (resistive circuit) in phase with the voltage, and thus 90 degrees in advance of the current at C, and 90 degrees behind the current at D.

When a circuit has inductive reactance and resistance, or capacitive reactance and resistance, or all three, it is said to offer 'impedance', which is the total, and is shown by Z. The resistance present cannot simply be added, because it is effective at a phase different from both inductance and capacitance in the circuit.

The impedance Z of a circuit having inductance, capacitance, and resistance, can be found from the following:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$



Here, R is the resistance, $X_L$ the inductive reactance $(2\pi f L)$ and $X_C$ the capacitive reactance $\frac{1}{(2\pi f C)}$. A component such as a choke will have some resistance. It is then usual to treat this, the DC resistance of the winding, as if it were the resistance R.

For example, a capacitor of $1\mu$F and a choke of 20H, and having a DC resistance of 200 ohms, are wired in series in an AC circuit whose frequency is 50cps. What is the impedance?

$$R^2 = 200 \times 200 = 40{,}000$$

$$X_L = 6{\cdot}28 \times 50 \times 20 = 6{,}280 \text{ ohms}$$

$$X_C = \frac{1{,}000{,}000}{6{\cdot}28 \times 50 \times 1} = 3{,}185 \text{ ohms approximately}$$

*Note:* Capacitive reactance $X_C$, or $\frac{1}{2\pi f C}$, is for capacity in Farads, so $X_C$ is:

$$\frac{1}{2\pi \times f \times C \times 10^{-6}} \text{ or } \frac{1}{2\pi f C \times \frac{1}{1{,}000{,}000}} \text{ or } \frac{1{,}000{,}000}{2\pi \times f \times C}$$

$$Z = \sqrt{40{,}000 + (6{,}280 - 3{,}185)^2}$$

$$= \sqrt{40{,}000 + 3{,}095^2}$$

$$= \sqrt{9{,}619{,}025}$$

$$= 3{,}100 \text{ ohms approximately}$$

If $X_C$ is larger than $X_L$, $X_L$ may be taken from $X_C$ – inductive and capacitive components are in 180 degrees relationship. There is often no need to go beyond a convenient number of significant figures, so 9,619,025 may be taken as 9,600,000, or $960 \times 10^4$. Therefore:

$$Z = \sqrt{960 \times 10^4} = 31 \times 10^2 = 3{,}100 \text{ ohms}$$

*Resonant Frequency*

The resonant frequency is that frequency at which the capacitive reactance $X_C$ equals the inductive reactance $X_L$. That is:

$$\frac{1}{2\pi f C} = 2\pi f L$$

For a given capacitance and inductance, this arises at one frequency. This, the resonant frequency, can be found from:

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

Here, the frequency is in cycles per second, inductance L in Henrys, and capacitance C in Farads. These units are not convenient for radio frequencies, and for this purpose the formula may be given as:

$$F=\frac{159}{\sqrt{LC}}$$

where resonant frequency F is in mc/s, inductance L is in $\mu$H, and capacitance C is in pF.

For example, suppose a coil having an inductance of 100$\mu$H is connected in parallel with a 100pF capacitor. What is the resonant frequency of the combination?

$$F(mc/s)=\frac{159}{\sqrt{L\times C}}=\frac{159}{\sqrt{100\times 100}}=\frac{159}{100}=1{\cdot}59mc/s$$

An ideal inductor and capacitor would have no losses. But in

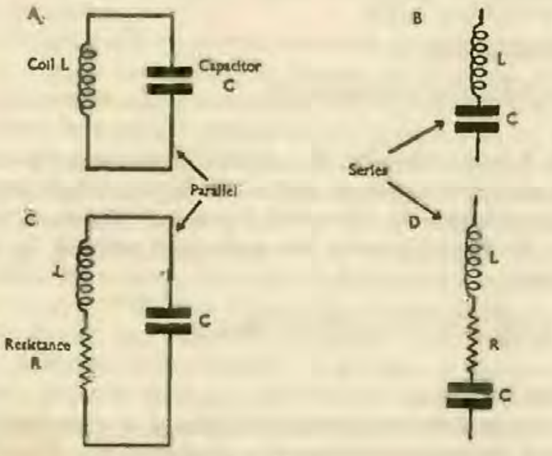



FIG. 12

practice some resistance will be present in the inductor coil winding, in particular. Fig. 12A shows an ideal parallel resonant



circuit, with coil L in parallel with capacitor C. At resonance, the impedance of the circuit is high. B shows an ideal series circuit. At resonance, the impedance is low. So circuit A (parallel tuned) is often termed a 'rejector circuit'. It will offer high impedance to the frequency to which it is tuned, so a required RF signal can be developed across it. This fact is much used in receivers, etc., as in Fig. 13A.

The circuit at Fig. 12B (series tuned) offers low impedance at resonant frequency, and is thus called an 'acceptor circuit'. In

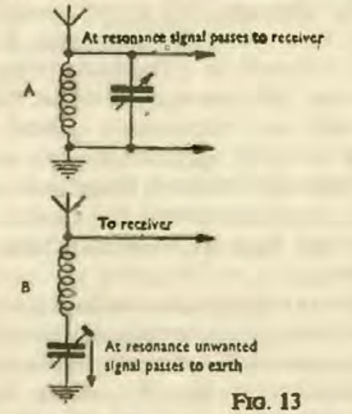



FIG. 13

Fig. 13B the components could form a wavetrap, series tuned to an undesired, interfering signal, which it could pass away to earth.

C (Fig. 12) shows the addition of resistance R, actually in the coil, but conveniently shown separately. D similarly shows series resistance in the series resonant circuit. The smaller the resistance which is present, the more nearly will the circuit approach the ideals at A and B in Fig. 12. If a resonant circuit is very efficient, with little loss due to resistance, it is said to be of high 'Q'.

*Q of Circuit*

The Q of a resonant circuit is its efficiency, or sharpness of resonance, and is high with efficient, low-loss components, but low if there are losses such as high resistance in the coil winding. The higher such resistance is, the lower the Q becomes, and the Q may be expressed as:

$$\frac{2\pi fL}{R}$$

where R is the circuit resistance in Ohms. With air-spaced (air-dielectric) tuning capacitors, and other low-loss capacitors, the losses will be confined primarily to the inductor, and arise largely from the resistance of the wire, as mentioned.

When the resonant circuit is incorporated in a receiver or transmitter, this loading of the resonant circuit will reduce the actual Q obtained.

*Losses in Coils*

Since Q, or coil efficiency, falls as resistance is increased, coil windings need to have a low DC resistance. RF resistance also arises, and can be reduced by using fairly stout wires, especially for high frequencies. RF currents travel on the surface of the conductor, so wires are occasionally plated, to reduce skin resistance, for special VHF applications. Litz wire, consisting of a number of individually insulated strands, is used for the same reason, especially for medium wave and similar coils. Small coils for short wave or high frequency bands are often of enamelled or tinned copper wire.

Low self-capacity is required, so windings are spaced, wound in a solenoid, wave-wound, or sectionalized, according to the number of turns to be accommodated. Formers are of materials having good RF insulation properties. To reduce losses from eddy currents, windings should be at least one half the coil diameter from metal parts such as screens and chassis, if practicable, and particularly with air-cored coils.

*Wavelength from L and C*

It may be convenient to find the wavelength of a tuned circuit directly from the inductance and capacity present, instead of finding the resonant frequency, and then converting this to wavelength.

This may be done from:

$$1{,}885\sqrt{LC}$$

Here, L is the coil inductance in $\mu$H, and C is the capacity in $\mu$F. For example, a coil with an inductance of 200$\mu$H is wired in parallel with a capacitor of 450pF. What is the result, in terms of the wavelength to which the circuit is tuned. 450pF = 0·00045$\mu$F.

$$1{,}885\sqrt{200 \times 0{\cdot}00045} = 1{,}885 \times 0{\cdot}3 = 565 \text{ metres approximately}$$



*AF Impedance Matching*

Dissimilar impedances may be matched with a transformer of appropriate ratio. Matching a valve with high impedance optimum load to a low-impedance speaker is an example. The turns ratio is the square root of the impedance ratio. E.g.:

$$\text{Ratio} = \sqrt{\frac{Z1}{Z2}}$$

where Z1 and Z2 are the respective impedances to be matched. For example, suppose an output valve with an optimum load of 4,800 ohms is to drive a 3-ohm speaker. Here, Z1 is the optimum load, and Z2 the speaker impedance.

$$\text{Ratio} = \sqrt{\frac{4{,}800}{3}} = \sqrt{1{,}600} = 40:1$$

*Decibels*

The decibel is often used to show the relationship between power ratios. An increase in 3db indicates a doubling of power. For example, if one signal were S9, and one 3db over S9, the latter would be twice the power of the former. (*See* RST Code.) A figure in decibels does not itself indicate any particular power, but only shows the relationship with another power.

The decibel is one-tenth of the bel, which is the common logarithm of the ratio of two powers, and the bel is not used, as it is not a convenient unit. The following shows decibels and corresponding power ratios which may be taken:

| | | | |
|---|---|---|---|
| 1db | 1·26 | 9db | 7·94 |
| 2 | 1·58 | 10 | 10 |
| 3 | 2·0 | 20 | 100 |
| 4 | 2·51 | 30 | 1,000 or $10^3$ |
| 5 | 3·16 | 40 | 10,000 or $10^4$ |
| 6 | 3·98 | 50 | 100,000 or $10^5$ |
| 7 | 5·01 | 100 | $10^{10}$ |
| 8 | 6·31 | 150 | $10^{15}$ |

For example, if one signal is 9db stronger than another, it is about 8 times stronger. A signal 20db stronger than another is 100 times stronger, and so on.

*Iron-cored Transformers*

Iron-cored transformers are used for AF coupling circuits, speaker matching, and power supplies, etc. The transformer has an iron or improved alloy core, this often being made up from T and U stampings, as in Fig. 14A, or W and I stampings, as at B. Enough stampings are used to make up a core of the necessary thickness. Stampings are insulated on one side, by thin paper, paint, or other substance, to avoid eddy currents, which would arise in a solid core.

The windings are generally on the centre limb of the core, often being contained in a bobbin. The ratio of the transformer is

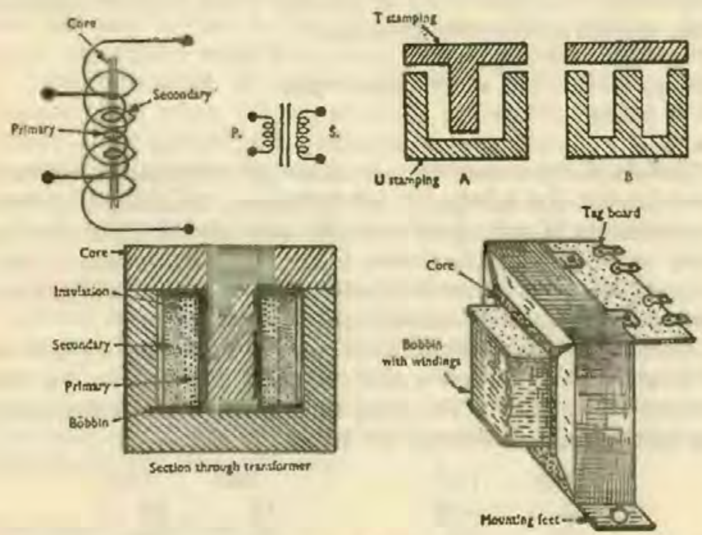



FIG. 14

the turns ratio of one winding to another. For example, if a transformer has 4,000 turns on its primary, and 80 turns on its secondary, its ratio if 4,000:80, or 50:1. Transformers intended for impedance matching generally have the ratio stated.

With a mains transformer, the turns ratio depends on the input and output voltage. For example, if a transformer is to be run from 240V mains, and to deliver 5V, for a rectifier heater, the ratio would be 240:5, or 48:1, but this is not stated. Instead, the primary and secondary voltages would be given, so the transformer would be a 240V/5V one. That is, it would have a 240V primary, and 5V secondary.



Mains transformers often have several secondaries, such as 6·3V and 5V for heaters, and 250V, or 350V, or other high-tension windings. HT windings are often centre-tapped, for full-wave rectifier circuits. If so, the secondary may be marked 250/0/250V, or as applicable, which indicates that 0 is the centre tap, and that 250V is available each side of this. (Such a winding could be regarded as a 500V winding, with centre tap.)

*Component Ratings*

The rating of a component shows its ability to withstand currents or voltages. For example, small paper fixed capacitors might have a 250V rating. This means they could be used with up to 250V but would be expected to break down if this voltage were exceeded. The voltage rating of bias and other small electrolytic capacitors may be very low – 12V, 25V, or 50V often being used in valve equipment.

Resistors have a wattage rating, this being the maximum that can be dissipated without the resistor growing unduly hot, or breaking down. The power being dissipated in any particular resistor can be found in the usual way; that is: $W = V \times I$, or $V^2/R$, or $I^2 \times R$. Voltage dropping resistors may be rated in terms of the maximum current they can safely carry.

In the same way, rectifiers, power chokes, transformers, and other components have a maximum power, voltage, or current handling capacity, which should not be exceeded. It is preferable to under-run components. That is, not to use them at their maximum rating. It is, of course, in order to use components in circuit positions where the actual voltage, power, or current is *lower* than the component rating, as the latter merely shows the maximum which the component *could* handle, if required.

CHAPTER THREE

# Valves, Rectifiers, Bias Methods

A VALVE is evacuated, and has a filament, or cathode with heater, the temperature of which is raised by the passage of an electric current. Valves with filaments are termed 'directly heated'. Small valves have a filament of thin wire, and may be run from a dry battery or accumulator. Larger valves, such as directly heated rectifiers, may have a thin ribbon or strip filament or heater, and may be run from a mains transformer.

Filaments are generally oxide-coated, to obtain a greater emission of electrons at a lower temperature than could be used with ordinary tungsten filaments. Thoriated-tungsten filaments are also an improvement over tungsten, in this respect.

Valves with separate cathodes are termed 'indirectly heated'. The cathode is frequently a small tube, and has a heater placed inside it (*see* Fig. 15), but electrically insulated from the cathode.

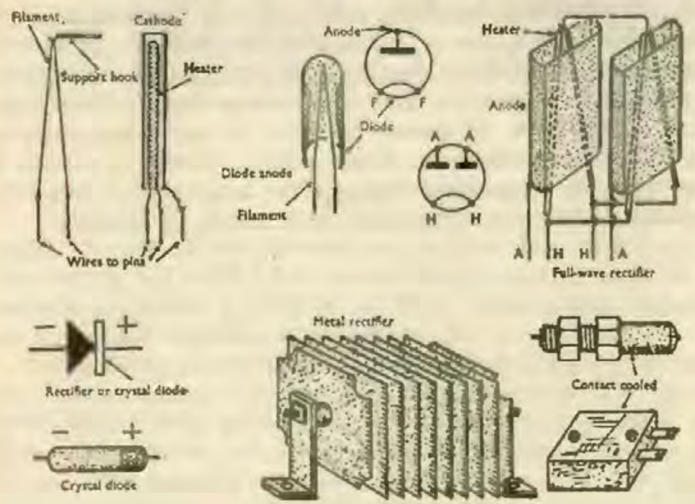



FIG. 15





The heater may be operated from direct current or alternating current. Directly heated valves gain their working temperature almost instantly, while indirectly heated valves require some 15 to 30 seconds or more to do so. Indirectly heated valves are generally used in AC equipment, where AC on a filament would cause hum.

When the filament or cathode is heated sufficiently electrons have enough velocity to escape. This is termed 'thermionic emission'. The emitted electrons form a space charge or negatively charged cloud, near the filament or cathode.

If another electrode is placed in the valve, and has a positive potential, some of the emitted electrons will pass across to this electrode. Such an electrode is generally termed an 'anode' or 'plate' and the flow of electrons is always from the heated cathode (or filament) to the anode. Such a valve may be used as a rectifier. It allows current to pass from cathode to anode, but not from anode to cathode. AC applied to it, from a mains transformer, can thus be changed to pulsating DC, flowing one way only.

Fig. 15 shows the elements of a valve with filament (heater) and anode. This is a single diode. It may be used for rectification of any form of AC, including radio frequencies. Often, two anodes are present, and this is a double-diode valve. If the valve is intended as a power rectifier, the single anode type is termed a half-wave rectifier, and the double anode type is a full-wave rectifier. Half-wave and full-wave rectifier circuits are shown in Fig. 16. The half-wave rectifier conducts on one half the AC cycle only. This pulsating current is smoothed by the large capacitors and choke forming the smoothing circuit, as described later. Fig. 16B shows a full-wave rectifier circuit, the electrodes of a directly heater full-wave power rectifier being shown in Fig. 15. With this valve, both halves of the AC cycle can be employed.

The current is from cathode to anode. In a receiver, for example, the current flows from negative HT line, through the receiver valves, to positive HT line, and from there to the rectifier cathode, and from rectifier cathode to rectifier anode. In actual circuits, this current is always from negative to positive. (This is the reverse of the current which is theoretically assumed to flow from positive to negative.)

If the anode is only slightly positive, the current flow through the valve from cathode to anode is small. As the anode is made more and more positive, the current increases. Eventually, if the anode is made very positive, all the electrons which are emitted by the cathode are passing across to the anode. The valve anode current has then reached 'saturation'. Virtually no more current can pass, even if the anode is made more positive. The maximum or saturation current of small diodes, such as may be used for detection, may be only a few milliamperes. But with power rectifiers, the current may be quite large – 100mA, 250mA, or even more.

The current may be high at those instants when the anode is most positive, falling as the AC cycle drops towards zero. The average rectified current of the valve is thus much less than the peak current. A typical small diode might have a maximum peak

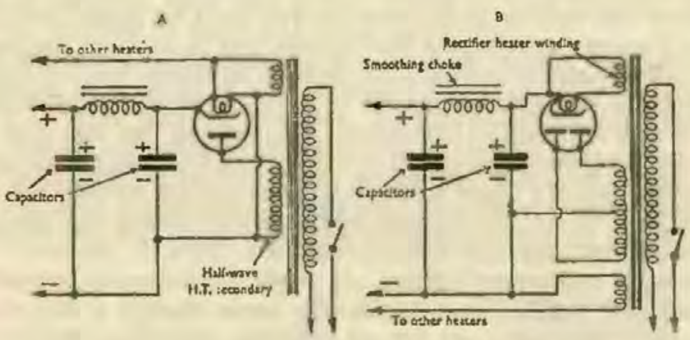



FIG. 16

current of 48mA, and a maximum average rectified current of only 8mA. A fairly large rectifier valve for a small transmitter could have a peak current rating of 650mA, and an average rectified current rating of 250mA.

Rectifiers also have a 'peak inverse voltage' rating – this is the maximum which can be applied to the valve, when the anode is negative. Indirectly-heated rectifiers also have a maximum 'heater-cathode' rating. This is the maximum voltage which may be allowed between the heater and cathode, which are insulated from each other, but in close proximity. It was seen that the rectifier cathode will be common to the HT positive line. If the rectifier heater-cathode rating is sufficiently high, the rectifier heater may be wired in parallel with other valve heaters, and to the HT negative line. But if the HT voltage is high, the potential



between rectifier heater and rectifier cathode would then be too great, so the valve would have a separate heater winding on the mains transformer. This winding would be used for the rectifier only, and would be connected to the HT positive circuit (rectifier cathode). Directly heated rectifiers also require a separate heater winding. (Compare Figs. 16 and 67.)

### *Triodes*

If a wire mesh grid is inserted between cathode and anode, the valve becomes a triode. A relatively low negative voltage applied to the grid will reduce the current flowing from cathode to

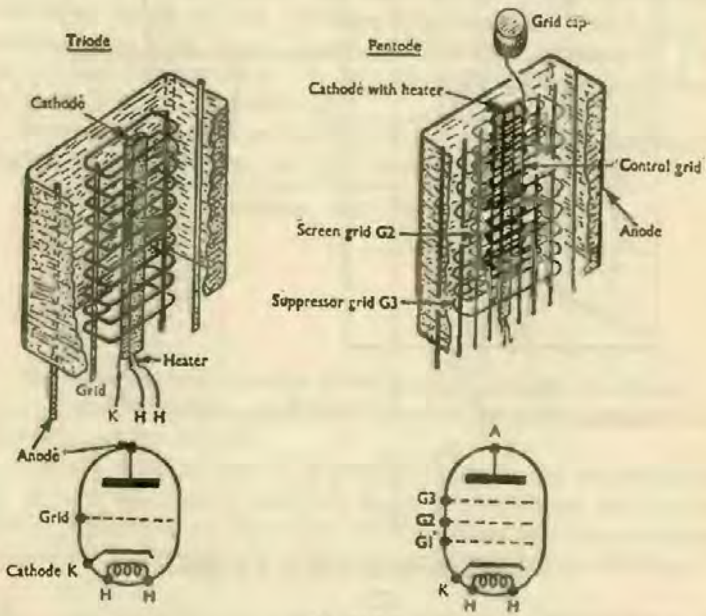



FIG. 17

anode. If the grid is very negative, all current may cease. A steady negative voltage is usually applied to the grid, and is termed 'bias'. If the voltage is sufficiently negative to prevent current flowing, the valve is 'cut off'.

Fig. 17 shows a triode. A change in grid voltage has more effect on anode current than does a change in anode voltage. The ratio between a change in grid voltage, and change in anode voltage to produce the same change in anode current, is the 'amplification factor' of the valve, or $\mu$.

Fig. 18 shows how the grid voltage of a triode produces a change in anode current. Here, the valve is assumed to receive 2V grid bias, and the anode current is then stable at 4mA. An audio or other signal is then applied to the grid, and swings the grid voltage

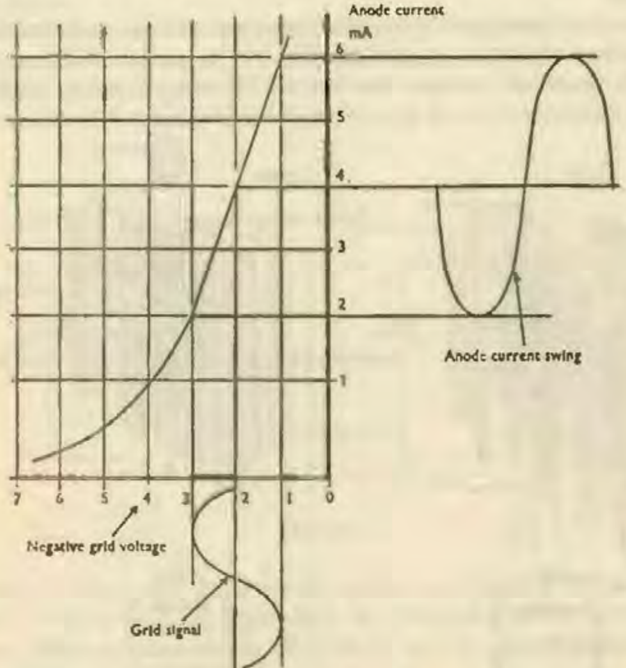



FIG. 18. Operation of class A amplifier

from 1V to 3V as shown. When the grid voltage is 1V, the anode current rises to 6mA. On the other hand, when the grid potential is 3V the anode current drops to 2mA. The signal at the grid thus produces a corresponding signal at the anode, where the change in anode current is 2mA for each 1V change in grid voltage. That is, the valve has a mutual conductance of 2mA/V. For example, 2mA change in anode current per 1V change in grid voltage.



If the grid voltage were too much negative, the output of the valve would no longer resemble the input, so that results would be distorted. Fig. 18 represents 'Class A' operation, with the valve conducting during the whole grid input cycle. Increased bias produces other forms of operation, such as 'Class B' and 'Class C' which are described later.

If the grid voltage remains constant, and the anode voltage is changed, the current through the valve changes. For small changes in voltage, the valve acts as would a resistor, and this is termed the anode or plate resistance, or impedance.

If the grid voltage is changed, the anode voltage remaining constant, the anode current changes. This is termed mutual conductance. Anode current is frequently given in mA, and a typical output valve might have a mutual conductance of 4mA/V. This means that a change of 1V on the grid produces a change of 4mA in anode current, as explained.

These facts can be expressed as follows, where $\mu$ is amplification factor, ra is impedance, and Gm is mutual conductance:

$\mu = \text{ra} \times \text{Gm}$ (ra in K-ohms, and Gm in mA/V)

$$\text{Gm} = \frac{\mu}{\text{ra}}$$

$$\text{ra} = \frac{\mu}{\text{Gm}}$$

For example, a triode has a mutual conductance of 2·5mA/V and an anode impedance of 8,000 ohms. What is its amplification factor? $\mu = 8 \times 2{\cdot}5 = 20$.

When a valve is used in a practical circuit, the amplification or gain of the stage is less than the amplification or gain of the valve. The signal at the anode must be developed across a load (resistance or impedance). The stage gain is found as follows:

$$\frac{\mu \times \text{Ra}}{\text{Ra} + \text{ra}}$$

Here, Ra is the anode load, given in ohms, and ra is the anode resistance or impedance. For example, assume a triode with an amplification factor of 25 and anode impedance of 30,000 ohms is used with a 33K anode load resistor. What is the stage gain?

$$\frac{25 \times 33{,}000}{30{,}000 + 33{,}000} = \text{approximately } 13$$

*Tetrodes, Pentodes, etc.*

Stray coupling between control grid and anode can introduce instability and other difficulties, in high frequency circuits. Such coupling arises from the capacity between grid and anode, in triodes. This difficulty is much reduced by adding a further grid, termed the screen grid, between control grid and anode. The valve is then a 'screen grid' or tetrode. The screen grid receives a positive potential, often of lower voltage than the anode.

Such valves have a higher mutual conductance or 'slope' than triodes, and are often used in output stages. Output valves of this kind are termed tetrodes. Beam plates may be introduced to direct the electron stream towards the anode, and these valves are 'beam tetrodes'. If the valve is intended for radio frequency purposes, it is generally termed a 'screen grid valve'. However, screen grid valves are not now much used in RF stages.

With a screen grid valve, some electrons may tend to bounce back from the anode, or cause emission from the anode, and these electrons may be attracted by the positive potential of the screen grid. This is largely eliminated by adding a further grid, termed the 'suppressor grid', between screen grid and anode. The suppressor grid is maintained at about cathode potential. Such valves are termed 'pentodes' and are used in both RF and audio output types. Older RF valves have a top cap for the control grid connection, as in Fig. 17. This allows control grid and other circuits to be well separated. Miniature valves and audio stage valves do not usually have the top cap, as all connections are provided by pins. Top caps are, however, provided on some fairly large valves, which may be used for both RF and audio circuits. With these, the top cap is generally the anode.

A triode or other valve may have one or more diodes, to economize on the total number of valves in a receiver. This results in a diode-triode (diode and triode assembly in one envelope); double-diode-triode (two separate diodes, and one triode, in a single assembly); double-diode-pentode, etc., according to the electrode assemblies fitted.

RF pentodes may be intended for use with a fixed, small bias voltage. Such valves are termed short grid base or sharp cut off and may be used in early audio amplifier stages, etc.

Rather similar valves may be made with the control grid mesh wires growing more widely spaced, as in Fig. 17. These are variable amplification valves, generally termed 'vari-mu'. Bias can be



varied between wide limits. As bias is increased, amplification falls. A typical RF vari-mu valve might receive anything from zero to 50V negative bias, according to the amplification wanted. The bias is often produced by an automatic volume control circuit. As signal strength increases, this circuit produces more negative bias, thereby reducing the amplification of the vari-mu valve. Such valves may be termed long grid base, vari-mu, or remote cut off.

Additional grids may be introduced, to provide an oscillator, or mixer, in addition to the screen grid or pentode assemblies. Such valves are often used as frequency changers in superhets. Fig. 19 shows symbols of various popular valves. These symbols indicate clearly the cathode, grid (or grids), anode, and other electrodes.

*Bias*

A steady difference in voltage between the control grid and cathode (or filament) is the 'grid bias'. As bias is made more negative, the anode current falls, as in Fig. 18. This allows the operating conditions of amplifiers to be described in terms of the bias required.

With a *Class A* amplifier, moderate bias is applied, and the valve conducts over the whole of the cycle of the grid signal. Early audio stages are of this kind (Fig. 18). The output is of similar waveform (but amplified) to the input, as at A in Fig. 20. The grid voltage is never positive with respect to the cathode. Class A output stages are also used in receivers.

In a *Class B* amplifier, bias is increased, so that anode current flows for only about one-half the grid cycle. This is shown at B1. Two valves working in this way may be arranged to amplify positive and negative halves of the grid cycle, as at B1 and B2. This is how a Class B Push-pull stage, largely used in audio amplifiers of other than small type, operates.

With a *Class AB* amplifier, conditions are between those for Class A and Class B. The valve conducts for more than a half-cycle, but not for a whole cycle.

A *Class C* amplifier has a very large bias, so that anode current only flows for less than half a cycle of the grid signal. It resembles a Class B amplifier, but with more bias. It is often used as a radio frequency power amplifier in a transmitter.

Class A, Class AB, and Class B may be termed Class A1, Class

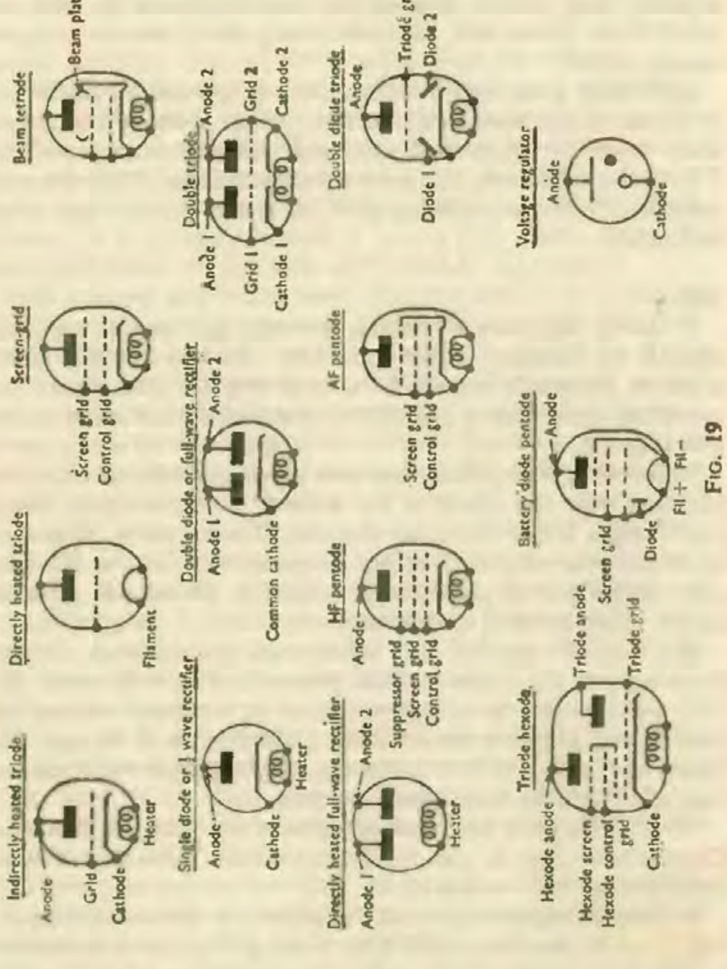



FIG. 19



AB1, and Class B1, denoting that no grid current flows. If the grid receives a very strong signal, driving it much positive, appreciable grid current flows, and this is termed Class A2, Class AB2 and Class B2. In ordinary amplifiers, Class A2 is unusual. Similarly, Class B amplifiers are generally in fact Class B2, as some grid current probably flows, as also with Class C amplifiers.

If a complete cycle, at the grid, is regarded as 360 degrees, the stages can be classified by saying that a Class A amplifier conducts

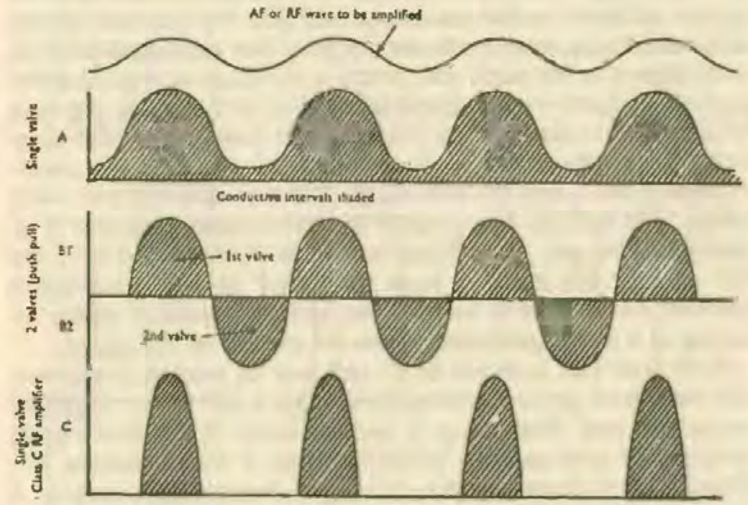



FIG. 20. Class A, Class B, and Class C

for 360 degrees, a Class AB amplifier conducts for less than 360 degrees, but more than 180 degrees, while a Class B amplifier conducts for about 180 degrees. The Class C amplifier will conduct for less than 180 degrees, but probably not less than 120 degrees. Simplified, a Class A stage conducts for the whole cycle, a Class B stage for about half the cycle, and a Class C stage for about a third of the cycle. This is illustrated in Fig. 20 which shows the grid signal to be amplified. A is amplification by a Class A stage, B1 and B2 is amplification by two valves forming a Class B stage, and C is a single valve working in Class C conditions.

*Bias Methods*

There are several methods of obtaining the required grid voltage, or bias. This voltage places the control grid negative, relative to filament or cathode.

*Battery bias* was much used in the past. A battery, of suitable voltage (or tapped) is connected as in Fig. 21 at A. Bias reaches the control grid through the grid load, which could be a coil, resistor R1, or a choke, transformer winding, or similar component.

*Cathode bias* is very largely used, and is shown at B. The cathode current of the valve flows through the resistor R2. This cathode current is equal to the anode current, plus the currents of any other electrodes, such as the screen grid. The cathode is positive with respect to the earth line, which is the same as regarding the cathode as positive with respect to the grid, or the grid as negative with respect to the cathode. From Ohm's Law, the voltage drop in R2 (bias voltage) can easily be found. Assume the valve anode current is 50mA and the valve needs 25V bias. $R2 = 25/0{\cdot}05 = 500$ ohms. The cathode bias resistor has the by-pass capacitor C in parallel. This may be of fairly low value (0·05$\mu$F or 0·1$\mu$F) for RF circuits, but must be large (say, 25$\mu$F or 50$\mu$F) for audio circuits. Its purpose is to hold the cathode potential stable by acting as a low-impedance by-pass for the RF or AF signal.

*Grid Leak bias* is shown at C, and may be used in low power AF amplifiers, or in RF amplifiers. With a RF power amplifier using grid leak bias, the grid rectifies some of the grid signal, resulting in grid current, which develops a voltage across R1. Ohm's Law indicates the bias developed. For example, suppose a transmitting valve has a 22K grid resistor, and a meter shows that 2mA grid current flows. Bias is $22{,}000 \times 0{\cdot}002 = 44$V. If the RF drive (grid signal) should cease, no bias is obtained. This could easily damage a transmitting valve, which would pass a large anode current. So cathode bias, or a fixed bias, may be applied, and is termed 'protective bias'. The fixed bias may be obtained from a battery or rectifier, the latter being most usual. If no protective bias is provided, then anode and screen grid voltages must not be applied to the valve until tuning of earlier stages has resulted in a suitable grid current being obtained.

In the case of small AF stages, R1 is very high in value (say, 1 megohm or more) and the bias and grid current will be very small.

*Contact Potential bias* resembles the above, in the case of small



AF stages, and is the same as at C in Fig. 21. Some space charge electrons flow to the grid, and through R1. If R1 is of high value, a small bias voltage is developed.

In receiver RF stages, some cathode bias is usual, with additional bias from the AVC line. In small AF stages, such as pre-amplifiers, contact potential or grid leak bias may be found, or cathode bias. In average power output stages of audio circuits, cathode bias is often found. In larger power stages, bias may be obtained from a rectifier. In early RF stages of transmitters, bias is often obtained by means of voltage drop due to grid current in a grid resistor. This may be found in moderate power PA stages, but with larger PA stages some fixed bias from a rectifier is more usual.

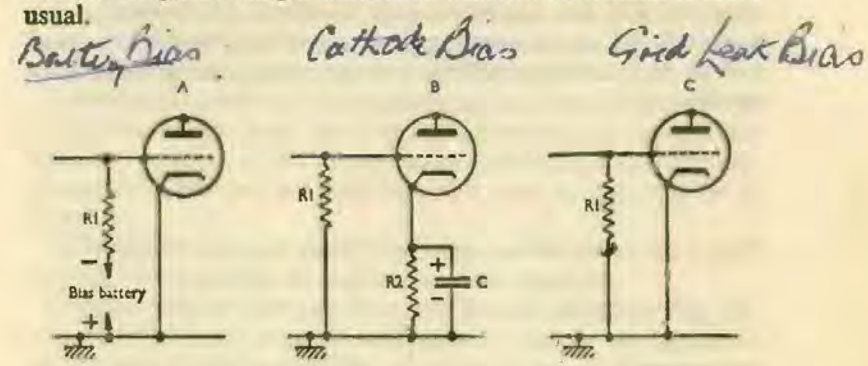



FIG. 21

*Zero bias* operation is occasionally used in push-pull audio stages. Tetrode or pentode valves are employed, and control grid and screen grid are connected together. The low SG potential thus reduces anode current to a low level, when drive is not available. When each control grid and associated SG are driven positive, the valve conducts. Special zero bias valves are also made.

*Semi-conductor Rectifiers*

A device allowing current to pass more freely in one direction than the other is a rectifier. In the valve, the current is from heated cathode to anode.

For RF purposes, crystal diodes, or germanium diodes, and similar small rectifiers may be used, instead of a valve diode.

Most such diodes are of very small size, with wire ends. Fig. 15 shows such a diode, with symbol, and the polarity.

For larger voltages and currents, junction germanium or silicon diodes may be used. Selenium rectifiers, or metal rectifiers, are also popular for power circuits. A number of elements may be mounted on a spindle, with cooling fins, to make up a large rectifier. Such rectifiers are also made in such a way that they can be clamped to a metal chassis, which conducts heat away. These are termed 'contact cooled'.

When the rectifiers are used in RF and similar circuits, where power is small, they do not require cooling. Rectifiers for these purposes are often termed 'diodes'. Units intended for power supply circuits are usually termed 'rectifiers'. All types of semi-conductor or metal rectifiers have maximum rectified current ratings, and maximum inverse voltage ratings, just as have valve rectifiers.

CHAPTER FOUR

# TRF and Superhet Receivers

In TRF receivers, all tuning is carried out at the radio frequency of the station being received. Some knowledge of such receivers is necessary. They can be of very simple design, and may be inexpensive and reasonably satisfactory, but they lack high selectivity, and other features generally required for Amateur Band work. Economically priced broadcast band receivers, such as small mains table models, are sometimes of TRF type.

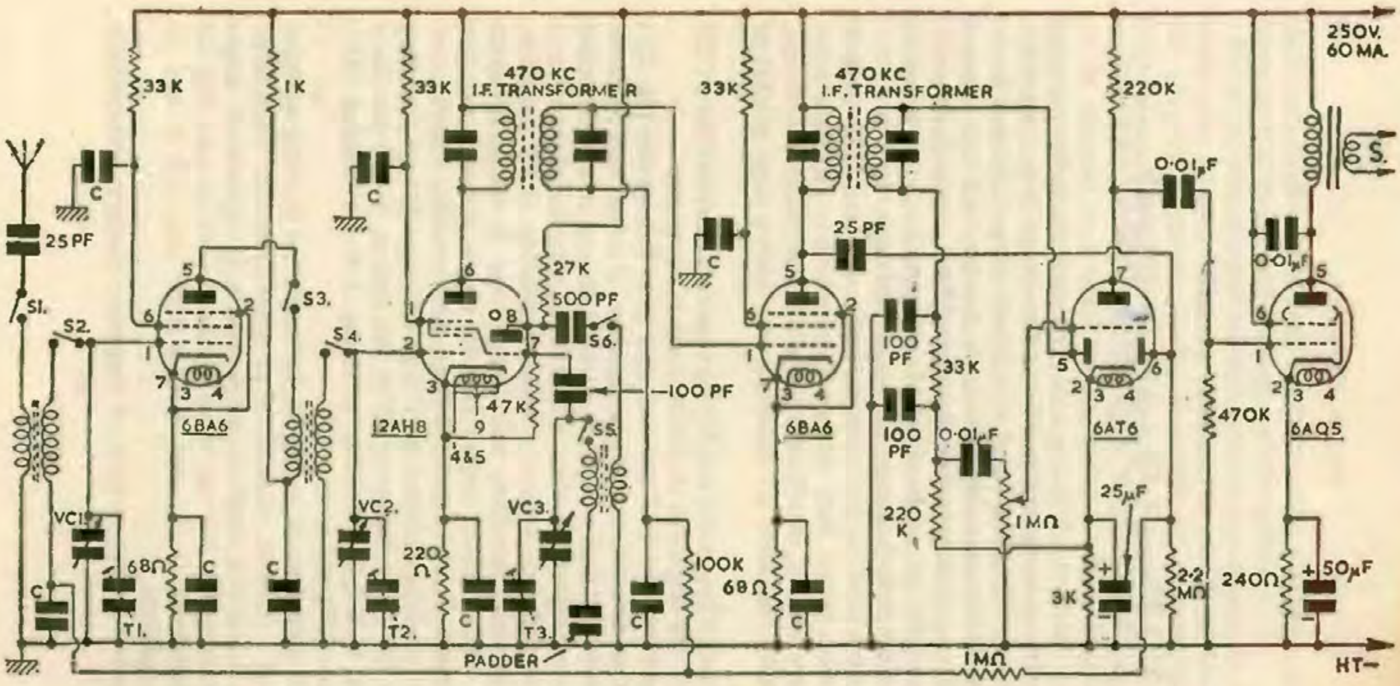
Superhet receivers are more generally used and often have 3, 4, or more valves. Such sets are more selective, and have other necessary features, as will be explained. Communication receivers, as used by Amateurs, are superhets with quite a large number of valves.

RF (radio frequency) amplifying stages, as described for a TRF receiver, are employed in similar form in superhets.

Simple forms of TRF receivers may be as follows (*see* Fig. 22): *1 valve*, as detector, working headphones; *2 valves*, used as detector followed by audio amplifier, to work phones, or a loudspeaker with strong signals; *3 valves*, acting as RF amplifier, detector, and audio amplifier or output; *4 valves*, consisting of RF amplifier, detector, audio amplifier, and output stage. It will be apparent that a 4-valver could employ two RF stages, detector, and one audio stage. Other combinations are also possible. The detector stage is sometimes denoted by 'V' with RF stages (if any) preceding it, and AF stages following. With this system, 0–V–0 denotes a 1-valver, 0–V–1 is a 2-valver as above, 1–V–1 a 3-valver (RF–Detector–AF), and so on.

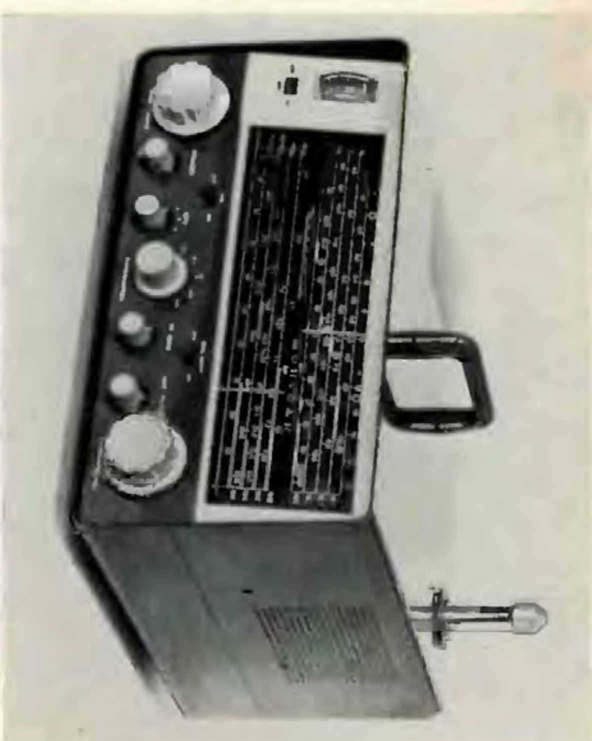
Block diagrams, as in Fig. 22, are useful for showing essential stages of a receiver, transmitter, or other apparatus. Each stage can be shown as a simple rectangle, with brief explanation, stages being arranged in the way in which they would be used. Fig. 22 thus represents 1-, 2-, and 3-valve TRF sets, and 5- and 6-valve superhets.

A basic superhet consists of frequency changer, intermediate

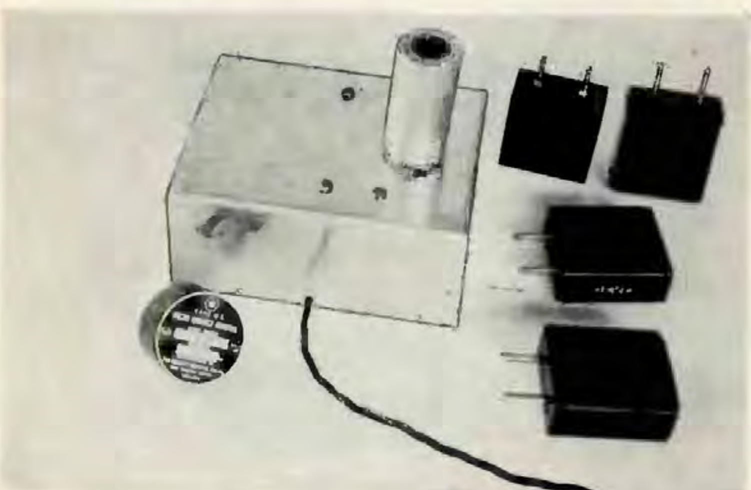


General purpose receiver. By-pass capacitors **C** all 0·05µF. VC1, VC2, and VC3 3-gang 360pF. T1, T2, and T3 50pF trimmers. Coils for all bands may be selected by 6-pole switch S1–S6.

4. *Above* General coverage GC-1U 10 transistor receiver for amateur and short wave listeners. (Heathkit, Daystrom Ltd., Gloucester.)
5. *Below* Eddystone "960" 12 transistor receiver covering 500kc to 30mc and operation from 12V battery. (Stratton & Co. Ltd., Eddystone Works, Alvechurch Road, Birmingham 31.)



6. *Above* Eddystone 13 valve communications receiver tuning 480kc to 30mc in five bands showing 4-gang capacitor for RF, RF, mixer, oscillator tuning. (Stratton & Co. Ltd.,) 7. *Below* 100kc crystal marker built to circuit in Chapter 7 with 100kc crystal removed. Four crystals to right for Amateur band transmitters.





frequency amplifier, detector, and audio amplifier, which may be denoted as FC/IF/DET/AF. A radio frequency amplifier is often used before the FC stage, while more than one IF amplifier valve is also common. The audio amplifier section will generally consist of at least two valves: voltage amplifier, followed by an output stage, as in Fig. 22. A 7-valve set using all separate valves with these stages could thus be denoted as RF/FC/IF/IF/DET/AF/OUTPUT. In all cases, a rectifier will be required, for AC mains working. If this is a valve, as is often so, the foregoing receiver would be an 8-valver.

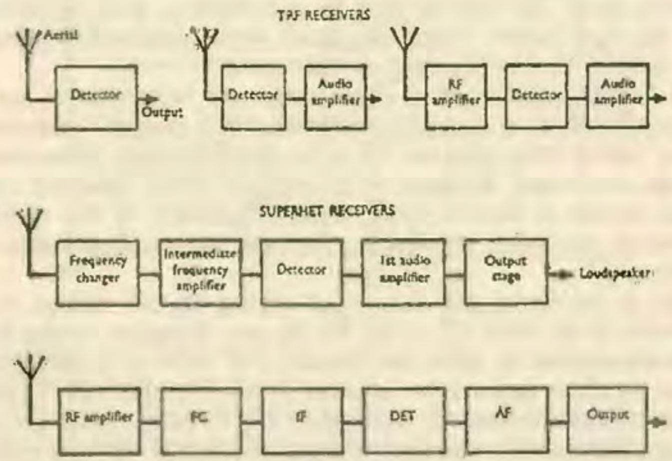



FIG. 22

One valve may have more than a single electrode assembly, as previously described. For example, in the DET/AF stages of a superhet, it is common to employ a double-diode-triode. Because of such multi-assembly valves, the number of valves in a receiver is not an exact guide to the number of stages which may be present. There will also be valves for other purposes in a communications set – such as separate local oscillator or beat frequency oscillator. However, fairly complete details are usually available for commercially made receivers. In some modern equipment, many multi-assembly valves are employed. Semi-conductors (such as power rectifiers and crystal diodes) may also be used in some circuit positions instead of valves.

*RF Amplifier*

The radio frequency amplifier is tuned to the frequency of the signal being received. Few receivers have an untuned RF amplifier, though this is possible. Popular domestic receivers of small type have no RF amplifier. Very many communications receivers have either 1-valve or 2-valve RF amplifiers. It is unusual to have more than 2 RF stages, due to the number of coils required, and switching and ganging difficulties.

A typical RF stage is shown in Fig. 23. L1 is the aerial coupling winding. For an end connected type of aerial, L1 may be wired from aerial to earth (receiver chassis). For a doublet or similar 2-wire input, the winding may be connected to each conductor of the twin feeder. These alternative aerial connections (single or double) may be provided on the receiver.

L2 is the tuned winding of the aerial coil, with variable capacitor C1, which is normally one section of a ganged component also tuning other circuits. C2 is an aerial trimmer, sometimes panel controlled, to allow stray capacity to be balanced out. This circuit is always tuned to the frequency of the station required. For other wavebands, the wavechange switch brings in further coils.

R1 is the screen grid resistor, dropping the SG voltage to a suitable level, while C3 is the SG by-pass capacitor, which has low impedance at radio frequencies. The valve is a variable-$\mu$ type, in which gain can be adjusted by varying bias, and R2 is a variable cathode resistor, which thus acts as gain control for the stage. This variable resistor is generally absent in ordinary superhets, but is employed in RF/DETECTOR/AF type receivers, and may also be found in a communications type receiver. C4 is the RF by-pass capacitor for R2.

Typical values for Fig. 23 could be: V1, 6BA6; R1 33K; R2 68 ohm fixed, or 25K variable; C3 and C4, each 0·05$\mu$F; HT 250V; L2 175$\mu$H, C1 500pF and C2 50pF, for medium wave coverage.

In a TRF receiver, RF gain is controllable by the variable resistor R2, as described. In a superhet, automatic volume control (AVC) bias will be available, and can be applied to the control grid of the valve, through the tuning coil windings, or through a resistor. In domestic type superhets, AVC is applied to the RF stage, so R2 is not variable.

The output from the RF stage is of the same character as the



received signal, but is stronger. Detection is required to make the signal audible. If two RF stages were used, they may be very similar, another valve, with its own tuned circuit, following that in Fig. 23.

It is important that the first RF stage, in particular, should give good amplification, yet introduce the lowest possible valve and circuit noise. Noise will be amplified by later stages, and be

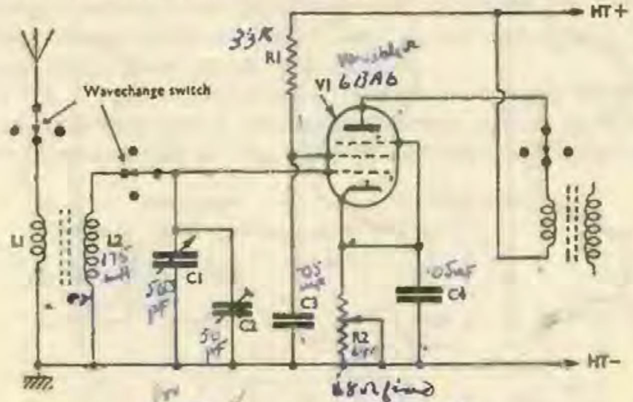



FIG. 23

troublesome. The valve type and operating conditions are thus chosen to have a low noise level.

There are other methods of coupling the aerial and RF circuits, but there is no real need to go into these here. New developments include grounded-grid and cascode amplifiers.

*Diode Detectors*

In a superhet, RF, frequency changer, and intermediate frequency amplifier stages precede the detector (*see* Fig. 22). But in very simple receivers the detector can be operated directly from the aerial. Therefore the detector is dealt with first, here.

Modulation places intelligence (e.g. speech) on the carrier (as described in the sections on modulators and transmitters) and the process of recovering this intelligence at the receiver is demodulation, or detection. A diode, which conducts in one direction only, is commonly used for this purpose in superhets.

Fig. 24 illustrates the processes in demodulation, and Fig. 25 the circuit. A, in Fig. 24, is the unmodulated carrier. That is, a radio frequency signal of uniform strength. B is the modulated

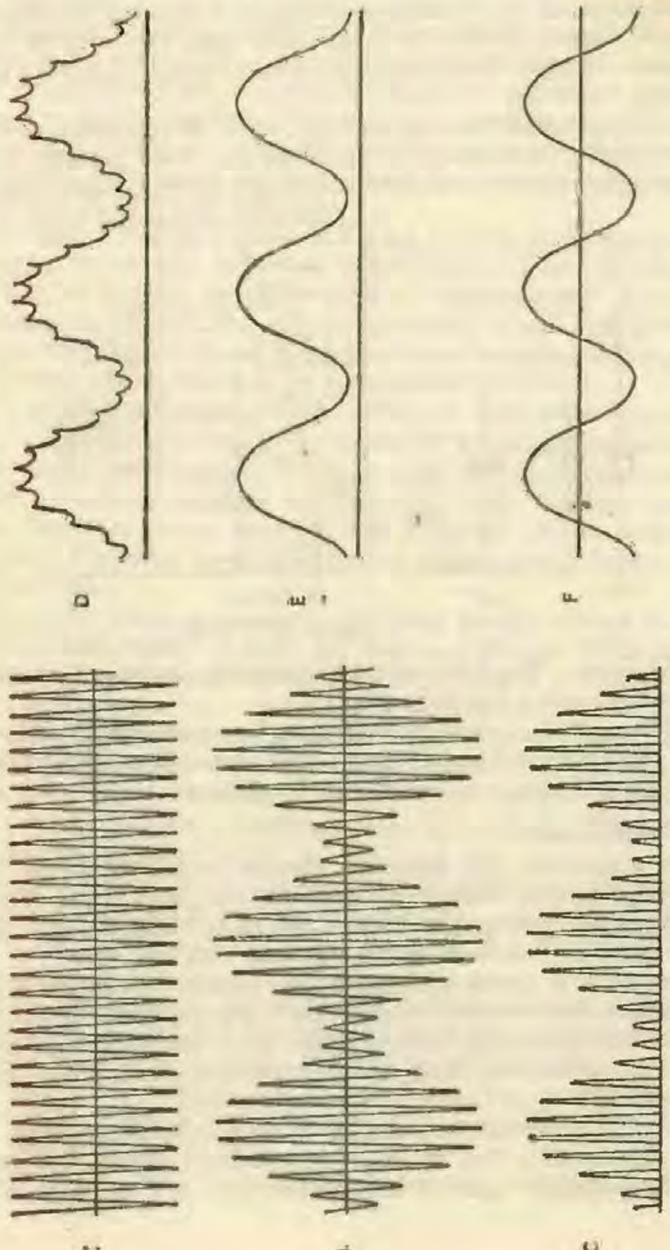



FIG. 24



radio wave, in which the strength of the radio wave depends on the audible or modulation signal. From a near-by station, the modulated wave B would be strong enough to apply to the diode detector. But in ordinary practice the signal will have received considerable amplification before reaching the detector.

The diode conducts in one direction only, and this can be shown by removing the negative half-cycles, leaving the waveform at C. In actual receivers, the diode is generally connected in a similar manner to that shown in Fig. 25, and it is thus conducting during those instants when the anode is positive.

In Fig. 25, the small reservoir capacitor C1 charges during RF peaks, and only partly discharges between peaks, so that the wave then resembles D, Fig. 24. After the resistor R1 and further

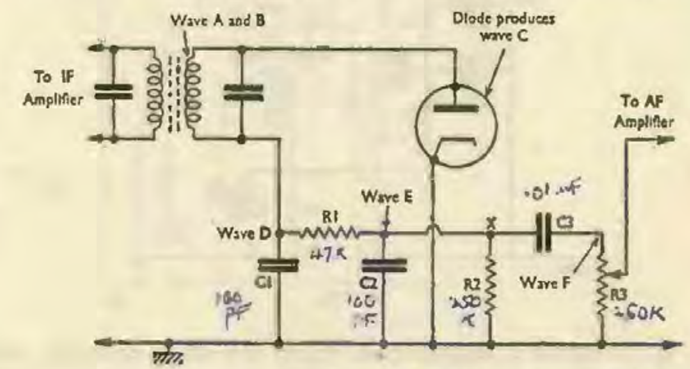



FIG. 25 Detector or Demodulator circuit

capacitor C2, which complete the RF filter, the wave resembles E. A capacitor C3 removes the DC voltage, which was obtained as a result of rectification, so that the audio signal resembles F, which was the original sound or audio wave used to modulate the transmitter. The signal could be heard if phones were connected across R3, but audio amplification normally follows to work a loudspeaker.

The diode detector or demodulator circuit, as shown in Fig. 25, would be used in a superhet. The secondary of an intermediate frequency transformer supplies the amplified signal to the detector. C1, R1, and C2 form the RF filter, and the audio signal is taken from the slider of the potentiometer R3, which acts as volume control.

Typical values for Fig. 25 are: C1 100pF; R1 47K; C2 100pF; R2 250K; C3 0·01$\mu$F; R3 250K. The IF transformer is permanently tuned to the intermediate frequency – often 470kc/s.

Germanium or silicon diodes may be used instead of the diode valve. When a valve is used, the diode is generally one part of a double-diode, double-diode-triode, or similar valve. This is to save space and reduce the total number of valves in the receiver, and need not change actual working conditions of the detector.

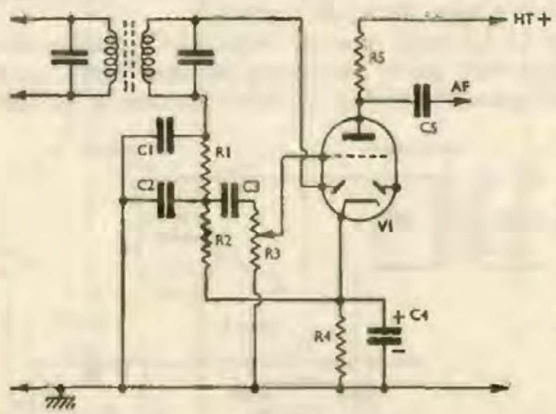



FIG. 26

Double Diode Triode

Fig. 26 shows a double-diode-triode providing detection and audio amplification. (The remaining diode is commonly used for AVC, described later.) Typical values are: V1 6AT6; C1 100pF; C2 100pF; C3 0·01$\mu$F; C4 25$\mu$F; C5 0·05$\mu$F; R1 47K; R2 220K; R3 0·5 megohm volume control; R4 3K; R5 250K.

*Other Detectors*

In TRF receivers, a triode, tetrode, or pentode is often used for detection. Such detectors can be more sensitive to weak signals than the diode, and are thus useful in simple receivers having little or no RF amplification. Triode and similar detectors can provide amplification as well as detection. A diode provides no amplification.

Fig. 27 shows a triode detector, frequently called a 'grid' or 'grid leak', or 'leaky grid' detector, due to the grid resistor R1. L1 is the coupling coil, from aerial or RF amplifier. L2 is the tuned winding, tuned by C1 to the frequency of the station received. C2 is the grid capacitor. The radio frequency choke RFC allows audio signals to pass, as it has little DC resistance, but the inductance of its windings stops RF passing. This prevents RF reaching later circuits, and also helps to direct RF into the regeneration or reaction circuit, L3 and C3. If the RFC, L3 and C3 were omitted, the circuit could still provide detection of amplitude modulated signals, but could not be used for CW (Morse) reception, when the detector needs to be oscillating.



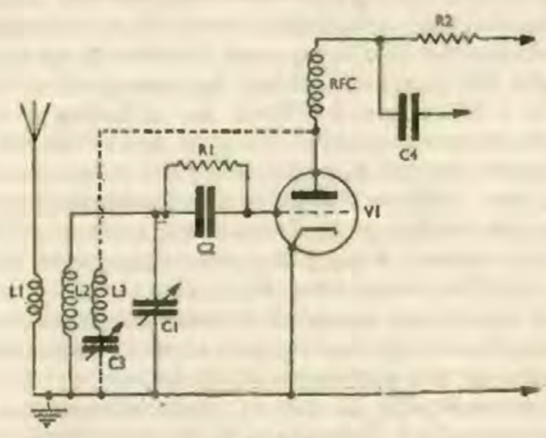



FIG. 27

Leaky Grid Detector or 'grid-leak'

When a signal is received, rectification takes place at the grid, because the valve will conduct from cathode to grid (just as the diode valve conducts from cathode to anode). This results in a signal resembling C, in Fig. 24, being obtained at the grid, and this is smoothed out to resemble D, because the charge stored in C2 can only leak away slowly through R1. The audio component or signal E, which is present on the grid, is amplified in a similar way to that in an audio amplifier, and is available at the anode, where it could be developed across the anode resistor R2, and taken to a further amplifier via C4.

Amplified RF is also available at the anode, and some RF passes through the reaction or regeneration circuit L3 and C3. L3 is so phased that the RF in it intensifies RF already in the winding L2, and the amount of RF in L3 can be adjusted critically by means of the variable reaction capacitor C3.

As feedback is increased by closing C3, coil and other losses are cancelled, and sensitivity and selectivity both increase. If feedback is further increased, the valve oscillates. With feedback just below oscillation point, sensitivity to weak signals is very high.

With reaction adjusted to any level below oscillation point, ordinary modulated signals (speech, music, etc.) may be received. Such a detector is normally used in this way.

If feedback is increased until oscillation begins, the frequency of oscillation will depend on the setting of the tuning capacitor C1. This allows an audible beat note to be produced when a CW transmission is tuned in. The audio note obtained is the difference between transmitter frequency and receiver frequency. For example, if a CW signal of 1,900kc/s is present, and the receiver is tuned to 1,901kc/s or 1,899kc/s, the difference is 1kc, or 1,000 cycles per second, and this would be heard. The CW signal of 1,900kc/s by itself is inaudible; so is the receiver oscillation of 1,901kc/s or 1,899kc/s. The audio note would thus cease if the valve were not oscillating. Similarly, it will cease when the CW signal is not present. Keying the transmitter carrier will thus result in an audible output from the receiver.

In actual equipment, regenerative detectors are seldom used for the reception of CW, but the way in which such a detector could be used for this purpose should be known.

Typical values for Fig. 27 are: V1, medium impedance mains or battery triode; R1 2·2 megohms; R2 47K; C1 500pF for long and medium waves, 150pF for short waves; C2 100pF; C3 300pF; C4 0·01$\mu$F; L2, for waveband required; L1, about one-half the number of turns on L2; L3, about two-thirds the number of turns on L2.

Triode, screen grid or pentode valves may also be used as 'anode bend' detectors. These have a fairly high bias applied, often by the voltage drop in a cathode resistor. R1 and C2 are omitted. Such detectors are not particularly sensitive to weak signals, but are sometimes used in some modest TRF mains receivers of the RF/DETECTOR/OUTPUT type.

*Tuning*

Simple TRF receivers with only one tuned circuit use a single tuning capacitor. Most receivers have two or more tuned circuits, and tuning capacitors for them are generally provided in a single, ganged component. A 2-gang capacitor allows two circuits to be tuned simultaneously, while a 3-gang capacitor would tune three circuits. The capacitor spindle is turned through a reduction drive, incorporating some form of tuning dial or scale.



A single waveband in a general coverage receiver might extend from 15mc/s to 8mc/s (about 20–37 metres). In this frequency coverage lies an Amateur Band, extending from 14 to 14·35mc/s. It is clear that this Amateur Band could occupy only a very small part of the tuning scale. To simplify exact logging or tuning over a narrow band of frequencies, 'band spread' tuning may be used. Such tuning does not in itself increase the selectivity or efficiency of the receiver, but allows a narrow band of frequencies to be covered with a large pointer or scale movement. Manipulation is thus easier, and frequencies within the narrow band can be read more accurately and easily.

Band spread tuning may be mechanical, or electrical. With mechanical systems, a high-ratio, geared reduction drive is used, and so arranged that a long scale length, or many scale divisions, are available, for a very small movement of the tuning capacitor spindle. If the system functions through the whole tuning range, it is better described as a vernier scale, or logging scale, though it is much the same as mechanical bandspread tuning.

With electrical bandspreading, the tuning drive need not have a very high ratio, and the bandspread tuning capacitors are very small in value, so that only a small band of frequencies is covered in the full 180 degrees swing. Alternatively, larger capacitors may have further series capacitors, and may be tapped down the tuning coils, so that coverage is small. This allows coverage to be adjusted to particular small frequency bands, such as the Amateur Bands.

General coverage receivers with no form of bandspreading are much used. Specialized Amateur Band receivers often have bandspreading. Or they may have some form of vernier tuning, and give general coverage. But for specialized Amateur use only, the receiver may be so constructed that the tuning covers the Amateur Bands only, and the set cannot be used on other frequencies at all. The tuning of any communications receiver should be smooth, easy, and free from backlash (looseness of movement). Scales giving accurate indication of frequency are also desirable.

*Ganging and Tracking*

When two or more circuits tune simultaneously to the same frequency, the coils and sections of the gang capacitor must be closely matched. Stray capacity, due to wiring, etc., is different from stage to stage, and trimmers are used to help compensate for this. There is usually one trimmer for each coil, and the maximum capacity of each trimmer is often about 50pF. Adjustment of trimmers for best results is termed 'trimming' and is carried out at a high frequency (low wavelength) on the particular waveband for which the trimmers are used.

During manufacture, slight variations in the inductance of the tuning coils can be expected, while the inductance of receiver wiring becomes more significant, at high frequencies. To help compensate for such effects, coils often have some means of adjusting the inductance. This is generally a special core, threaded or attached to a threaded rod, so that it may be screwed in or out of the coil. A dust iron core is common, and bringing this more nearly into the coil winding increases the inductance of the coil. Adjustments to coil inductance are made at a fairly low frequency (high wavelength) on the band in question.

On each band, trimming may be carried out at a low wavelength, and core adjustment at a high wavelength, to secure best agreement with a marked tuning scale. Gang capacitors also generally have split end plates, permitting capacity adjustment at various parts of the swing of the plates. This is done by slightly bending the plates towards the fixed plates to increase capacity, or from them to reduce capacity. This must be done systematically from the low capacity position of the tuning capacitor, or early adjustments will be upset by those made later.

Trimming and coil adjustments are made to obtain maximum sensitivity, as shown by an output or tuning meter. Signals for such adjustments are best obtained from a signal generator. Some degree of adjustment is possible by ear, with actual stations, if weak signals are selected. But the AVC action makes exact adjustment by ear difficult, with many receivers.

In superhet receivers, the oscillator is generally tuned to a higher frequency than the aerial (or signal frequency) circuits. The difference in frequency corresponds to the intermediate frequency of the receiver, as explained later. This difference has to be maintained through the tuning range. For example, assume the waveband is from 20mc/s to 10mc/s (i.e. 15 to 30 metres) and that the IF is 470kc/s. All signal frequency circuits (aerial circuit, and any RF circuits, and the signal grid circuit of the frequency changer) will be tuned simultaneously from 20mc/s to 10mc/s, or



20,000kc/s to 10,000kc/s. But the oscillator will tune from 20,470kc/s to 10,470kc/s. Similarly, with a medium wave band of 200–500m, or 1,500kc/s to 600kc/s, the oscillator would tune from 1,970–1,070kc/s. That is, 470kc/s higher all the way.

Maintenance of this frequency difference is called 'tracking'. To achieve the required result, the oscillator coil is of lower inductance than the signal frequency coils, and the effective tuning capacity in the oscillator section is reduced, either by using a capacitor with smaller plates, or by having a further capacitor in series with the oscillator section. The extra capacitor method is more usual, and the capacitor may be in series with the oscillator coil, as indicated by 'P' in Fig. 28. The extra capacitor is

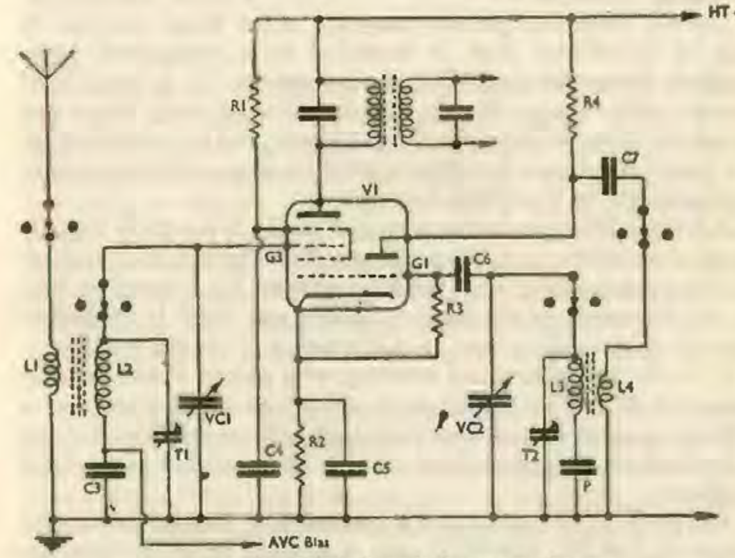



FIG. 28. Triode-hexode frequency changer

termed the 'padder'. Trimming is carried out as already described. At the low frequency end of the band, adjustment is generally by means of a screwed core, the padder being of fixed capacity. However, the oscillator coil could be of fixed inductance, the padder then being pre-set. Such a pre-set padder resembles an adjustable compression trimmer, except that it is normally of higher capacity.

One section of the ganged tuning capacitor is thus normally used for the oscillator, while another section is used for the signal frequency circuit of the frequency changer. If there is an RF amplifier, a further section on the gang capacitor is used to tune this.

The padder value required for each wave band is quite important, and different values will be wanted for most bands. As a guide, some typical padder capacities for various bands are as follows:

Long waves, 800–2,000 metres, 150pF padder
Medium waves, 190–550 metres, 470pF padder
Short waves, 18–50 metres, 2,500pF padder

*Frequency Changers*

The FC stage changes the frequency of the signal received, so that all signals can then be amplified by a fixed-tuned, intermediate frequency amplifier. For example, in a multi-band receiver with 470kc/s IF, the stations tuned in could be on any frequency from perhaps 30mc/s to 150kc/s, but the output of the FC stage will always be 470kc/s. So there is no need for variable tuning in any of the 470kc/s circuits.

A typical FC stage, using a triode-hexode, is shown in Fig. 28. In small receivers, L1 is for aerial coupling, but in larger receivers L1 provides coupling from the RF amplifier. L2 is tuned by VC1 to the frequency of the desired station, and AVC is applied to grid G3 of the valve, through this winding. T1 is the trimmer.

L3 is the oscillator tuned winding, with padder P and variable capacitor VC2. The padder is in series with the coil, so that a different padder can be used with each coil, as mentioned. L4 is a feedback winding, so phased that the triode section of the valve oscillates.

The frequency of oscillation is governed by the oscillator tuned circuit (L3, P, T2, and VC2) and is 470kc/s removed from the signal frequency, to which L2 is tuned. The electron stream from the cathode passes through both oscillator grid G1 and signal grid G3. To obtain the required IF (470kc/s in this case) the oscillator circuit may be tuned 470kc/s above the signal frequency, or 470kc/s below the signal frequency. For example, if the signal is 2,000kc/s, the oscillator could be tuned to 2,470kc/s, or 1,530kc/s. The oscillator is usually tuned to the frequency which is higher than the signal frequency, though not exclusively so in some receivers.



This combining of two frequencies, to produce the intermediate frequency, is termed mixing. When the valve is also an oscillator, as in Fig. 28, it may be termed a self-oscillating mixer, but is generally simply called a frequency changer.

The oscillator may be a separate valve. In this case, the mixer does not itself employ electrodes for the oscillator circuit, but only serves to mix signal frequency and oscillator frequency, to produce the required IF. The triode-hexode, in Fig. 28, could be looked upon as two separate valves in one envelope, with grid G1 of the hexode section directly connected to grid G1 of the triode oscillator. Separate oscillators can give better results on very high frequencies. But the use of a single valve saves space and reduces cost.

*Image Frequency*

It was pointed out that the oscillator could be above or below the signal frequency. In the example, the desired station was at 2,000kc/s, and the oscillator was working at 2,470kc/s. As the oscillator may be either side the frequency of a signal, and still convert it to 470kc/s, it is apparent that a signal at 2,940kc/s, if present on G3 of the valve, would also reach the IF amplifier, and would be amplified with the desired signal. This unrequired frequency is termed the 'image frequency' and interference from this cause is called image frequency interference, or 2nd channel interference. It is a defect which cannot possibly arise in TRF receivers.

Difficulties from image frequency interference increase, as the frequency is raised. For example, when receiving a medium wave transmission on 300m or 1,000kc/s, the oscillator could be tuned to 1,470kc/s. The image would then be at 1,940kc/s (470kc/s higher) or about 155m. The tuned circuit L2, Fig. 28, should be able to eliminate any signal around 155m when tuned to the desired 300m signal. So image frequency interference is unlikely.

But assume the same receiver is tuned to 15m, or 20mc/s. The oscillator is on 20,470kc/s, and the image falls on 20,940kc/s, or 20·94mc/s, which is about 14·3m. The tuned circuit L2 will not be sufficiently selective to eliminate an unwanted signal on about 14·3m when tuned to the desired signal on 15m. So image interference is probable.

To overcome this fault, additional selectivity may be provided *before* the FC stage. One or more RF stages, each with its own tuned circuit, will reduce image frequency interference. Generally, such interference will be virtually absent on lower frequency bands, but gradually becomes more apparent as the receiver is tuned to higher frequencies, as explained.

Another method of reducing image frequency interference is to use a higher intermediate frequency. For example, if the IF is 1,600kc/s, instead of 470kc/s, images will fall 3,200kc/s (2 × 1,600kc/s) away from the desired signals, instead of 940kc/s (2 × 470kc/s) away from them. A tuned circuit such, as L2 in Fig. 28, will then better eliminate the unrequired frequencies. The need for high selectivity before the FC stage is then less pointed.

Unfortunately, an IF amplifier using a high frequency does not give such good selectivity. As a result, stations very near in frequency to the desired transmission may prove troublesome. If a high intermediate frequency is used, to avoid images, this is often converted to a lower frequency, at a later stage. As example, it could be assumed that the first IF were 1,600kc/s, and that this was followed by a 2nd frequency changer, and 470kc/s amplifier. As the first IF is fixed, no variable tuning is required in the 2nd FC stage.

Such an arrangement is termed a 'double superhet' or double conversion superhet, and it is quite often encountered. But many communications receivers use only one intermediate frequency, in the region of 470kc/s. A few specialized sets are triple conversion superhets.

Typical component values for Fig. 28 are: V1 12AH8; VC1 and VC2 2-gang 500pF tuning capacitor; T1 50pF trimmer; T2 50pF trimmer; C3 0·1μF; C4 0·1μF; C5 0·1μF; C6 100pF; C7 200pF; P padder to suit waveband and coils; R1 33K; R2 220 ohms; R3 47K; R4 27K. HT 250V.

*Heterodynes*

When two different frequencies are mixed or made to beat together, the result is a heterodyne. The frequency of the heterodyne is the difference between the two original frequencies.

This fact is used in the superhet (supersonic heterodyne) type of receiver, as described. In the superhet, a local oscillation is mixed with the incoming signal, to produce a signal which can be amplified by circuits having fixed tuning.

Heterodynes may be of audible frequency. If a receiver has a Beat Frequency Oscillator, as described later, the signal from



the BFO could be at 471kc/s or 469kc/s, and could be mixed with the 470kc/s signal available at the intermediate frequency amplifier. This would produce a 1kc/s, or 1,000 cycle, audible tone. Such a method is employed to receive CW Morse.

A TRF receiver, with regenerative detector, may be made to oscillate, as previously described. If such a receiver is oscillating, and is tuned through a steady carrier, or continuous radio wave, the heterodyne will be clearly heard. The audio note will rise in frequency, as the receiver is tuned away from the signal which is producing the heterodyne. When the carrier is interrupted by keying the transmitter, the audio tone will only exist when the transmitter is radiating. It is in these circumstances that CW Morse can be heard with a TRF receiver.

*IF Amplifier*

The intermediate frequency amplifier often has 1 valve only, in domestic receivers, but 2 valves or more are usual in larger receivers. The IF amplifier increases the strength of the signal provided by the frequency changer, and will supply this amplified signal to the detector (commonly called the 2nd detector).

A typical 1-valve IF amplifier is shown in Fig. 29. Both the primary and secondary of each IF transformer are tuned to the

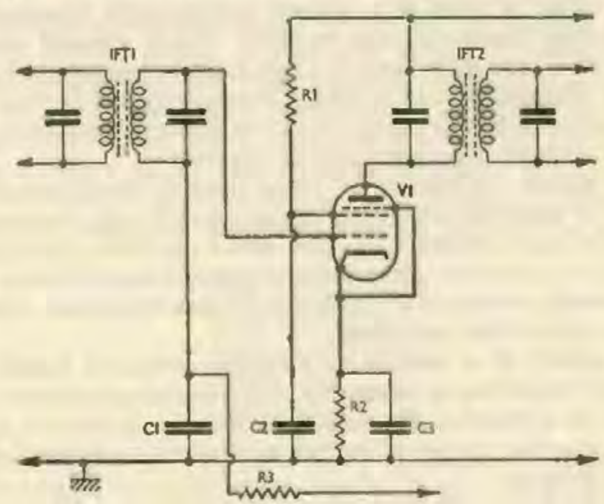



FIG. 29

intermediate frequency. This can be assumed to be 470kc/s, though other frequencies are also used. Fixed tuning is employed. This may be by means of fixed inductance coils, and pre-set trimming capacitors. Generally, however, fixed capacitors are used, and the coils have adjustable cores. Alignment of the circuits is then by adjusting the cores.

The circuit in Fig. 29 has four tuned circuits, and can thus provide a great increase in selectivity, or the ability of the receiver to select a chosen transmission, and reject stations on adjacent frequencies.

If the IF amplifier is compared with the circuit of the RF amplifier, it will be seen that it is much the same, except that the tuning coils and variable capacitor have been replaced by the IF transformer windings, and trimmers. AVC can be applied through the IF transformer secondary, exactly as it could be through the tuning coil.

In a 2-stage IF amplifier, two stages such as that in Fig. 29 may be used. Typical values for Fig. 29 are: V1 6BA6; C1 0·1$\mu$F; C2 0·1$\mu$F; C3 0·1$\mu$F; R1 33K; R2 68 ohms; R3 100K; IFT1 and IFT2, 470kc/s IF transformers.

*Adjacent Channel Selectivity*

If a circuit is tuned to a required station, other transmissions on adjacent frequencies may be heard. This is adjacent channel interference, and arises because a tuned circuit has some response to near frequencies. This is readily demonstrated by the fact that a transmission can be heard even if the receiver is tuned slightly from it, though volume and quality degenerate.

The greater the number of tuned circuits, the higher is the ability to eliminate interfering signals on adjoining frequencies. Efficient, high Q circuits also give better selectivity than low Q circuits. In a superhet, quite a large number of tuned circuits may be provided, as several IF transformers, each with tuned primary and secondary, can be utilized.

The ability of a receiver to eliminate unwanted signals, on near-by frequencies, is termed its adjacent channel selectivity, or merely its selectivity. The selectivity may be given as a graph curve, or as the number of decibels an adjoining, unwanted signal will be reduced.

Fig. 30 shows selectivity curves. A is for a receiver of poor selectivity, which tunes flatly, and which could not remove



interference from adjacent transmissions. B is a much more selective curve, and would be quite useful for general purposes. C is a highly selective curve, with transmissions only slightly removed in frequency being much reduced in strength. The degree of selectivity is sometimes termed the 'pass band'. A is thus a wide pass-band, B a medium pass-band, and C a narrow pass-band.

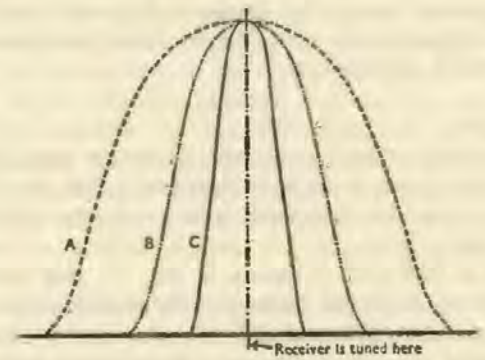



FIG. 30

The highest possible selectivity is not always required. An extremely selective receiver is difficult to tune. In addition, speech and music produce sidebands, which must be accepted by the receiver, for good quality reproduction. For these reasons, a communications set usually has variable selectivity. This may be controlled by a switch, which may be numbered with selectivity positions, or the approximate pass-band provided. Typical pass-bands, for a receiver with switch selected degrees of selectivity, are as follows:

6,000 cycles (6kc/s)
3,000 cycles (3kc/s)
1,000 cycles (1kc/s)
500 cycles
100 cycles

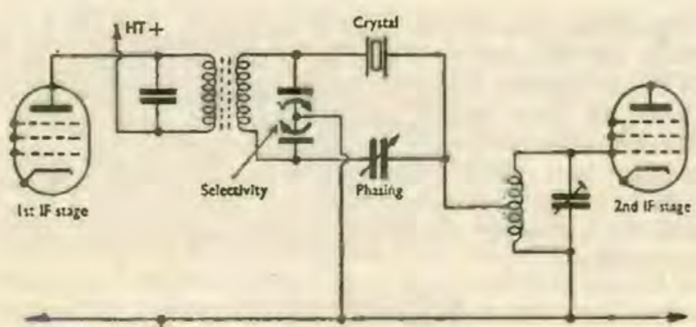
Other degrees of selectivity may, of course, be found. The highest degree of selectivity can only be generally employed when receiving Morse. If the IF amplifier has sufficient tuned circuits to be highly selective, lower degrees of selectivity can be obtained by damping some of the IFT's with resistors, or by slightly de-tuning some windings. De-tuned IFT's are generally termed 'staggered' because the frequencies to which the windings are tuned are a little each side the actual intermediate frequency.

To sharpen tuning further, more IF transformers may be brought in. The selectivity switch can thus give a range of working conditions, to suit requirements. When very high selectivity is needed, a crystal filter is most often utilized. Crystal filters are not fitted in receivers made for domestic purposes. But in highly specialized receivers, such as the better communications receivers, a crystal filter is provided.

*Crystal Filter*

A piezo-electric crystal, as described later for crystal controlled oscillators, has a sharp resonant frequency, and may be used to replace a tuned circuit. Employed in this way, the crystal will give high selectivity.

A circuit of this kind is shown in Fig. 31, and various other circuits exist. The crystal filter may be switched in or out, as required, and may be automatically introduced when the selectivity switch is turned towards positions giving maximum selectivity.




Crystal Filter

FIG. 31

The crystal filter is used between valves in the IF amplifier, and the crystal is ground to the correct frequency, such as 470kc/s, for this purpose. The response of the circuit can be symmetrical, exactly as if the crystal were an IF transformer giving very sharp resonance. By adjusting the phasing capacitor, the filter can be



made to give very sharp suppression of an unwanted signal on a near-by frequency. This is sometimes termed the 'rejection notch' and can help eliminate interfering CW signals, etc. In receivers with a crystal filter, the tunable intermediate frequency transformers must be aligned very near to the crystal frequency, or efficiency will be greatly reduced.

*Sensitivity*

This is the ability of the receiver to respond to a weak signal, or to give an intelligible output with a weak signal. It is not possible to increase sensitivity merely by increasing the number of amplifying stages, because thermal and circuit noise will be amplified, together with the required signal, and will give a high background noise level. High sensitivity thus depends on a high 'signal-to-noise' ratio in the receiver, as well as high amplification. A receiver with a high signal-to-noise ratio is one giving much amplification to required signals, but introducing the minimum of noise itself.

Actual sensitivity may be expressed in terms of a minimum signal input, for a given output. For example, $3\mu V$ input, modulated 40 per cent, for 50mW output. A sensitivity of $1\mu V$ to $5\mu V$ is very good. Sensitivities over $1\mu V$ are obtainable.

The results realized in practice will naturally depend on the aerial, and other circumstances. A receiver with high sensitivity, used with a poor aerial, might give worse reception of a distant station than a less sensitive receiver, employed with a good aerial. But sensitivity figures, if accurate, do allow comparison of receivers on this point.

*2nd Detector*

The diode detector has been described, and is often used in superhets. A circuit is given in Fig. 26. The sequence of stages in the superhet will be RF/FC/IF/DETECTOR, and the 2nd detector is often merely termed the detector, or demodulator. On some occasions the frequency changer was regarded as a type of 1st detector, so the detector following the IF amplifier could then be termed the 2nd detector.

The operation of the diode detector in Fig. 26 has been described. In Fig. 26, the valve is a double-diode-triode, and the triode section provides audio amplification, as described later. The remaining diode, unused in Fig. 26, is generally employed for automatic volume control.

*AVC*

Automatic volume control is provided in superhets, in an attempt to maintain a more even output, with changes in signal input. The automatic volume control circuit reduces the gain, or amplification, of some stages, when a strong signal is being received.

Fig. 32 shows a typical AVC circuit. Here, two valves are connected to receive AVC bias. V1 is the RF amplifier, and V3 is the IF amplifier. If more than one IF valve were employed, AVC could be applied to the extra valves. AVC is sometimes applied to the frequency changer also. The valves are vari-mu types, in which amplification is reduced when the control grid bias is made more negative.

The AVC diode of V4 receives part of the IF signal, through C5, and rectifies this, producing negative bias. This bias reaches V1 through R5, R2 and the coil winding L1. In a similar way, the bias reaches the control grid of the IF valve through R5, R3 and the secondary of the IF transformer. C1 and C3 are by-pass capacitors.

If a weak signal is tuned in, little bias is produced, so the controlled valves provide almost maximum gain. But if a stronger signal is being received, the negative bias increases, thereby reducing gain in the controlled valves. The output of the receiver is thus more uniform, even when tuning in transmissions of greatly varying strength. This helps prevent overloading of some stages, with powerful local stations. It also helps counteract fading, or variations in signal strength due to propagation conditions.

Sets for domestic listening have the AVC permanently in use. Communications receivers generally have a switch, so that the AVC can be switched off, if required.

It would also be possible to take an AVC voltage from the point X in Fig. 25, and this type of circuit is also used. The AVC for each valve in a receiver is taken from the AVC line by means of resistors, such as R2 and R3 in Fig. 32. These resistors, in conjunction with the by-pass capacitors C1 and C3, prevent RF signals travelling along the AVC line, which would cause instability.

If the AVC action commences immediately any RF is present at the AVC diode, gain in the early stages will be reduced by the AVC voltage, even with weak signals. To avoid this, a 'delay'



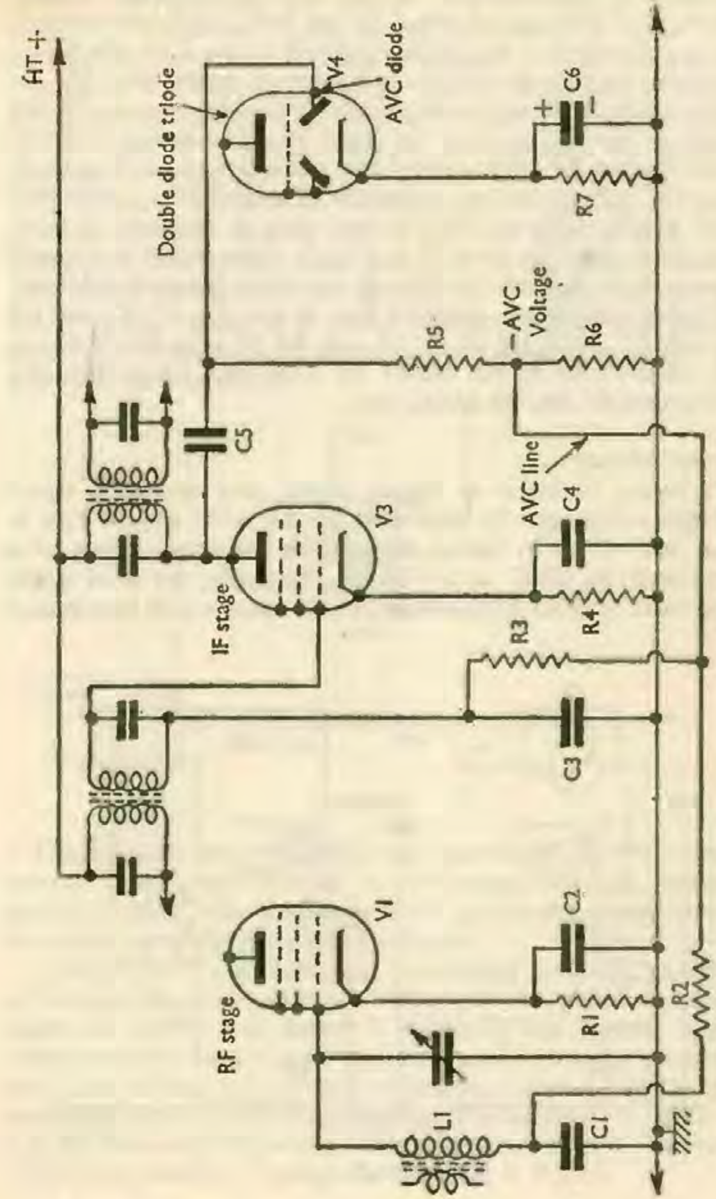



Fig. 32

AVC with 2 Valves connected

voltage can be arranged, so that the AVC action does not commence until the signal applied to the AVC diode exceeds this voltage. A common way of doing this is to use a double-diode-triode having cathode bias, in the manner shown for V4 in Fig. 32. The cathode is positive to the extent of the bias required by the triode section of the valve. So the AVC diode section will only conduct when RF peaks exceed this voltage. As a result, there is no AVC voltage, and no reduction of amplification, with very weak signals. Delayed AVC is most usual in receivers. If AVC were taken from the point X in Fig. 25, there would be no such delay voltage, because the cathode is at earth (chassis) potential.

Typical component values for Fig. 32 are: C1, C2, C3 and C4 0·05μF; C5 30pF; C6 25μF; R1 and R4, 68 ohm for 6BA6, or 220 ohms for 6K7; R2, 100K; R3 100K; R5 1 megohm; R6 1 megohm; R7 3K, V4 6AT6, 6Q7.

*Tuning Indicators*

A tuning indicator or tuning meter, also termed a signal strength meter, can be controlled by the AVC circuit. This is most easily done by having the meter in the anode circuit of a valve receiving AVC, as in Fig. 33A. Typically, the valve might pass 10mA with no AVC voltage, so the meter would be adjusted

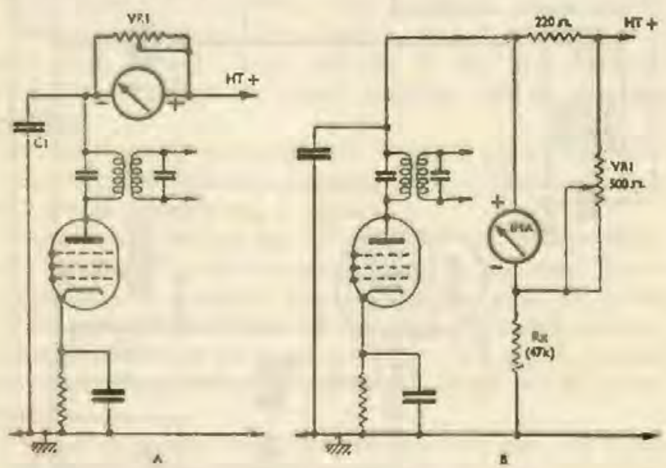



FIG. 33



to read full-scale with this current. When a signal is tuned in, the AVC voltage will depend on the strength of the signal, and the valve anode current will thus be reduced to some lower level. The meter will thus fall back, its reading depending on signal strength. VR1 is a variable or pre-set shunt, so that the meter can be adjusted to give a full-scale reading, when no signal is tuned in. C1 is the RF by-pass capacitor of about 0·05μF.

To obtain a rise in meter reading, with an increase in signal strength, a circuit such as that in Fig. 33B may be used. The meter then rests at zero, with no signal, instead of at full-scale. VR1 allows adjustment. The resistor Rx is chosen to suit the valve, or can consist of a pre-set resistor, or fixed and pre-set resistors in series. Meter sensitivity can be adjusted by employing a shunt in parallel with it.

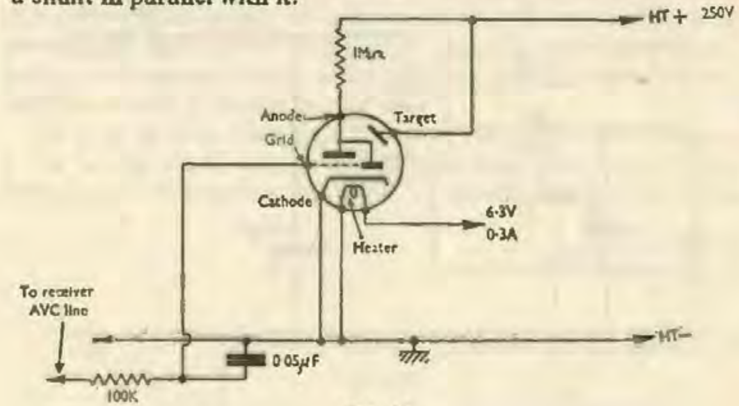



FIG. 34

The actual reading provided by the meter depends on the meter circuit, receiver, and its aerial, as well as signal strength. Despite these limitations, such meters are useful, and extensively employed, and allow comparisons of signal strength.

A magic eye is sometimes used as a tuning indicator. This has an electron beam controlled by an electrode voltage and striking a target, so that correct tuning is shown by the shadow angle. Various similar devices exist, and are most suitable for domestic sets – that is, they act as tuning indicators, not as signal strength indicators. Similar indicators are made in which the luminous area is in the form of a strip, which extends as signal strength increases. A typical circuit for a 'Magic Eye' is shown in Fig. 34.

*BFO*

A beat frequency oscillator is used in superhets, to make CW Morse audible. (*See also* Regenerative Detectors.) CW Morse, as delivered by the receiver IF amplifier, is an interrupted radio wave, not itself audible. If the set has a 470kc/s IF amplifier, the signal is at this frequency. The signal is only present when the transmitter Morse key is pressed.

The BFO is a local oscillator. It is tuned to a slightly different frequency from the receiver IF, and its signal is mixed with the signal from the IF amplifier. As a result, an audio tone is heard, its frequency being the difference in frequency between IF and BFO. For example, if the IF is 470kc/s, and the BFO is tuned

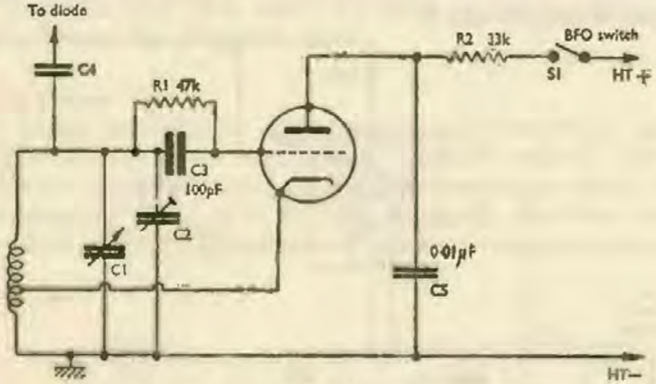



FIG. 35

to 468kc/s or 472kc/s, the difference would be 2kc/s, or 2,000 cycles per second, so an audio note of this frequency would be produced.

The BFO is switched off for the reception of speech, music, and similar modulated signals. In an ordinary domestic superhet, no BFO is provided.

The BFO is generally tunable over a small frequency band. The audio note may then be varied, so that best reading of a desired signal in interference is possible, and so that the BFO may be tuned above or below the IF amplifier signal.

A BFO circuit is shown in Fig. 35. The trimmer C2 is set to give a suitable frequency, and adjustment can then be by the panel control C1. The switch S1 puts the BFO out of action, for



phone (voice) reception. C4 is a very small capacity (2–5pF) connected to the detector diode.

A method of transmission termed single sideband is also employed. With this, the carrier and one sideband are eliminated, or much reduced. To resolve such a signal at the receiver, the BFO may be switched on, and its output may be adjusted to occupy the position of the removed carrier. RF gain should be reduced, so that the signal at the detector is not too strong. The signal will then become intelligible as speech. Receivers especially designed for SSB reception have circuits for this purpose, but it is possible to receive such signals, with a BFO.

*AF Amplifiers*

The audio-frequency amplifier of a receiver often has one or two stages, and brings the signal up to sufficient strength to operate the loudspeaker. Resistance capacity coupling is commonly used between stages, and a popular type of 2-valve receiver amplifier circuit is shown in Fig. 36.

The first valve is often used for other purposes – for example, it can be the triode section of a double-diode-triode, the diodes being used for detection and AVC, as described. Fig. 36 is quite

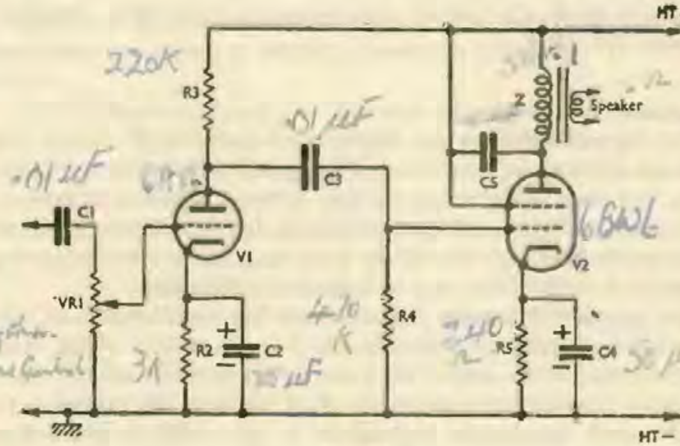



FIG. 36

typical of a communications receiver, or ordinary domestic set, and is capable of reasonable power output. In some receivers, push-pull output stages are used. Audio-frequency amplifiers are covered in detail in the section on modulators.

In many receivers the output is a single valve, as shown in Fig. 36. Commonly used valves have a power output of up to about 4½W. Bias is obtained from the voltage drop across the cathode bias resistor R5. The value of this bias resistor may be found from Ohm's Law:

$$\frac{V}{I} \text{ or } \frac{\text{Bias voltage} \times 1{,}000}{\text{Cathode current in mA}} = \text{bias resistor value in ohms}$$

The output stage (and also V1) operates as a Class A amplifier, as described earlier. The output is developed across the anode load Z (speaker transformer and speaker). Most power is delivered when Z is of the optimum load for the valve. To achieve this, the ratio of the transformer is obtained as previously described. That is:

$$\text{Ratio} = \sqrt{\frac{\text{Optimum load for valve}}{\text{Speaker speech coil impedence}}}$$

Typical circuit values for Fig. 36 are: V1 triode section of 6AT6; C1 0·01$\mu$F; VR1 1 megohm volume control; R2 3K; C2 25$\mu$F; R3 220K; C3 0·01$\mu$F; R4 470K; V2 6BW6; R5 240 ohms; C4 50$\mu$F; C5 0·01$\mu$F. Output transformer 50:1. Speaker, 2 ohms. HT 250V.

*Loudspeakers*

Moving-coil speakers are widely used, and Fig. 37 shows the essential elements of such a unit. The speech coil is attached to the cone, and rests in the magnetic gap. When a signal is present in the speech coil this winding is displaced, due to the interaction of its magnetic field with that of the fixed magnet, and this vibration is imparted to the cone, and to the surrounding air.

The speech coil usually has relatively few turns, and is of low impedance. Typical impedances are 2–3, 7, and 15 ohms. The optimum load of the output valve will be much higher, so a speaker matching transformer is necessary. This has a step-down ratio, so as to match the higher impedance of the valve to the lower impedance of the speaker. The method of determining this ratio



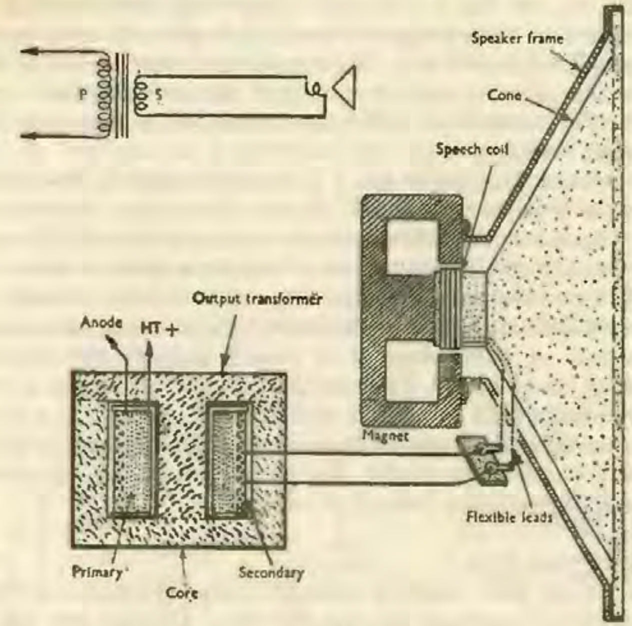



FIG. 37

is described above. The ratio required for particular optimum loads and speakers can be taken from the following:

| *Valve Optimum Load, ohms* | *Speaker Impedance, 2–3 ohms* | *15 ohms* |
|---|---|---|
| 2,000 | 28:1 | 11½:1 |
| 2,500 | 31½:1 | 13:1 |
| 3,000 | 35:1 | 14:1 |
| 4,000 | 40:1 | 16:1 |
| 5,000 | 45:1 | 18:1 |
| 6,000 | 49:1 | 20:1 |
| 7,000 | 53:1 | 21½:1 |
| 8,000 | 57:1 | 23:1 |
| 10,000 | 63:1 | 26:1 |

If the receiver has a push-pull output stage, as described for modulators, a centre-tapped transformer primary is required, with equal ratios each side. The transformer must also be able to handle the power required, and pass the output stage anode current. For example, a 10W output stage would require a 10W (or larger) transformer.

The speaker frequently has a permanent magnet. The unit is then a PM (permanent magnet) speaker. It will be of this kind in battery equipment, and is often so in mains equipment. But energized speakers are also used in some mains equipment, instead of the PM type. The field, or energizing coil, is a large winding, on the centre limb of the magnet assembly, which is not permanently magnetized. A direct current is passed through the field, to magnetize the assembly. This may be arranged by having a fairly high resistance field in parallel with the HT supply. Or a rather lower resistance field may be in series with the HT line, and may replace the smoothing choke. For proper results, the field must receive its appropriate voltage or current.

*Receiver Power Packs*

The power pack delivers suitable voltages for the receiver valves. DC is required for the HT line. Heaters are usually operated from AC, however.

With AC operated equipment, valve heaters are generally wired in parallel. The heaters may then be of unequal current rating, but of the same voltage rating. All are then run from a mains transformer secondary delivering the appropriate voltage (*see* Modulator Power Packs).

Valve heaters may also be wired in series, usually for AC/DC operation. Heaters may then be of unequal voltage rating, but they should have the same current rating. A heater chain of this kind is shown in Fig. 7.

For battery equipment, valve filaments may be wired in parallel, and they are the of the same voltage rating. Or they may be in series, and have the same current rating.

With mains equipment, the HT line will often be about 250V or 350V. Current consumption depends on the receiver, and will be perhaps 60mA for many average small domestic receivers, but up to perhaps 100mA or so for some communications receivers employing a large number of valves. Power pack circuits are given later.



*Super-regenerative Receivers*

This type of receiver is little used today, but had occasional application on very high frequencies. Any RF and AF stages in the receiver are of normal type, as might be used with an ordinary TRF receiver for the same frequencies. The detector stage, however, is operated in a condition of super-regeneration, which results in high sensitivity.

In a super-regenerative circuit, the detector is taken in and out of oscillation at a frequency above audibility, so that very much regeneration can be used, with increased sensitivity. The frequency at which the detector is taken in and out of oscillation is termed the quench frequency, and may lie between about 15kc/s and 150kc/s or so.

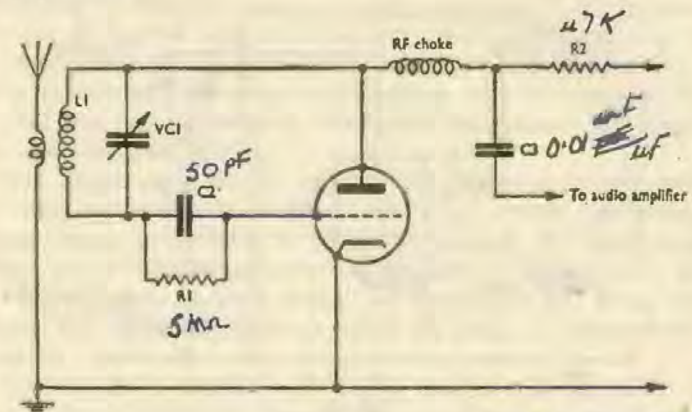



FIG. 38

The valve may be self-quenching, in which case the detector itself goes in and out of oscillation at a frequency arranged by employing suitable quench coils, or as a result of grid blocking. Fig. 38 shows a self-quenching detector. C2 and R1 are so chosen that quenching of oscillation arises at the required frequency. Violent oscillation builds up a negative voltage on the grid, which reduces conductance and stops oscillation. This charge leaks away through R1, so that oscillation begins again. This effect takes place at the quench frequency, which must be above audibility.

A separate quench valve may be used instead. This valve oscillates at quench frequency, and is coupled to the detector, so that the latter is taken in and out of oscillation.

Super-regenerative detectors tune flatly, and will radiate interference, if there is no RF stage. They were once quite largely employed, but are not very suitable for present-day use.

Typical values for Fig. 38 are: R1 5 megohms; R2 47K; C2 50pF; C3 0·01μF; VC1 and L1, for frequency required.

*Noise Limiters*

Static noise may be picked up by the receiver aerial, or it may reach the receiver through the mains. A peak noise limiter may be employed to reduce interference of this type. A typical circuit, using a double-diode for detection and noise limiting, is shown in

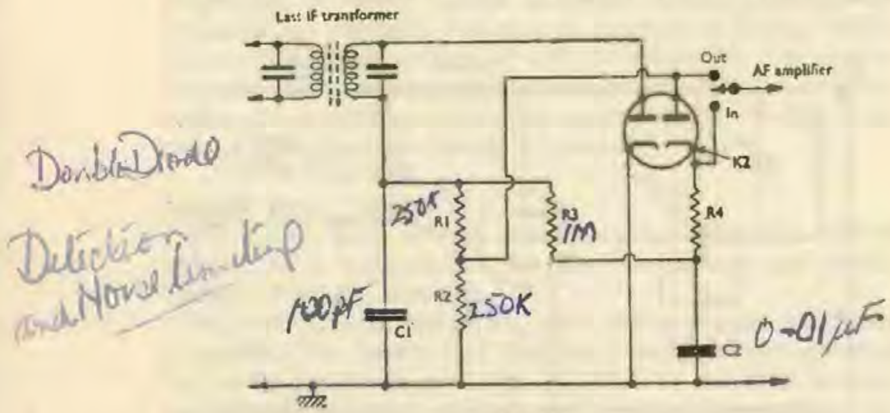



FIG. 39

Fig. 39. This limiter automatically adjusts itself to the average signal strength, because an average voltage is maintained on the cathode K2, through R3 and R4. Static signals do not much influence the voltage on K2, due to C2, and so the diode fails to conduct at a level much higher than the general signal strength.

A 2-way switch is included, so that the noise limiter can be switched out of circuit, when required. The limiter causes some degeneration in speech and music quality, so it is not left permanently in action, but only switched in when static type interference is troublesome.

Suitable component values for Fig. 39 are: C1 100pF; C2 0·01μF; R1 250K; R2 250K; R3 1 megohm; R4 1 megohm. Valve, 6H6, 6AL5, etc.

CHAPTER FIVE

# Oscillators and CW Transmitters

*Crystal Oscillators*

A PIEZO-ELECTRIC crystal is one in which mechanical stress of the crystal produces an electric potential, and an electrical potential produces a mechanical force. Such crystals are common in microphones and gram pick-up units, where mechanical movement produces the electrical output. Quartz piezo-electric crystals may be cut to have a natural frequency, and oscillation may be maintained by a valve. This forms a crystal controlled oscillator, able to maintain the working frequency of a transmitter. The crystal may be regarded as a very stable tuned circuit, working at its own fixed frequency.

The crystal plate can be cut from the quartz in various ways, to obtain advantageous features, such as high activity, or freedom from frequency drift as a result of changes in temperature. Plates cut at various planes to the dimensions of the quartz, and at right angles to each other, are termed X-cut, Y-cut and Z-cut, but many intermediate angles are used, to obtain desired features.

The crystal is usually in a holder having a 2-pin, valve, or similar base. It can be chosen to have a frequency which gives operation in the required band. For example, a 3·6mc/s crystal would allow the transmitter to work on 3·6mc/s. Or it may be selected to allow working in several bands, by frequency multiplying. For example, a 1,850kc/s (1·85mc/s) crystal could be used for this frequency, and also 3·7mc/s, by 'doubling'. Such frequency multiplication (2×, 3×, 4×, etc., the original frequency) is much used in transmitters.

A simple tuned anode crystal controlled oscillator is shown in Fig. 40. The crystal acts as a resonant circuit connected to the grid, while the anode circuit is tuned by the variable capacitor VC1. If the anode circuit is tuned to a frequency far from that of the crystal, no oscillation arises. When the anode circuit frequency is near that of the crystal, the circuit commences to oscillate, producing radio frequency energy. The RF is generally amplified by one or more further stages, before reaching the aerial.

A crystal oscillator does, however, form a very simple CW (Morse) transmitter, and is occasionally used in this way. A more powerful circuit for this purpose is shown later.

Typical values for the crystal oscillator in Fig. 40 are: V1, 6C5, 6C4, or other triode; R1 100K; VC1 100pF; C2 100pF; L1 – to suit crystal frequency.

With a suitable circuit, oscillation may be produced when the anode circuit is tuned to twice the crystal frequency. This provides

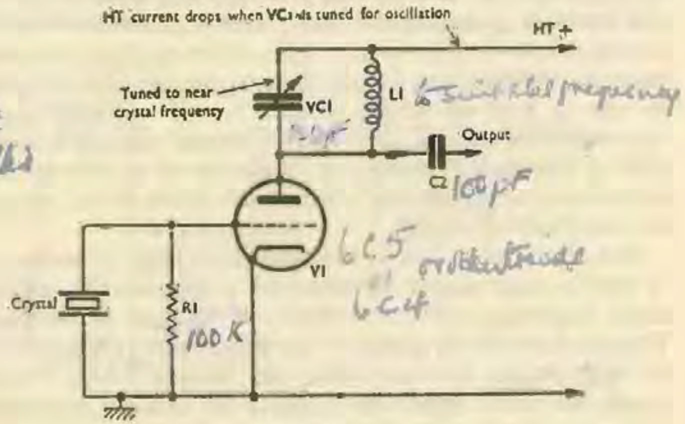
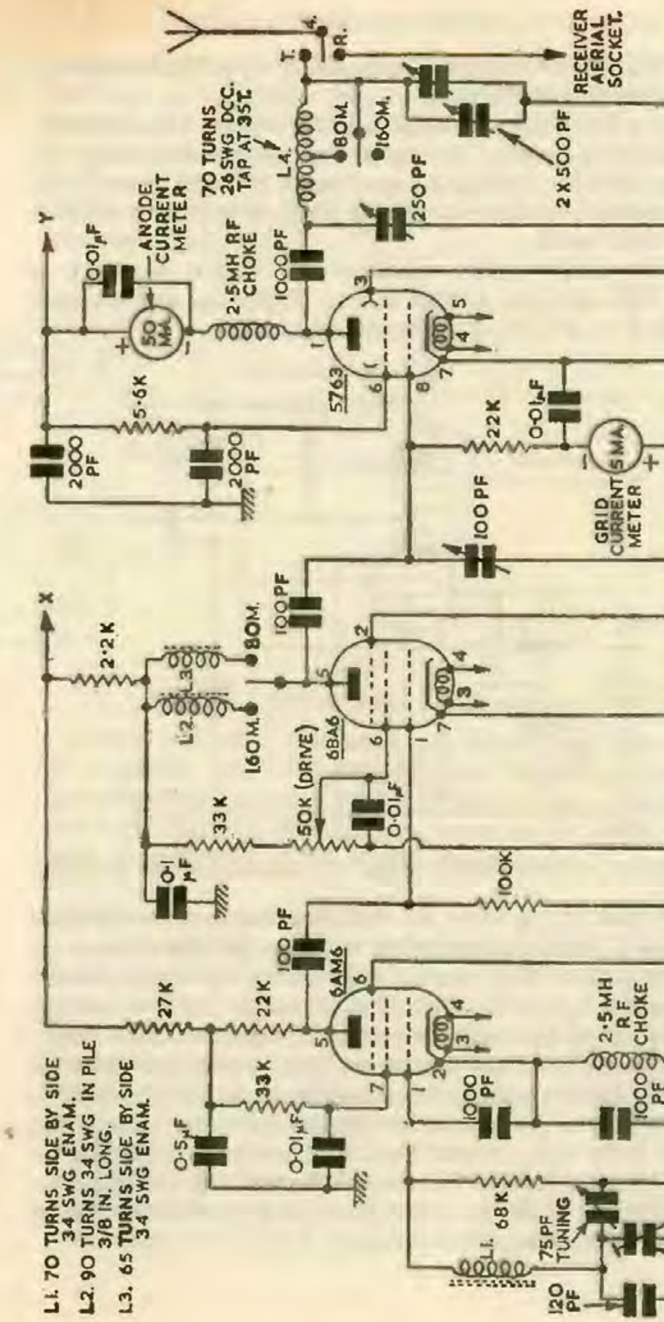



Fig. 40

frequency multiplication, often termed harmonic operation, because multiples of the original frequency are harmonics. As example, if the original frequency were 1·8mc/s, the 2nd harmonic is 3·6mc/s, the 3rd harmonic is 5·4mc/s, the 4th harmonic is 7·2mc/s, and so on.

To obtain a greater output, and reduce feedback which may heat the crystal, tetrode or pentode valves are often employed. Circuits especially intended for harmonic operation are better and also give a much greater harmonic output. Fig. 41 shows a Colpitts type harmonic oscillator, often employed. The anode circuit may be tuned to the crystal frequency, or to multiples of the crystal frequency.

The following values may be used in Fig. 41: R1 100K; R2 47K; VC1 100pF; C2 30pF; C3 100pF; C4 0·05$\mu$F; C5 100pF; V1




Speech transmitter. 10W on 160M and 12W on 80M. 50K drive control is adjusted for 3mA. 5763 grid current. L1, L2, and L3 wound on ⅜in diam. formers with cores. L4 1¼in diam. former 2¾in long. Transmit-receive switching is included here and in modulator, p 132.

5763; RFC 2·5mH RF choke; L1, tunable to the crystal frequency, or to the required harmonic.

Crystal controlled oscillators may have two or more crystals, with a selector switch, to permit changes in frequency. Or frequency may be changed by inserting a different crystal. The actual frequency, and any harmonics used, must of course fall in the permitted bands.

A further simple crystal oscillator, the Pierce, is shown in Fig. 42. This provides output at one frequency, and its main advantage is in the few components required.

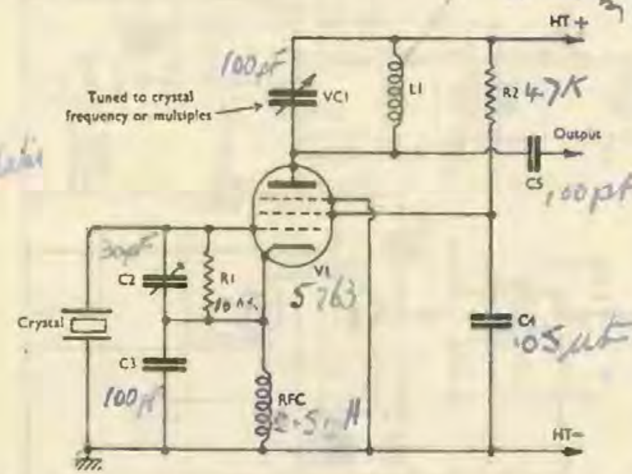



FIG. 41. Crystal oscillator giving output on fundamental and harmonics

Further multiplying stages are often used between the oscillator and the valve which delivers power to the aerial. These stages are termed multipliers. There may also be one or more stages which are intended to amplify the oscillator output, to give enough power to drive a large output stage. Such stages are called amplifiers or drivers. Or a stage may be present to avoid changes in the working conditions in the power amplifier having much influence on the oscillator. Such a stage is termed a buffer. A stage may work as a buffer only, on one band; and as a buffer-multiplier on higher frequency bands. The stage will generally furnish some amplification, in addition, in any case. So one valve may act as buffer, multiplier, and driver.



As already mentioned, one valve, as a crystal controlled oscillator, is sometimes used as a complete CW transmitter. As variations in aerial loading, and similar effects, may cause some frequency variations, a more popular method is to use a crystal oscillator, followed by a power amplifier, which energizes the aerial. Even better are 3 valves, as oscillator, buffer-multiplier, and power amplifier.

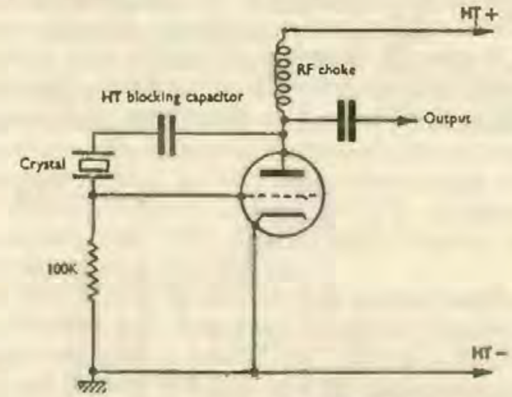



FIG. 42. Pierce crystal oscillator

Crystal controlled oscillators and transmitters have the virtue of simplicity, low cost, and excellent frequency stability. But operating frequencies are limited to those of the crystals available, and harmonics. For these reasons, tuned oscillators are very much used, in preference to the crystal oscillator.

*Variable Frequency Oscillators*

A fully tunable oscillator is generally termed a variable frequency oscillator, or VFO. It is more likely to suffer random, unwanted changes in frequency, than is a crystal controlled oscillator. Such changes in frequency may arise from variations in temperature influencing the inductance of coils, or the capacity of tuning capacitors, etc. Fluctuations in the voltage reaching the valve may also cause changes in frequency, as may mechanical vibration, or coupling from later stages.

All these effects have to be reduced to a low level, if the VFO is to be an adequate substitute for the crystal. To avoid mechanical weaknesses, the VFO is rigidly constructed, and it may receive anode and screen-grid voltages from a voltage regulated supply. The effects of temperature changes are counteracted by using special components, such as negative temperature-coefficient capacitors, baked coils, etc. It is also usual to have a buffer between the VFO and power amplifier stage, so that tuning or other variations in the PA stage will not affect oscillator frequency.

The use of a VFO has the great advantage that the transmitter can be tuned to any frequency in the permitted bands. Except when simplicity and low cost are important, Amateur transmitting equipment is generally controlled by a VFO. The VFO can tune one frequency band, such as 1·75mc/s to 2mc/s. This output can be multiplied, exactly as with the crystal oscillator, to give

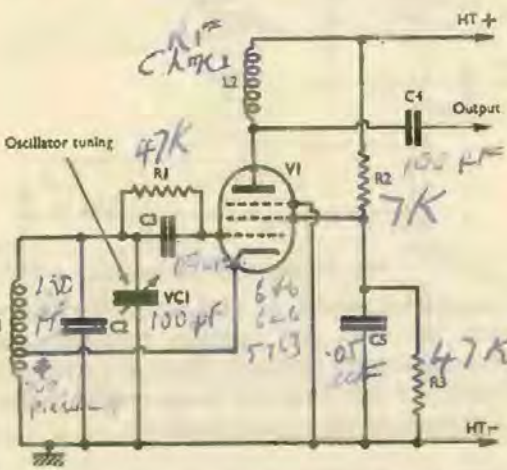



FIG. 43. A variable frequency oscillator

operation in other, harmonically related bands. For example, the 1·75mc/s to 2mc/s VFO output could be multiplied to cover 3·5mc/s to 4mc/s, of which the 3·5mc/s to 3·8mc/s coverage would be the 3·5–3·8mc/s Amateur Band.

A great deal of multiplication would be needed to obtain a 21mc/s or 28mc/s output, from the 1·75mc/s oscillator. So when it is intended to use the transmitter on higher frequency bands, a further coil may be provided in the oscillator. This could give a fundamental around 7mc/s, easily multiplied to 14, 21 and 28mc/s.

A typical VFO circuit is shown in Fig. 43. Rigid construction,



high quality components, voltage stabilization, and the use of a buffer after the VFO, allow a sufficient degree of frequency stability to be achieved.

When an initial warming-up period causes some frequency shift, after which the oscillator begins to settle down to more stable working, this is termed 'drift'. It is considered good practice to switch on any such oscillator (including signal generator test equipment) well in advance, so that initial drift will have largely ceased by the time the equipment is to be used.

Exactly the same buffer, multiplier, amplifier, and power amplifier stages may follow the VFO, as might be used after a low output crystal controlled oscillator. As a VFO is most stable when loosely coupled to the following circuit, and running at low power, it is quite usual to feed the VFO output into a stage which could act as a crystal oscillator. Crystal or VFO operation is then possible at will. The VFO may be built into the transmitter, or it may be in a separate cabinet.

With a circuit such as that in Fig. 43, C2 is often of high capacity, to reduce drift from small changes in capacity elsewhere. L1 thus has relatively few turns. L2 may be a RF choke, or a pre-tuned coil broadly resonant on the operating frequency.

Typical values for Fig. 43 are: R1 47K; R2 7K; R3 47K; VC1, 100pF; C2 250pF plus 100pF pre-set in parallel; C3 100pF; C4 100pF; C5 0·05μF; L1 (1·75–2mc/s) 35 turns 20 SWG on 1¼in diam. former; L2 RF choke; V1, 6V6, 6L6, 5763, etc. L1 tap 7 turns from HT−.

### *Frequency Multiplication*

When the oscillator operates at a lower frequency than will be radiated by the transmitter, frequency multiplier stages are placed between oscillator and PA (power amplifier energizing the aerial). These stages provide multiplication of 2 (doubling), 3 (tripling), and so on. Such multiplication is used over the necessary part of the oscillator range.

If the oscillator tuned from 1·8mc/s to 2mc/s, this would allow driving the PA without multiplication, for the 1·8–2mc/s band. But for the 3·5–3·8mc/s band, oscillator tuning, with doubling, would be from 1·75mc/s to 1·9mc/s. So the oscillator would actually be required to tune from 1·75mc/s to 2mc/s. On the 1·8–2mc/s band, the oscillator would only be used over the frequency range 1·8–2mc/s. On the 3·5–3·8mc/s band, the oscillator would be tuned from 1·75 to 1·9mc/s, its output being doubled to 3·5–3·8mc/s.

When frequency multiplication is used, it is thus necessary to see that the transmitter is not operated outside the permitted bands, because the coverage required for one band is not an exact multiple throughout of the coverage for another band. Similar care is needed when using crystals – some may do for higher frequency bands, while others may fall outside these bands. Nor should the transmitter be operated near the extreme limits of any band.

When using multiplier stages, it is also necessary to take care that the correct harmonics are employed. For example, a 1·85mc/s crystal might be used in the 1·8–2mc/s band, and doubling from the crystal oscillator would provide 3·7mc/s, in the 3·5–3·8mc/s band. But if the multiplier stage were carelessly tuned to the third harmonic, instead of the second, the output would be on 1·85×3, or 5·55mc/s, which is not permitted. Harmonics may readily be checked with a simple wavemeter, as described later. With ready-made transmitters, or equipment assembled from kits of parts, coils and tuning capacitors are usually so selected that operation outside the permitted bands is unlikely.

If much frequency multiplication is obtained from a stage, the efficiency falls, so most stages are arranged for doubling or tripling only. When using a low frequency crystal or VFO, and working on the higher frequency bands, two or more multiplier stages may be used, to reach the required frequency. For example, two doublers would give 4× the original frequency, while a doubler followed by a tripler would give 6× the original frequency, and so on.

A multiplier stage often acts as a buffer and amplifier in addition, as mentioned. With a crystal-controlled oscillator, the buffer is scarcely required, as the oscillator can drive the PA stage. But with a VFO, a buffer is required, because the output of the VFO is generally smaller than that of the crystal oscillator, and the VFO is more susceptible to suffer changes in frequency, due to loading from the PA.

*CW Transmitters*

A CW transmitter is one which will produce a continuous radio wave, or carrier. This is interrupted with a key, when Morse is transmitted. That is, the transmitter only radiates its signal when the key is closed by pressure on it.



For telephony (voice) working, the wave is modulated. To do this, a modulator (audio amplifier) is added, as described later. A voice or phone transmitter is thus virtually a CW transmitter to which a modulator has been added.

The simplest form of CW transmitter is a single valve crystal controlled oscillator, feeding the aerial. Crystal controlled oscillators as already described may be used. However, a 1-valve transmitter of this kind would only have a small output, and some means of coupling the aerial would also be required. To overcome these limitations a circuit such as that in Fig. 44, and employing a larger valve, may be adopted.

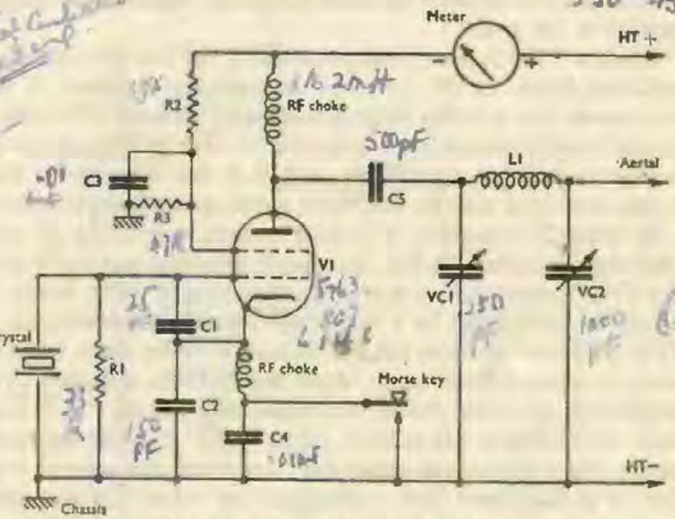



FIG. 44. Practical 1-valve crystal controlled transmitter

VC1 and VC2 in conjunction with the coil L1, form a $\pi$ output circuit. Loading the transmitter by means of an aerial with this type of circuit is described later. When making initial adjustments, it is preferable to use an artificial load, such as a 200/250V 25W, 40W, or 60W domestic lamp, connecting this from transmitter aerial terminal to earth (HT negative). This avoids unnecessary interference to other stations.

Typical values for Fig. 44 are: R1 33K; R2 15K; R3 47K; C1 25pF; C2 150pF; C3 0·01μF; C4 0·01μF; C5 500 pF; VC1 250pF; VC2 1,000pF (2×500pF gang capacitor); RF chokes, 1mH to 2mH, V1 5763, 807, 6146, for approximately 8W, 15W, and 35–45W input. HT, 250V to 450V.

A preferable method is one in which a crystal oscillator drives the PA, which in turn supplies power to the aerial. The crystal oscillator, in Fig. 41, could be used for this purpose, and the coupling to the PA, and PA stage, could be as shown later. This would also allow the transmitter to operate on more than one band, with a given crystal.

The PA stage is occasionally run as a doubler, but this system is not recommended. It is preferable to provide doubling in an earlier stage, and to allow the PA to work 'straight through'. That is, the PA delivers the same frequency signal to the aerial, as applied to the grid.

When a VFO is used, it is particularly necessary to isolate the oscillator from the PA, to avoid changes in frequency. It is for this reason that a buffer stage is employed between VFO and PA. Crystal oscillators are less susceptible to change frequency with a change in loading conditions, and it is for this reason that a crystal oscillator may be employed alone, as a simple transmitter.

In small transmitters, a 2-valve circuit, consisting of crystal oscillator, followed by PA, is entirely practical and quite useful. If a VFO is used, a 3-valve circuit, consisting of VFO, buffer, PA, would be preferable. In a few much simplified transmitters, the VFO is allowed to drive the PA without a buffer stage, but this is likely to cause difficulties. In larger transmitters, a 4-stage circuit, employing oscillator, buffer-multiplier, driver, and PA, is largely used. More stages are seldom required for amateur equipment, except when individual multipliers are fitted for several bands. The VFO may itself have more than one valve. For example, it may consist of the variable frequency oscillator valve, followed by a low-power buffer. This assures that the frequency of the VFO is not influenced by loading or adjustment in later stages.

When the oscillator is too tightly coupled to the aerial or PA, its frequency will not remain stable. With a CW transmitter, this will result in a 'chirpy' signal, while the phone transmitter would suffer from undesirable frequency-modulation effects. An oscillator running at low power, and isolated by one or more buffer or multiplier stages, will be unlikely to suffer from these defects.

*Couplings*

RF coupling from one stage to the next is often provided by



means of a small capacitor, C in Fig. 45A. This is a simple and useful arrangement.

In Fig. 45B the tuning capacitor VC is connected to the grid circuit of the following valve, while the coil L remains in the anode circuit of the first valve. This allows the spindle of VC to be at earth potential, instead of being common to the HT positive line. The effective capacity across L now depends on the capacity of C, as well as VC, because these capacitors are in series. For example, if C and VC are both 100pF, the effective capacity across L is 50pF (*see* 'capacitors in series'). Both A and B are suitable for practical transmitters.

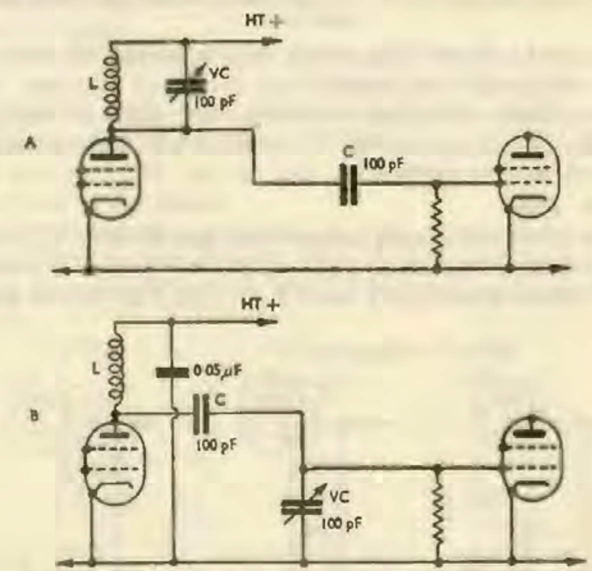



FIG. 45

Another method of coupling RF circuits is shown in Fig. 46, and is termed link coupling. The link winding L2 is connected to the link winding L3 by the twin feeder. Both windings are of similar inductance. RF energy in L1 is thereby carried to L4. This is particularly convenient when L4 is situated some distance from L1, as might arise in a transmitter constructed as separate units. To avoid effects due to stray capacity coupling, the link windings L2 and L3 are near the 'earthed' ends of L1 and L4, and one conductor of the feeder may be earthed. This, or a similar method, is useful for coupling a PA stage to an aerial tuner.

If either L1 or L4 were a push-pull or balanced circuit, the link winding would be at the centre. This would arise with a link

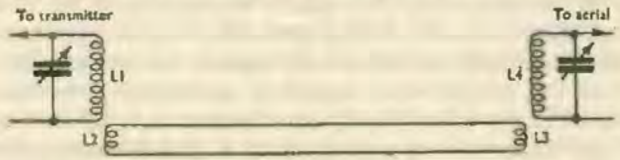



FIG. 46. Link coupling for use between valves or between transmitter and aerial tuner

winding used to couple to a tuning coil employed with twin tuned feeders, such as a tuned doublet.

The $\pi$ circuit, described elsewhere, also forms a method of coupling a PA to an aerial. The $\pi$ circuit is also occasionally employed between valves.

*Amplifier Bias*

In low power RF stages, cathode bias may be used. This bias is developed across a cathode resistor, R1 in Fig. 47A. The voltage may be found from Ohm's Law ($V = I \times R$). This system has the

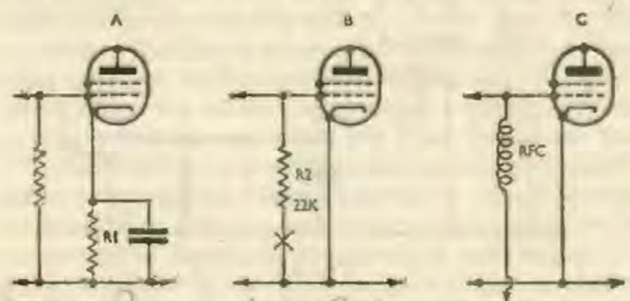



FIG. 47

advantage that bias will always be available, to protect the valve.

In stages where RF is present, such as an oscillator or buffer, bias is often obtained by grid rectification. This method is also used in PA stages of moderate power. Fig. 47B shows this circuit, R2 being the grid resistor across which bias is developed. A



meter may be inserted at the point X, to observe grid current. If R2 is 22K (a usual value) and RF drive is adjusted until the meter shows 2mA, then from Ohm's Law it will be seen that the bias is 44V.

Such circuits are popular, in view of their simplicity. The arrangement has the disadvantage that no bias voltage will be obtained if the RF drive fails. It is therefore necessary to tune the oscillator and other exciter stages (buffer, multiplier, or driver) until a suitable grid current has been obtained, before applying anode and SG voltages to the PA. Cathode bias, as in Fig. 47A, is not normally employed in PA stages, except for low power transmitters, because it is wasteful of HT voltage, when the bias required is high.

Bias for the PA stage may be obtained from a fixed voltage source, such as a battery or small power pack. The latter is more usual, and the same power pack as described for modulator bias may be employed. The bias is then applied as in Fig. 47C. The RF choke acts as a path for the bias. Sometimes a resistor may be used as well as the choke.

Many small transmitting valves can pass a very heavy current, if correct bias is not available. This current could very quickly damage or destroy the valve. Typical bias for some transmitting valves is:

| *Valve* | *Negative Bias Voltage* | |
|---|---|---|
| | *Telegraphy* | *Phone* |
| 5763 | 28V | 42V |
| 807 | 45V | 90V |
| 6146 | 65V | 87V |
| 813 | 150V | 160V |

*Metering*

It is necessary to check PA anode current, and probably other circuit currents. Separate meters may be used for this, as in Fig. 48A. Here, M1 shows the combined anode and SG current of the PA stage. The DC anode input must not exceed 10W on 1·8–2mc/s, or 150W on 3·5mc/s, 7mc/s, 14mc/s, 21mc/s, and 28mc/s bands. The DC input is the product of voltage × current. For example, if the stage draws 100mA at 300V, then $0{\cdot}1 \times 300 = 30$W. If the meter is to show anode current only, the SG resistor R1 can be transferred to the positive meter terminal. However, the SG current is usually small, compared with the anode current.

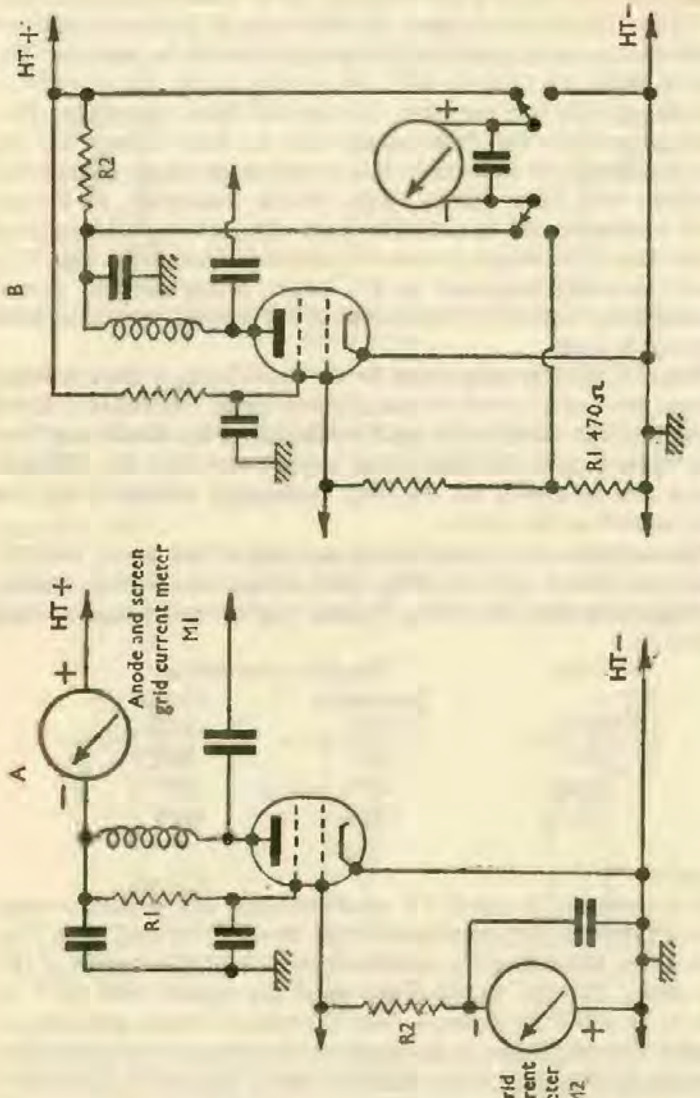



Fig. 48

Metering



M2, in Fig. 48A, shows the grid current, and with grid leak bias the grid drive would be adjusted to obtain the correct bias, as described. If fixed bias is used, the meter shows that the valve is receiving the best grid drive, even though the bias voltage is not dependent on this. Typical grid currents are listed later.

To avoid the use of several meters, one meter is often switched into several circuits, as required. A circuit of this kind is shown in Fig. 48B. R1, of relatively high resistance, completes the grid circuit, when the meter is not connected. When the meter is switched to read grid current, R1 has no significant effect on readings. R2 similarly completes the anode circuit, and is of such a value that it acts as a shunt for the meter. For example, the meter could be an 0–5mA instrument, and would show grid current from 0–5mA. But when switched in parallel with R2, the shunting of this resistor could result in the meter reading 0–250mA (or any other selected figure) so that it can deal with the higher currents in the anode circuit. The value of R2 can be found as described in the section on instruments.

Meter circuits may be provided for earlier stages, if needed. They may also be included to show modulator current, as a guide to modulation in a phone (speech) transmitter.

The meter or meters act as a check upon operation, to see that suitable grid current is obtained, and to assure that the anode current does not exceed a safe level.

### *Tetrode Amplifiers*

Tetrodes and pentodes are largely employed, as the screen grid avoids too much interaction or coupling between control grid and anode. Fig. 49 shows a typical tetrode amplifier, which may be used as the output stage of a transmitter.

A tetrode or pentode must not receive SG voltage when anode voltage is absent, or the SG dissipation may be exceeded, so that the valve is damaged. A similar result may arise if the SG voltage is too high. The SG voltage has a considerable effect on anode current, and this fact is utilized in SG modulation, which may be used in a speech transmitter.

A well designed tetrode or pentode stage will operate satisfactorily with grid and anode circuits tuned to the same frequency. Stray coupling between anode and grid circuits must be minimized, by the layout, and use of screening. This is generally simplified by the grid pin being at the base of the valve (under the chassis) and the anode cap being at the top of the valve (above the chassis). If there is too much stray coupling between anode and grid, the valve will oscillate.

The output of the oscillator, in Fig. 41, could be taken to the control grid of V1, in Fig. 49, to form a complete transmitter. Oscillator tuning would be adjusted until the grid current meter

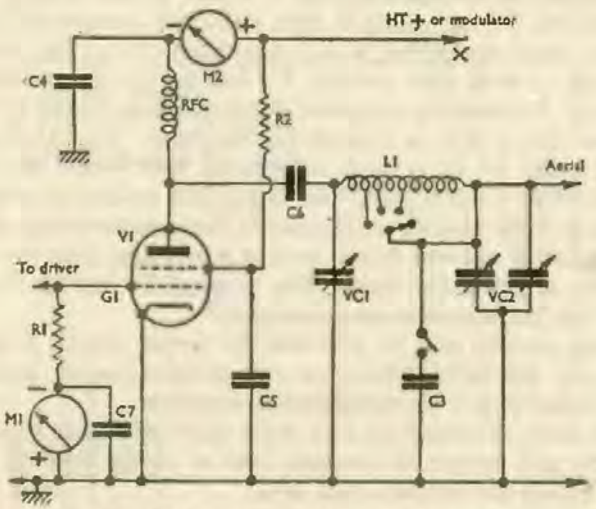



FIG. 49. Tetrode amplifier with π output

M1 indicates suitable grid current. The HT positive circuit to V1, in Fig. 49, may then be completed, and VC1 is adjusted until meter M2 shows a dip in anode current. RF energy is then being fed into the aerial, or into the lamp load previously described.

*Loading with π Tank*

VC1, L1 and VC2, in Fig. 49, form a typical π tank circuit. VC1 is frequently termed the PA, tank, or anode tuning capacitor, while VC2 is called the aerial loading or output capacitor. The π tank acts as an impedance matching network, in which a range of impedances in parallel with VC1 (input) can be matched to a range of impedances in parallel with VC2 (output). In the transmitter, the input impedance will depend on the PA stage. The output impedance load will depend on the aerial, or method of coupling it. Adjustments are directed towards securing a suitable



impedance match, so that the aerial loads the PA stage correctly.

If the PA stage is not sufficiently loaded, it will draw much less than normal HT current, and the power output of the transmitter will be small. To adjust this stage of the transmitter, the correct grid current is first obtained, as mentioned. HT voltage is then applied to the PA, and VC1 is adjusted until a dip in anode current shows that the tank is tuned to resonance. VC2 is initially closed, or at maximum capacity.

If the current shown by the meter M2 is too low, VC2 is opened slightly, and VC1 is readjusted for resonance, as indicated by the lowest meter reading on M2. This reading will be larger than before. If necessary, VC2 is opened farther, and VC1 again tuned to resonance. This is continued until the PA valve draws its rated anode current, with VC1 tuned to resonance. If a lamp load is being used, the lamp will grow progressively brighter; if an aerial is connected, the power radiated will increase. If VC1 is tuned off resonance, the current shown by M2 may be heavy, and this should be corrected immediately. VC1 is always tuned for minimum current, as shown by M2.

Should anode current be too high, with VC2 at maximum capacity, more capacity may be needed here, and this can be introduced by switching in a fixed capacitor C3. This may be necessary on low-frequency bands, if VC2 is itself of rather small value.

Should VC1 reach maximum capacity, before resonance is obtained, this can be cured by increasing the number of turns on L1. Or VC1 may be of too small capacity. Alternatively, it may be desirable to use an aerial tuner, so that the transmitter may be fully loaded into a lower impedance (VC2 nearly closed).

A ½-wave aerial, end-fed, will be high impedance, so VC2 will need setting to a fairly low capacity. A ¼-wave aerial, end fed, will be low impedance, so VC2 needs to be set at a high capacity. For intermediate lengths, VC2 will need setting between these limits. Aerials and coupling are dealt with later. The π output circuit is capable of working directly into many aerials, including some wires of random length.

Loading of a PA stage can also be accomplished by having a variable link near the coil, and adjusting coupling until the PA draws the required current. This method is much less used than formerly, because mechanical adjustment of the link is a little awkward. In addition, the π tank can help suppress harmonics which might cause television interference.

Typical component values and operating conditions for the circuit in Fig. 49 are: R1 22K; R2 27K; VC1 250pF; VC2 1,000pF (2-gang 500pF); C3 500pF (may not be necessary); C4 2,000pF; C5 2,000pF; C6 2,000pF; C7 0·01pF; RFC 2·5mH; L1 for band required, or tapped for several bands; V1 6146; grid current (M1) 2mA to 2·5mA; HT current (M2) loaded to 100mA at 500V= approximately 50W input. Alternatively, V1 807, grid current 4mA.

*Neutralizing*

When stray capacity exists between anode and grid circuits, and these are tuned to the same frequency, the valve may oscillate. To avoid this, the stage can be neutralized. This is not usually necessary with a well-designed tetrode or pentode stage, using a suitable transmitting type valve. But if an audio type output valve is used there will be more grid/anode capacity, and neutralizing will probably be needed. For the same reason (inter-electrode

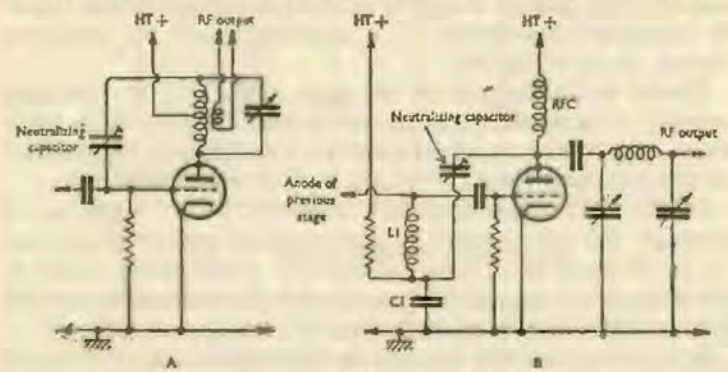



FIG. 50

capacity) neutralizing is required when using a triode, as there is no screen grid between control grid and anode. Triode output valves are little used in amateur transmitters. However, a means of neutralizing such a circuit should be known.

To neutralize such a circuit, a small amount of RF is deliberately fed back from anode to grid, in opposite phase to the undesired back coupling already present. One method of doing this is shown in Fig. 50A. Here, a centre tapped anode coil is employed. Feedback through the neutralizing capacitor is in opposite phase to any feedback due to the anode/grid capacity of the valve. A centre



tapped anode coil would already be present, if a push-pull output stage were used.

In Fig. 50B, a $\pi$ output circuit is used, so the method in Fig. 50A is impossible. Instead, the neutralizing capacitor is taken from the anode to the lower end of the grid coil L1, and the capacitor C1 provides bottom-end coupling.

When a stage is neutralized, tuning the anode circuit through resonance has little or no effect on grid current. So neutralizing may be effected by removing the valve anode and SG voltages, and applying grid drive. When the anode circuit is tuned through resonance, the grid current meter will show a slight dip in grid current. The neutralizing capacitor is adjusted to the value which results in the least dip in grid current, as the anode circuit is tuned through resonance. With Fig. 50A the neutralizing capacity will be similar to the interelectrode and stray capacity of the valve and circuit, and may only be a few pF. In Fig. 50B, the neutralizing capacity will be larger, due to C1.

The PA or other RF amplifier should not oscillate by itself, when normally tuned. If it does, layout or neutralizing may be defective. If such stages oscillate themselves, they can radiate on incorrect frequencies.

*Parallel Amplifiers*

It is quite common to use two valves in parallel, for a PA stage, to obtain greater power. Such a stage is shown in Fig. 51A. Grid

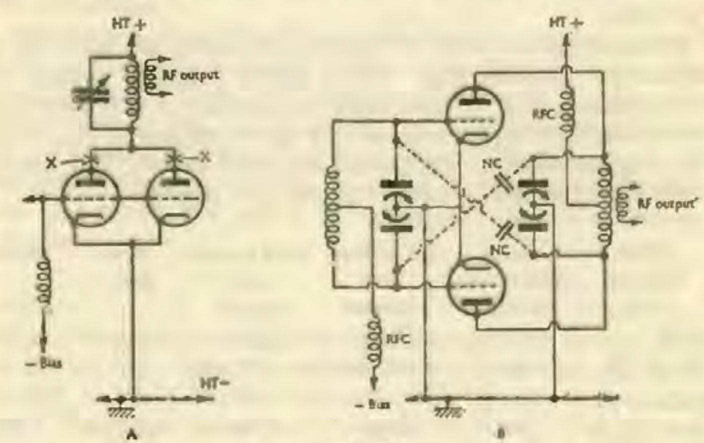



FIG. 51

drive requirements will be twice those of a single valve, and anode, SG and heater currents will also be double those of one valve. The power input to the stage can be twice that for a single valve of the same type.

With two valves in parallel, some slight adjustment to tuning capacitances, or coils, may be necessary. This is due to the extra stray capacity, both in the valves themselves, and in their holders and wiring.

Tetrodes are often employed in parallel. The screen grids are then joined, and receive current through a common SG resistor. Such valves will usually not require neutralizing. Triodes require neutralizing, as with a single valve, though the neutralizing capacity will be a little higher.

*Push-pull Amplifiers*

These are not much used in amateur equipment, due to the disadvantage of requiring centre tapped grid and anode tank coils. A push-pull PA circuit is shown in Fig. 51B. It will be seen that the grids receive drive 180 degrees out of phase, from the centre tapped grid coil, and the outputs are combined in the centre tapped anode coil.

With a push-pull circuit, a symmetrical layout is preferred, and each valve should closely match the other, and be operated under identical conditions. Triodes are neutralized as shown by the dotted lines, the neutralizing capacitors being indicated at NC.

*PA Valves*

Power amplifiers, used to energize the aerial, are generally of tetrode or pentode type. These valves generally require no neutralization, and the grid drive requirements are smaller than for triodes. Operating conditions for valves commonly used in the PA stage of amateur equipment are given below. The smaller valves are often used singly, or in pairs, in parallel.

| *Valve Heater rating* | *Anode voltage and current* | *SG voltage and current* | *Grid voltage and current* | *Grid Drive* | *Output* |
|---|---|---|---|---|---|
| 5763<br>6V 0·75A | 350V<br>48mA | 250V<br>6·2mA | 28V<br>1·5mA | 0·1W | 11W |
| 807<br>6·3V 0·9A | 750V<br>100mA | 250V<br>6mA | 45V<br>3·5mA | 0·23W | 50W |



| *Valve Heater rating* | *Anode voltage and current* | *SG voltage and current* | *Grid voltage and current* | *Grid Drive* | *Output* |
|---|---|---|---|---|---|
| 6146<br>6·3V 1·25A | 750V<br>120mA | 160V<br>11mA | 60V<br>2·5mA | 0·2W | 70W |
| 813<br>10V 5A | 1,000V<br>150mA | 250V<br>28mA | 150V<br>10mA | 2·5W | 110W |

For the three smaller valves, these are maximum ratings, and it is quite in order to use them at lower anode and SG voltages. With the 813, input must not exceed 150W, though the valve could be used with greater inputs. When using the valves in a telephony transmitter, the above ratings are reduced by roughly 20 per cent.

*Parasitics*

These are unwanted oscillations, possibly of brief duration, and may cause interference. They denote instability. This may arise when a valve is operating with a high voltage, as on modulation peaks in a phone transmitter. Or the trouble may be more persistent, and remain when no modulation is present, or may arise in a CW transmitter.

One cause is stray capacity and circuit wiring forming an oscillatory circuit. Anti-parasitic chokes or stoppers are very often added in the PA stage. Such stoppers may consist of a low value carbon resistor (say, 30–100 ohms) and a small choke consisting of 5 or 6 turns of wire, often wound round the resistor, or to a diameter of about ¾in. In Fig. 51A, such stoppers could be added near each anode, at X and X. For a single valve, only one stopper is needed.

*Keying*

The RF output of a CW transmitter is switched on and off by the Morse key – the transmitter radiates only when the key is pressed. If the transmitter were switched on and off instantaneously, the Morse signal would appear as at A in Fig. 52. This method of working would cause interference in the form of key clicks, due to the abrupt interruption of the RF wave. These key clicks are momentary spurts of RF energy, radiated over a band of frequencies, and they may be heard at frequencies considerably removed from the frequency upon which the transmitter is operating.

To avoid key clicks, the RF should rise rapidly to maximum, remain here for the duration of the dot or dash, and fall rapidly to zero, as represented at B. Various methods are used to help achieve this.

A long rise and decay must not be present, or the signals would resemble C, and would be very difficult to read, especially if sent at speed.

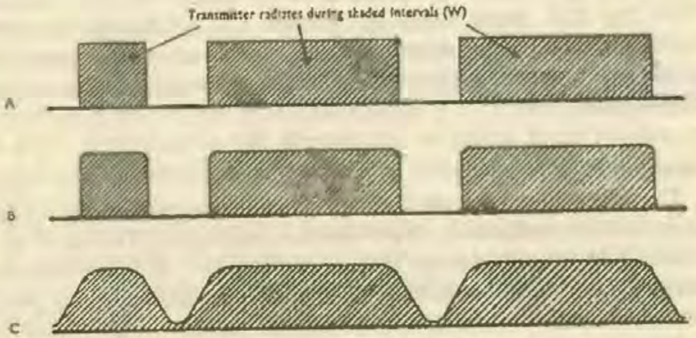



FIG. 52. Shape of Morse characters with various types of keying

Another fault which may be introduced by keying is 'chirp'. This is a change in frequency of the transmitter. When such a signal is received, it is heard as a series of chirps, as the word suggests, instead of as an interrupted audio tone of stable frequency.

If an oscillator is keyed, the oscillator is repeatedly stopped and has to start up again, and this is likely to cause chirp. A keyed crystal controlled oscillator is, however, much less likely to suffer from bad chirp, than is a variable frequency oscillator.

If the oscillator stage is left running, and a buffer or amplifier stage is keyed, the oscillator frequency will remain unaffected, if the keyed stage is well isolated from the oscillator. This is therefore a good method.

It is also possible to key the PA. This is feasible in low or



moderate power equipment, but is less popular with higher power, in view of the high current which may have to be interrupted. To avoid high voltages on the key, a keying relay may be incorporated in the circuit.

A transmitter is thus generally keyed at a position where there is relatively small power, but probably not in the oscillator stage. In addition, a capacitor or choke, or both, may be used in the key circuit, to avoid the too instantaneous rise and fall of the RF (fault A in Fig. 52). This is termed a key click filter.

*Cathode Keying.* A simple, popular method is to insert the key in the cathode circuit of a stage where only moderate power is available, as in Fig. 53A. The capacitor C helps avoid key clicks. Such keying is sometimes used with quite high power. The valve may be a triode, tetrode, or pentode. A high value resistor may be wired from cathode to chassis line, to avoid the cathode

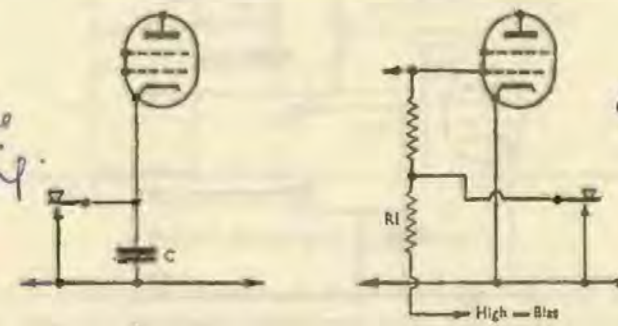



FIG. 53

voltage becoming dangerously high, when the key is open. A PA stage running up to perhaps 50W may be keyed in this way.

*Grid Block Keying.* With this method, sufficient bias is available to block the keyed stage, so that it ceases to operate. A typical circuit is shown in Fig. 53B. When the key is pressed, the blocking bias is shorted, and the stage operates. R1 is merely to avoid shorting the source of bias. The method has the disadvantage that a source of bias is required, and this may need to be of quite high voltage, in order to cut off the valve.

*SG Keying.* A valve with screen grid can be cut off by removing the positive SG voltage, and taking the SG to a zero or negative supply. The key can be arranged to do this, as in Fig. 54. For complete cut-off, the screen grid generally requires to be made negative.

A modification of this method is used in PA stages, where the SG is controlled by a clamp valve. In this type of circuit, the transmitter is keyed at an earlier stage. When the key is up, absence of RF results in the clamp valve conducting, making the PA voltage very low. This works effectively even if the PA anode current does not fall completely to zero, as the stage is only acting as an amplifier, and has no output in the absence of the RF drive.

A SG clamp circuit is shown in Fig. 55. When the normal RF drive is available from the oscillator and exciter stages, grid rectification in the PA results in a voltage drop across R1, so that

Screen Grid Keying

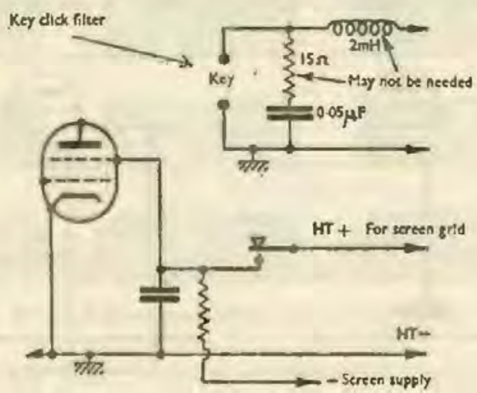



Fig. 54

the control grid of the clamp valve is negative. The clamp valve thus passes little anode current, and the PA SG voltage is normal. In these circumstances, the PA is amplifying the RF applied to its control grid, and the transmitter is radiating.

When a buffer or other stage is rendered inoperative, by releasing the key, RF drive to the PA ceases. In these conditions, the PA stage might pass a very heavy current. However, the absence of RF drive results in the bias voltage no longer being developed across R1. The clamp valve control grid thus becomes positive, and the clamp valve conducts heavily, causing a large voltage drop in the SG resistor R2, so that the SG voltage falls, and the PA



anode current is reduced to nearly zero. Such a method of keying is not unusual, in fairly high power transmitters. The clamp valve is also a safety device, since it cuts off the PA stage if the RF drive to the PA valve grid should fail for any reason and it is thus found in some phone transmitters.

A CW transmitter may be operated with a send/receive switch, in the same way as a phone transmitter. This allows periods of transmission and reception, in the usual way.

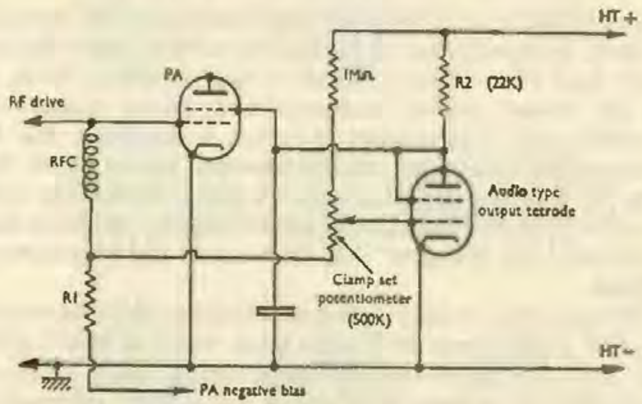



Fig. 55. Screen grid clamp circuit

A CW transmitter may also be worked on the 'break-in' system. Here the receiver is permanently operating and either station can signal to the other, at any time, in the interval between the reception of characters. This allows rapid queries regarding missed characters or other points. With this system, the transmitter oscillator needs to be very effectively screened indeed, or must be inoperative when the key is up, or the receiver may be blocked by this local source of RF. With break-in keying, the oscillator stage is often keyed with the other stages. If the oscillator has a stabilized HT supply, and is well isolated by buffer/amplifier stages, objectionable chirp or other faults may be avoided, though there is less latitude than when the oscillator need not be keyed.

Various other keying systems also exist. Most are intended to obtain some particular advantage. They are probably of most interest to the CW enthusiast.

CHAPTER SIX

# Microphones, Amplifiers, Modulators, and Power Packs

IN AN amplitude modulated telephony transmitter, the strength of the radio wave is varied, or modulated, so as to carry the audio signal. Such transmitters are used to send speech or music, etc., and are termed 'phone' transmitters. A phone transmitter is essentially a CW transmitter to which a modulator has been added. A CW transmitter can be converted into a phone transmitter by adding a modulator, and a phone transmitter can be used for CW by leaving the modulator switched off. Most phone transmitters are employed with both voice and Morse key, as required.

Fig. 56A shows a steady carrier wave (such as would be produced by a CW transmitter). At B is an audio wave, or steady audible tone. At C, the carrier has been modulated to nearly 100 per cent by this tone. If the signal were tuned in on a receiver, the audio tone could be recovered and made audible by the detector, or demodulator, as explained in the section on receivers.

This method of modulation, in which the carrier is varied in strength from nearly zero to a maximum whose peaks may be nearly twice those of the unmodulated carrier, is termed 'amplitude modulation' or AM. It is the system used by ordinary medium and long wave broadcasting stations, and it is very much used by amateur stations. Other methods of modulation exist, but it is better to study them later.

The modulator resembles an audio amplifier, such as might be used with a record player or microphone. If modulation is applied to one of the control electrodes of the PA of the transmitter (such as control grid or screen grid) much modulation power is not required, and an amplifier delivering a few watts will do. But if anode modulation is used, the modulator needs to be able to deliver about one-half the PA stage input. For example, a 100W transmitter would need a 50W modulator. Anode





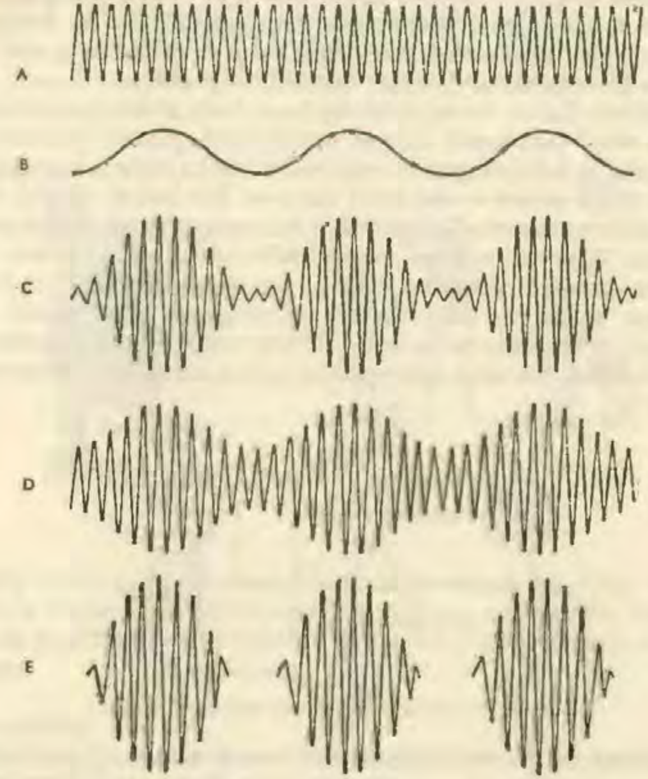



FIG. 56

modulators are thus generally more powerful than audio amplifiers which would be used for domestic purposes.

*Microphones*

A knowledge of the working principles of the most generally used microphones is necessary. All have particular advantages and limitations.

*Crystal Microphones* are much used, and contain a piezo-electric crystal, which is stressed by sound waves reaching the microphone. This produces an electrical output, which will be amplified to the required level. Such mikes are of quite low cost, give good speech quality, require no matching transformer or battery, and can be coupled directly to the first valve, as in Fig. 57. Sizes, shapes, and exact details of the microphones vary considerably. A screened microphone lead is used, to avoid pick-up of RF or hum, and the outer brading of this lead is returned to the chassis.

*Moving Coil or Dynamic Microphones* have similar construction to a small permanent magnet moving-coil speaker. The coil is attached to a diaphragm or cone, and is free to move in a magnetic gap. When sound waves cause the cone and coil to vibrate, this produces an electrical output. Such microphones give good quality results. They are not necessarily preferred to crystal mikes, for communication purposes, because an extremely high level of speech quality is not required. Moving-coil microphones are usually of low impedance, so a coupling transformer will generally be required. But some microphones have a miniature transformer built in.

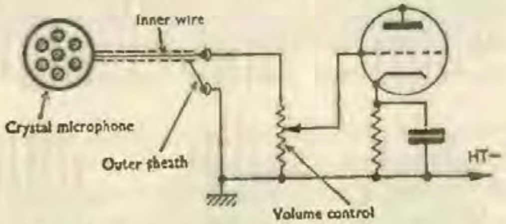



FIG. 57. Crystal microphone and input circuit

*Ribbon or Velocity Microphones* have a ribbon of conductive foil suspended between magnetic poles. Vibration of this ribbon produces an electrical output. The output is not very great, and they are not extensively used. Quality is good. A matching transformer is needed.

*Ceramic Microphones* resemble the crystal types, except that a piezo-electric ceramic material is used, instead of the crystal. Working is similar.

*Carbon Microphones* do not in themselves generate any output, but they act as a varying resistance to direct current, which may be obtained from a battery or other source. Such a mike is shown in Fig. 58. The carbon granules are loosely packed between two electrodes, one of which is attached to the diaphragm. As sound waves strike the diaphragm, pressure on the granules varies, so that a fluctuating current flows from the battery through the mike



and transformer primary. The transformer often has a step-up ratio of 1:50 or 1:100. A carbon microphone, with transformer and battery or other source of DC, gives quite a large output, so that simpler amplifiers, with fewer valves, are possible. Speech

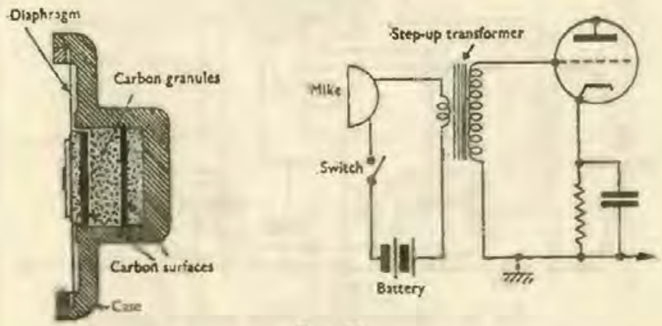



FIG. 58

quality is less good than with the types previously described. To avoid a battery and transformer, the cathode current of a valve may be passed through the mike, the control grid being earthed to chassis.

### *Pre-amplifier*

This is the first stage in an audio amplifier, and is occasionally constructed as a separate unit. It usually furnishes high gain, and should have a very low hum level.

When the whole equipment is built as a single unit, as is more usual, this stage will be the first in the amplifier, and a typical circuit is shown in Fig. 59. Such a stage is also termed a 'voltage amplifier' as its purpose is to raise the signal voltage to a level where it can operate a later stage. A triode may be used – often one section of a double triode, the second section of which furnishes additional amplification. A high-mu (high gain) triode would be usual.

Typical values for Fig. 59 are: V1 6BR7; R1 500K volume control or 470K fixed resistor with volume control in later stage; R2 1 megohm; R3 220K; R4 1·5K; R5 22K; C1 0·1$\mu$F; C2 50$\mu$F; C3 0·005$\mu$F; C4 8$\mu$F.

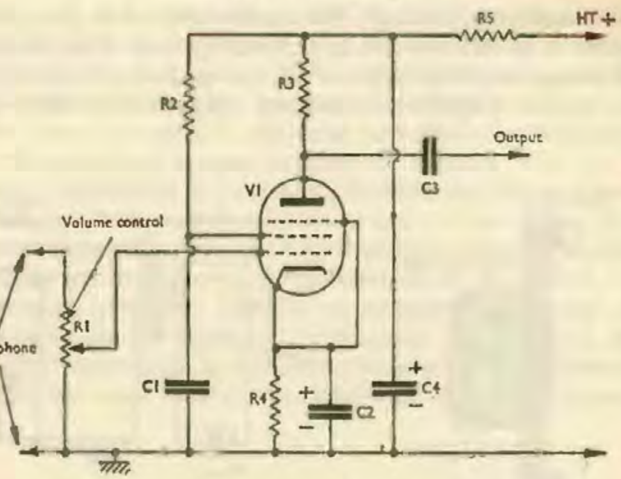



FIG. 59. Pre-amplifier or first audio stage

*Small Modulator*

Fig. 60 shows the circuit of a small modulator. The output would depend on the valves and HT voltage. It may be used to anode modulate a transmitter in which the PA input is about twice the modulator output. Or it could be used to screen grid modulate a much larger transmitter.

A crystal mike is indicated, and R1 and C1 help to prevent stray RF reaching the valve grid. R2 is the grid load of V1A. V1A and V1B are two sections of a double-triode, with the volume control R4 connected between stages. R6 provides cathode bias for V1B. C5 and R7 give additional smoothing to the HT supply, and prevent back-coupling through the HT circuit.

A crystal microphone giving a fairly high output is required. If a carbon mike were used, V1A could be omitted, and the microphone transformer secondary could be connected to R4.

Early stages, such as V1A and V1B, are sometimes termed the 'speech amplifier' to distinguish them from later stages, which may be called the 'power amplifier'. Generally, however, early stages can be termed voltage amplifiers. These stages are not called upon to deliver appreciable power. But later stages will

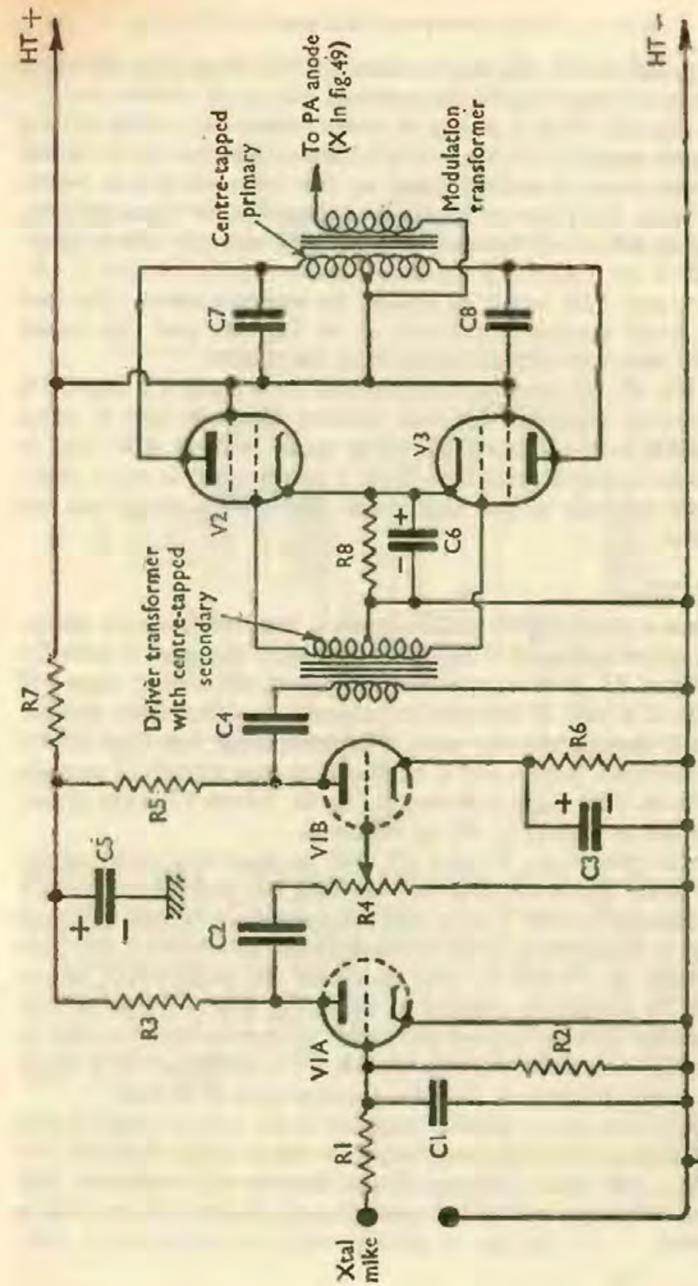



FIG. 60

have to deliver suitable power, either to drive the push-pull output stage, or to modulate the transmitter.

In Fig. 60, V1B is acting as driver, since only small driving power is required for V2 and V3. This is satisfactory for a 5W modulator (e.g. for Top Band) or for other fairly low power equipment. But when outputs in the order of 60–80W are required, a further valve will be used between V1B and the driver transformer.

V1A and V1B could, of course, be separate valves. The first stage could employ a pentode, as in Fig. 59, and this would furnish even more amplification than the triode.

In Fig. 60, R8 provides cathode bias for V2 and V3, and C6 is the by-pass capacitor for this resistor. Cathode bias is often employed in modulators delivering up to perhaps 40W, but in larger modulators, fixed bias, from a power pack, is more usual. C7 and C8 help to cut high audio frequencies, which are not required.

*Larger Power*

When a much higher audio output is required from the modulator, appreciable power has to be applied to the control grids G1 of V2 and V3. In most amateur equipment, the output stage will consist of a pair of tetrodes or pentodes, and the drive requirements of these is not very great. The driver stage thus need deliver only moderate power, and a small output type tetrode or pentode is suitable. This stage is shown in Fig. 61, where V3 is the driver, connected to V1B (Fig. 60) as indicated.

The output stage, V4 and V5, will be operating under conditions where grid current flows (*see* Class B2) and the grid circuit will consume power. This is why a stage able to furnish sufficient power is required in these circumstances. In addition, the load presented by V4 and V5 will vary over the audio cycle, so the driver V3 should be capable of operating over a range of load conditions. Triodes are less critical in this respect than tetrodes or pentodes, and this is why the tetrode V3 is connected as a triode (anode and SG joined). Triodes are also used as drivers.

The driving power actually required by the output stage (V4 and V5) will depend on the output of the stage, type of valves, HT voltage, and other factors. If the output stage delivers only moderate power, and grid current is small, little driving power is required.



In Fig. 60, the driver transformer primary is fed through C4. This is suitable for small transformers of high primary inductance. In Fig. 61, the primary is wired from anode to HT line, and then has to carry the anode (and SG) current of V3. This is usual with small power tetrodes and pentode drivers, so that they may receive adequate voltage.

Typical values for Fig. 60 are: R1 4·7K; R2 2·2 megohm; R3 470K; R4 500K volume control; R5 100K; R6 4·7K; R7

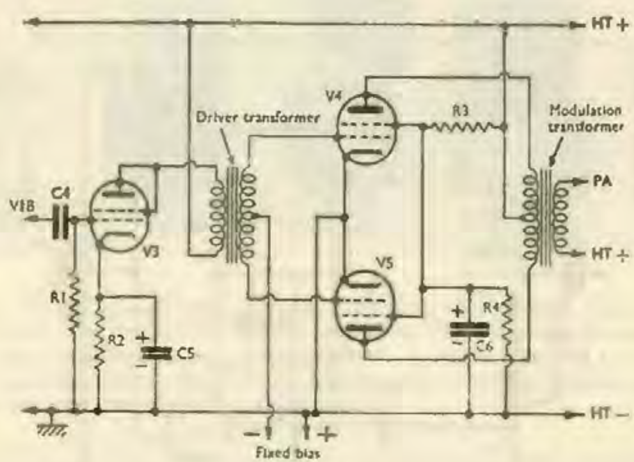



FIG. 61

47K; R8 240 ohms; C1 100pF; C2 500pF; C3 25$\mu$F; C4 1,000pF; C5 8$\mu$F; C6 50$\mu$F; C7 2,000pF; C8 2,000pF. V1A and V1B 12AX7; V2 6BW6; V3 6BW6. HT 285V. Output 12W.

Suitable values for Fig. 61 are: C4 1,000pF; C5 50$\mu$F; C6 8$\mu$F; R1 470K; R2 680 ohms; R3 4·7K; R4 47K; V3 6CH6; V4 6L6; V5 6L6. HT 360V. Bias 23V or 250 ohm common cathode bias resistor; output 24W, or: V4 807; V5 807. HT 600V. Bias 30V. Output 40W.

*Phase Splitting*

The grids of two valves in a push-pull output stage are driven 180 degrees out of phase. That is, one grid is receiving a positive signal, when the other is receiving a negative signal. To achieve this, some method of phase splitting is required.

A driver transformer with a centre tapped secondary can be used to supply audio to the output valves, as in Fig. 60 and Fig. 61. This method is often used, with output stages delivering up to the maximum required for amateur purposes; that is, 75–80W or thereabouts.

It is also possible to use a valve as a phase splitter, as in Fig. 62. This avoids the need for a driver transformer, but requires a few more other components.

The signal voltage at the anode of a valve is 180 degrees out

Phase Splitter

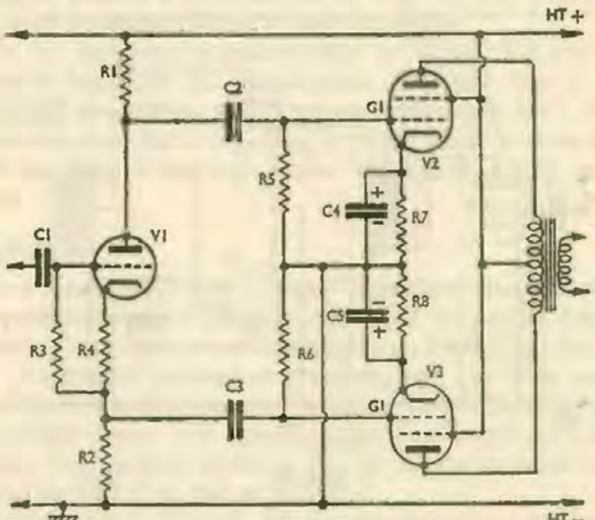



FIG. 62

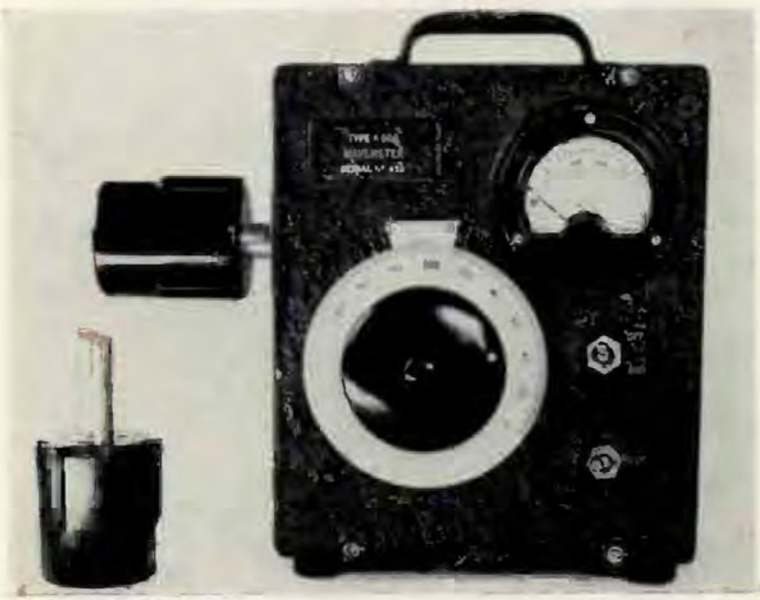
of phase with that at the cathode, and is of about equal magnitude, with a circuit like that in Fig. 62. R1 is the anode resistor, and R2 the cathode resistor, so that audio signals may be taken to the control grids G1, via C2 and C3. C1 provides coupling to an earlier stage, such as V1B in Fig. 60. R3 is the grid resistor, and R4 the bias resistor, of V1 in Fig. 62. R5 and R6 are grid resistors for V2 and V3, R7 and R8 providing cathode bias.

Such a circuit is particularly suitable for small and moderate power modulators, where the drive requirements of V2 and V3 are not very large. The triode is often one section of a double-triode, the remaining section being used in an earlier stage.

Typical values for Fig. 62 are as follows: C1 1,000pF; C2

8. *Above* Receiver and transmitter valves: 1, B7G double triode; 2 5U4G full-wave rectifier; 3, 807 (top anode cap); 4, 6146 (top anode cap); 5, 6BW6 miniature output tetrode. 9. *Below* DX-40U 10 to 80 metre transmitter, 75 watts CW, 60 watts peak controlled carrier phone. (Heathkit Daystrom Ltd., Gloucester.)

10. *Above* Absorption meter, as described in chapter on measurements.
11. *Below* Surplus type absorption meter, with plug in coils, vernier dial, and 250uA meter to show resonance.





0·01μF; C3 0·01μF; C4 50μF; C5 50μF; R1 100K 2%; R2 100K 2%; R3 1 megohm; R4 3·3K; R5 470K 2%; R6 470K 2%; R7 270 ohms; R8 270 ohms. V1 half of 12AX7; V2 6BW6; V3 6BW6. HT 250V. Output 9W.

*Output Stage Bias*

Bias may be obtained by means of cathode resistors, as in Fig. 62, or by means of a single resistor common to both cathodes, as in Fig. 60. This is a simple and convenient system, but is wasteful of HT voltage. It is used in small amplifiers, where adequate HT is available, and where a very high bias voltage is not needed.

In large power stages, some form of fixed bias is generally employed. This could be from a battery, being applied through the driver transformer secondary. However, batteries are seldom used, the voltage generally being obtained from a small power pack, or bias pack. The bias supply is then obtained from a mains transformer, with a metal or valve rectifier, and smoothing resistor and capacitors. To economize in components, suitable tappings may be provided on a transformer used for some other purpose. The circuit can be as shown for HT power packs, except that the polarity of the rectifier and smoothing capacitors is reversed, since negative bias is required. In Fig. 61, the driver transformer centre tap is taken to the bias circuit. The bias voltage may be obtained from a variable potentiometer, or potential divider, so that the exact figure can be adjusted. Some typical fixed bias voltages, for various valves and operating conditions, are as follows:

| | *Anode Voltage* | *SG Voltage* | *Bias Voltage* | *Output* | *Optimum Load* |
|---|---|---|---|---|---|
| 2 × 807 | 600V | 300V | 30V | 80W | 6·4K |
| | 600V | 300V | 27·5V | 47W | 10K |
| 2 × 807 with 270 ohm bias resistor | 500V | 300V | — | 32W | 9K |
| 2 × 6L6 with 250 ohm bias resistor | 360V | 270V | — | 24W | 9K |
| | 250V | 250V | — | 13W | 5K |
| 2 × 6BW6 with 260 ohm bias resistor | 285V | 285V | — | 12W | 8K |

The same bias pack is often used to provide fixed bias for the power amplifier in the RF section. By using suitable potential dividers, the modulator output stage and PA stage may each receive the correct value of bias. Typical bias voltages for various PA stages are given in the section on CW transmitters. The bias pack should make available the higher of any two bias voltages required, after allowing for voltage drop in smoothing circuits. The lower bias voltage (e.g. for modulator) may then be readily obtained by a potential divider or potentiometer.

*Output*

The modulator output stage is generally a pair of valves, as already shown. The stage uses valves and HT voltage to give the output required. Maximum permitted amateur power is 150W input to the PA. For 100 per cent anode modulation of this input, with a sine wave, 75W of audio power would be required. However, there are losses in the modulation transformer, so that the modulator would actually need to deliver a little over 75W, for 100 per cent sine wave modulation. On the other hand, modulation is not carried out to quite 100 per cent, because over-modulation may cause interference. In addition, voice modulation, if peaking up to near 100 per cent on the loudest syllables, will have an average level considerably lower. For these reasons, it is generally considered about adequate to use a modulator able to provide one-half the PA input, despite losses in the modulation transformer.

If the modulator were capable of a greater power output than required, this would be no disadvantage, except that larger components and higher voltages might be required, so that the modulator would be more expensive. The output of the larger modulator would be kept down to that needed for nearly full modulation of the PA.

Forms of grid modulation require very much less power, so that an economic modulator may be used. Some of the more popular modulation systems are described later. A grid modulator need not use a push-pull output stage, because a single output valve, such as might operate the loudspeaker in a radio receiver, can deliver enough power. In fact, single valves, as Class A modulators, are often used in economically designed equipment. When little modulation power is required, and a single valve is used, this valve is employed under conditions which allow it to



conduct over the whole of the audio cycle. That is, Class A operation, as described in Chapter Three.

Choice of valves for the modulator output stage will depend on the output wanted. The anode modulation requirements of a small transmitter will clearly be much less than those of a large transmitter. For example, only 10W input is permitted on 1·8–2mc/s and a very small modulator will suffice, compared with the 70–80W modulator which would be used with a 150W transmitter.

*Modulator Matching*

The load presented to the modulator will depend on the working conditions of the PA stage. For example, a small PA stage, drawing little current, will have a much higher impedance than a large stage passing a heavy current. For proper results the modulator output stage is matched to the PA, in a similar manner to that employed when matching an output stage to a loudspeaker.

The modulation impedance of the PA stage, for anode modulation, can be found from:

$$\frac{\text{PA anode voltage}}{\text{PA anode current}}$$

For example, assume the PA anode potential is 400V and the stage draws 30mA when loaded by the aerial. (30mA = 0·03A.)

$$\frac{400}{0 \cdot 03} = 13{,}300 \text{ ohms (approximately)}$$

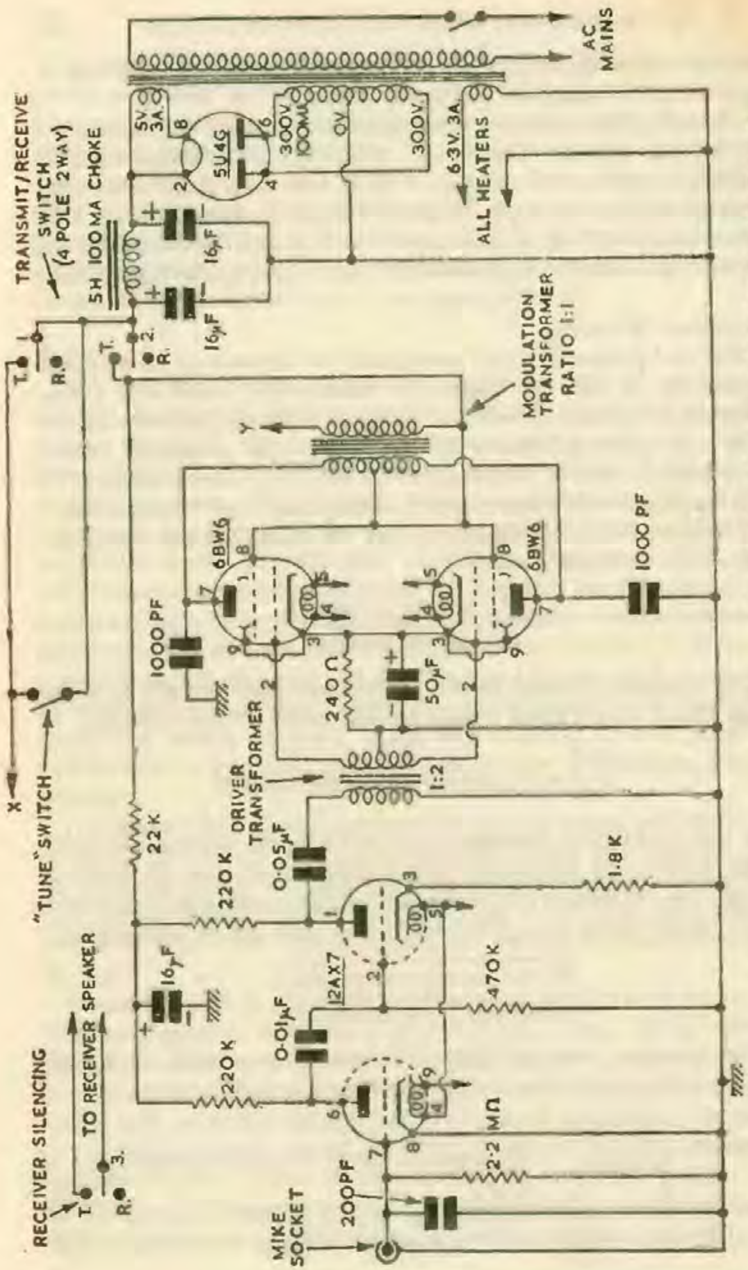
If the modulating impedance of the PA is the same as the optimum load of the modulator, a 1 : 1 transformer can be used to couple the modulator to the PA. But if the impedance is different from the optimum load, the transformer ratio can be found from:

$$\sqrt{\frac{\text{PA modulation impedance}}{\text{Modulator optimum load}}}$$

For example, assume the modulator uses a pair of 6BW6 valves, the optimum load of which is given as 8,000 ohms.

$$\text{Ratio} = \sqrt{\frac{13{,}300}{8{,}000}} = \sqrt{1 \cdot 7} \text{ approximately} = 1 \cdot 3 \text{ approximately}$$

So the modulation transformer would require to be of 1 : 1·3 ratio. It would need to have a wattage rating at least equal to the




Modulator and Power Pack for 160–80M transmitter, p. 97. 'Tune' switch applies HT to VFO and buffer only



power to be handled. The PA input is $400\times0{\cdot}03=12$W, so about 6W will be needed from the modulator.

Modulation-transformers to suit any required power are obtainable. Some models have tapped windings, so that a wide range of optimum load conditions can be matched to any PA.

### *Speech Tailoring*

Before considering modulation methods, the response characteristics required should be noted. If the transmitter were broadcasting musical programmes, the best possible reproduction over a wide range of frequencies would be required. It would thus be necessary for high fidelity circuits to be used. However, the main voice frequencies fall in a relatively narrow band, and the Amateur transmitter is mainly concerned with intelligibility, and 'good' quality reproduction. So if the modulator performs well over this frequency range, results are satisfactory.

It is generally considered that a very wide frequency response is undesirable, because it increases the width of sidebands, and complicates modulator design. So to curtail amplification of low frequencies, coupling capacitors (such as C2 in Fig. 60) are often of relatively small value. To curtail high frequencies, capacitors are often placed in parallel with the modulator transformer (C7 and C8, Fig. 60). The general result, for the average voice, is not very apparent. But this does mean that modulator circuits or values may be found to differ slightly from those used in radiogram or other high-fidelity systems.

### *Anode Modulation*

For anode modulation, the modulator is coupled to the anode of the PA stage, as shown in Fig. 63. Here, the PA is receiving grid drive from the oscillator, exciter, or driver, as described for a CW transmitter, and is delivering RF into a $\pi$ network tank, or other tuned circuit, coupled to the aerial. The primary of the modulation transformer T1 is connected to the modulator output valves, as in Fig. 62. HT current for the PA passes through the secondary of this transformer.

For one complete audio cycle, with nearly 100 per cent modulation, the modulator will drive the PA anode voltage from its normal figure up to nearly twice this voltage, then down to nearly zero. This results in the RF output building up to a high level, and then falling away towards zero, as shown in Fig. 56.

If the modulator does not deliver enough power, the radiated signal will resemble D in Fig. 56. This is much less than 100 per cent modulation. Alternatively, if too much modulation were used, the wave would be broken, as at E. This is 'over-modulation'. Methods of determining modulation percentages are given in the section on measurements.

If the output of the modulator is not symmetrical, it is possible for upwards peaks of modulation to be greater than the downward dips, or vice versa. More than 100 per cent downwards modulation must never be permitted (E in Fig. 56).

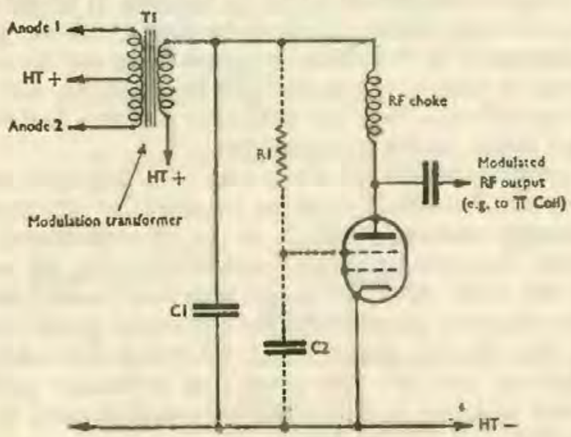



FIG. 63

Tetrode valves are often used in the PA stage, and modulation is then usually applied to both anode and screen grid, by adding the SG circuit shown dotted in Fig. 63. Capacitors C1 and C2 are of fairly low value (say, 2,000pF) to avoid too much loss of high audio frequencies. R1 drops the HT voltage to a level suitable for the valve SG.

The total modulating power required is actually that of the anode and SG, but the power required by the SG is very small, so this causes no difficulty. Fig. 63 shows a method which is very much used in good class amateur equipment. It is usually termed 'anode and screen' modulation, 'plate and screen' modulation, or 'high level' modulation, to distinguish it from systems using little audio power (e.g. grid modulation).



*Heising Modulator*

A Heising or choke modulated circuit is shown in Fig. 64. It is particularly suitable for small transmitters, where a single output type valve, in Class A, can furnish enough modulating power. V1 is the modulator, and is similar to the output stage in a domestic receiver. The audio output is developed across the choke L1, and the PA V2 draws its current through the resistor R1. The modulation impedance of the PA should be somewhat similar to

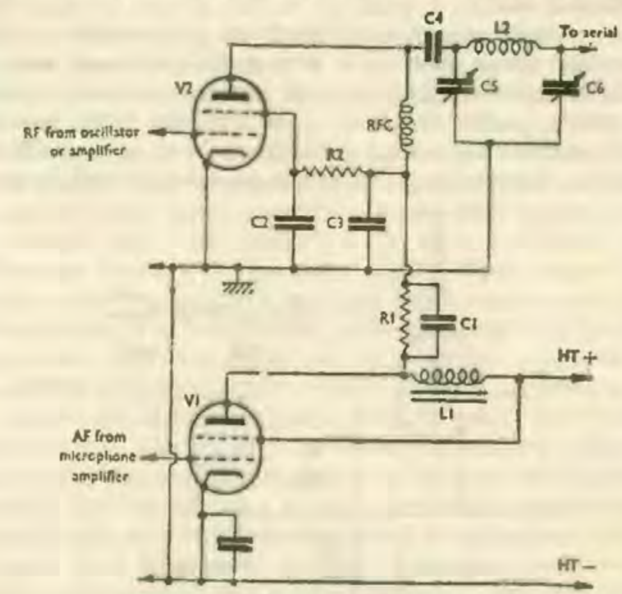



FIG. 64. Heising or choke modulation

the optimum load for V1. C1 is an audio by-pass capacitor across R1. R2 is the usual SG resistor, C2 and C3 being by-pass capacitors. C4 is the coupling capacitor to the output tank circuit formed by C5, L2 and C6, as described for CW transmitters.

In normal Class A operation of V1, the anode voltage never swings completely to zero. If R1 and C1 were omitted, over-modulation in a downward direction would thus be impossible, and the general modulation level might be rather poor. To increase the depth of modulation, resistor R1 drops the PA voltage. As the PA is working with reduced voltage, it can be more fully modulated by V1.

Heising modulation is practicable and satisfactory in small equipment, but it is not used in large transmitters, because the required audio power is more economically obtained from a push-pull output stage. If V1 were a fairly large power valve, good modulation is possible with V2 running at inputs of up to 6–12W or so. V1 might be a 6BW6, 5763, 6L6, or other typical power pentode or tetrode.

*Grid Modulation*

Various forms of grid modulation are quite popular, and the modulation power required is very small, compared with that needed for anode modulation. It is, however, less easy to obtain good speech quality. In addition, the apparent 'audio power' of a grid modulated transmitter is less than with an anode modulated transmitter, because in the latter the power output of the modu-

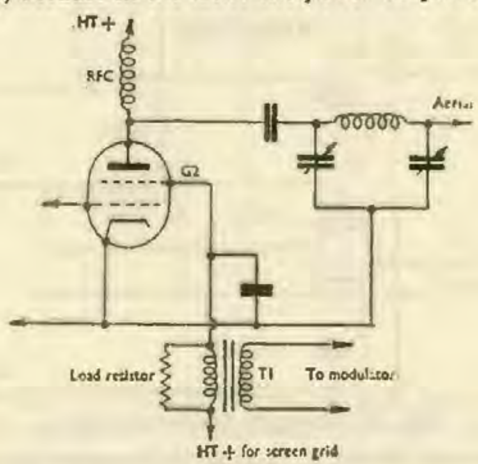



FIG. 65

lator is added to that obtainable from the PA. Despite these limitations, grid modulation is extensively employed, in low-cost or small equipment.

*SG Modulation.* Modulation may be applied to the PA screen grid, the anode not being modulated. A circuit for this purpose is shown in Fig. 65. T1 is the modulation transformer, connected in the HT circuit to the screen grid, G2. The input to the SG is small, so a small modulator is sufficient. Because of this a single valve, as a Class A modulator, is satisfactory.



The RF output of the PA is controlled by the SG voltage. The PA is thus modulated by the audio signal from T1. For adequate modulation the SG voltage should swing from zero, or a little below, up to the normal SG working voltage. It is thus necessary that the HT voltage actually applied to the SG, through the transformer, must be only one-half the normal maximum SG voltage. This reduces the power output of the stage.

Modulation may be applied to the SG by means of a modulation transformer, as in Fig. 65, or by using a choke, in a similar manner to that in Fig. 64. These circuits are relatively easy to adjust and use. The load resistor helps stabilize the load on the modulator, and depends on the transformer ratio and surplus power available.

Another system of SG modulation uses a valve between PA SG and HT supply. The valve cathode is connected to the SG of the PA, and amplified audio from the microphone is applied to the valve control grid. The valve thus acts as a modulator, as its conductance varies with the audio signal on its control grid, thereby controlling the PA SG voltage. This avoids the need for a modulation choke or transformer, but is not always easy to adjust.

*Suppressor Grid Modulation* may be used with a pentode PA. It resembles SG modulation, except that the suppressor grid must receive quite a high negative voltage, to reduce the PA anode current to zero. The method has similar advantages and limitations to other forms of grid modulation. Little modulating power is needed, but reproduction is likely to be less satisfactory. It cannot be used with tetrodes, which have no suppressor grid.

*Control Grid Modulation.* In this system the modulation is applied to the control grid, which will also be receiving the RF drive from the oscillator or exciter. It is not easy to adjust working conditions so that the valve can work effectively with both RF and audio applied to its control grid, and the system in general has similar limitations to other forms of grid modulation. It is not very widely used, but finds occasional application with triode PA valves.

Forms of grid modulation operate by changing the efficiency of the PA, and they are sometimes termed 'efficiency modulation' systems. It is also possible to place the modulator between PA cathode and HT negative line. In general, SG modulation is probably most used, among these systems.

*Power Circuits*

Power is generally drawn from AC mains, though battery running may be adopted in small portable equipment, and for mobile transmitters.

With AC mains operation, all heater, HT and other supplies are obtained from mains transformers. Current should be taken from a 3-pin plug, inserted in a convenient wall outlet. The large, earth pin is used to earth the chassis and other metal parts of the equipment, so that faults cannot make these alive with mains voltages. Of the remaining two pins, one is marked 'L' or red, and any fuse or single-pole mains switch should be in this conductor. The remaining pin, marked 'N' or black, completes the power-supply circuit. If a 13A plug is used, it can be fitted with a 5A or other relatively small fuse. The equipment should have good quality flexible cords of adequate length and current rating, correctly connected: green for earth, red for 'L', and black for 'N' circuits.

Indirectly heated valves are largely used, with heaters run directly from a mains transformer winding of correct voltage. This is 6·3V for many valves, but 5V for many rectifiers. The valve heaters are normally in parallel, and the total current consumption is the sum of all heaters. For example, a transmitter with five 6·3V 0·3A valves, two 6·3V 0·7A valves, and two 6·3V 1·25A valves would require 5·4A at 6·3V, so a 6A 6·3V winding would do. A centre tap, or one side of the winding, is generally returned to HT negative or chassis.

Valve rectifiers are of two types – indirectly heated, or directly heated. Directly heated rectifiers employ the heater as cathode, and this will be at HT positive potential, as in Fig. 67. A separate heater winding, insulated from the other windings, is thus required for the heater. Some indirectly heated rectifiers may be run in the same way. The cathode is then wired to one side of the rectifier heater, which receives power from its own winding, as in Fig. 67.

Indirectly heated rectifiers with a separate cathode may have their heaters operated from the same transformer winding as other valves, provided the heater/cathode rating of the rectifier is not exceeded. Such rectifiers are often for 6·3V operation, and relatively small HT voltages, such as encountered in receivers. They are suitable for transmitter grid bias supplies, receiver HT circuits, or the HT supplies to early stages in a transmitter.

In all but small transmitting equipment, rectifiers may be wired in parallel, to provide the relatively high current which may be needed, and which may be too much for a single rectifier.



*Half-wave Rectification*

Fig. 66 shows a half-wave rectifier, receiving current from a HT transformer. The AC at the transformer can be represented as at A. Half-wave rectification allows positive half-cycles to pass, and this may be represented as at B. The reservoir capacitor C1 smooths this to some extent. Additional smoothing is obtained by the smoothing choke L1, and further capacitor C2, so almost pure DC is obtained, as at C. R1 is a bleeder, which leaks off current from C1 and C2. C1 is commonly about 8$\mu$F, while C2 is often about 16$\mu$F to 32$\mu$F.

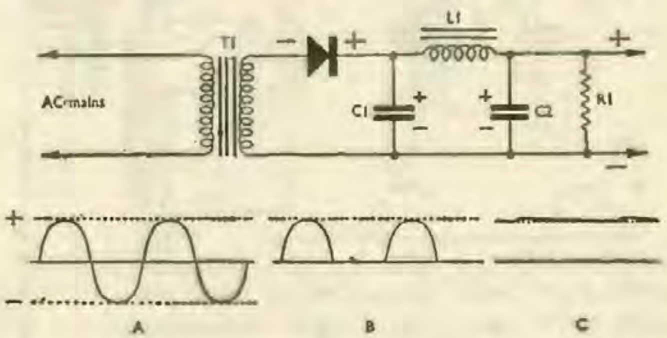



FIG. 66

If a metal rectifier were employed, it would be connected in the polarity shown. Should a half-wave valve rectifier be used, rectifier anode is taken to the secondary of the mains transformer T1, and the cathode is taken to C1. That is, valve cathode corresponds to metal rectifier positive. In Fig. 66, a positive supply is obtained for HT circuits.

If the rectifier is reversed, the supply obtained is of reversed polarity. Connections to the capacitors C1 and C2 must then be reversed also. The negative supply obtained would be suitable for bias for a modulator, PA, or both.

In a bias pack, a relatively low voltage is sufficient, so C1 and C2 need not be of such high voltage rating. The current required will also probably be small, so the choke L1 can be omitted, a resistor being substituted. Half-wave rectification is quite often employed in a bias pack, and in economically-priced receivers.

*Full-wave Rectification*

Fig. 67 shows a typical full-wave rectifier circuit, of the type commonly employed in receivers, amplifiers, and transmitters. A centre-tapped HT secondary is required, and the valve has two anodes. Each anode rectifies one-half of the AC supply. In Fig. 67, A represents the AC output of the transformer T1, and B shows the result of rectification of alternate half-cycles by the anodes

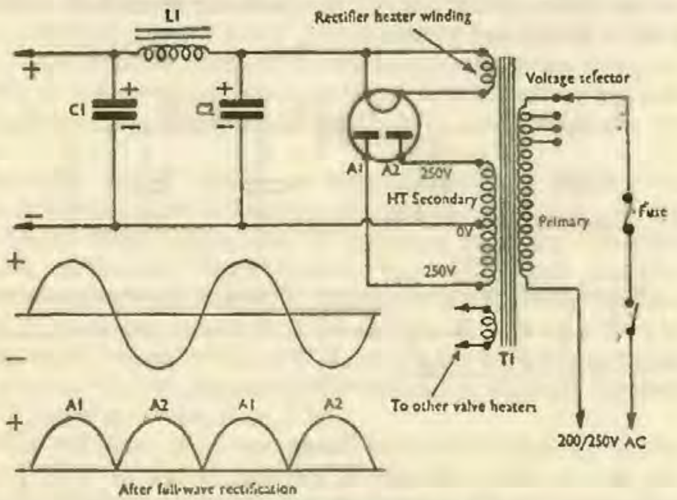



FIG. 67. Full wave rectifier circuit

A1 and A2. C1, C2, and L1 form the smoothing circuit, as for Fig. 66.

A smoothing circuit consisting of a choke L1, and two capacitors C1 and C2, is adequate for many purposes. When all ripple has to be removed from the HT supply, as for early stages of equipment, a resistor may be included in the HT circuit, with a further capacitor to chassis (HT negative). An example of this is seen in Fig. 59 (C4 and R5). It may also be necessary to reduce the voltage to early stages, and the resistor then serves this purpose.

The voltage rating of C1 and C2 must be adequate for the HT



voltage, and should in fact be higher than the peak output voltage obtained with no load. The current rating of the choke L1 must be at least equal to the demands of the HT circuit. As previously explained, the rectifiers will have a peak inverse voltage rating, maximum rectified current rating, and maximum peak current rating, and in normal design none of these should be exceeded.

Metal or silicon rectifiers may also be used in full-wave circuits, and two are shown in Fig. 68. The smoothing circuits have been omitted. Voltage doubler and other circuits are also used occasionally.

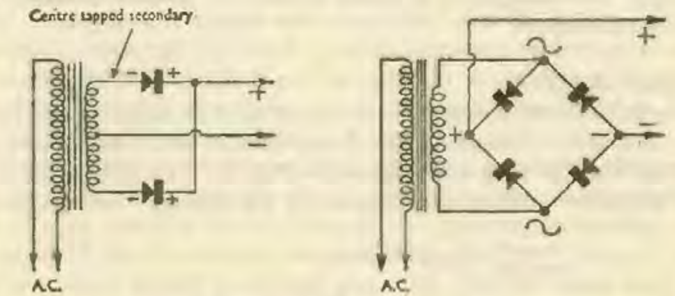



FIG. 68

The voltage obtained from a rectifier and smoothing circuit depends to some extent on the current drawn. If no current is taken, the capacitors will charge up to the peak voltage (Chapter Two). The voltage will also be unusually high at low currents, falling to the specified, correct level when the correct current is drawn. If even more current is taken, the voltage will drop, and the rectifier or choke may be damaged. A supply in which the voltage changes severely, with moderate changes in current, is said to have bad regulation. A supply obtained from a transformer of adequate rating, with rectifiers of ample size, and a choke of low resistance, will have good regulation. That is, the voltage will remain moie constant, with varying HT demands.

*Bleeder*

The large capacity electrolytic capacitors used in parallel with the HT supply for a receiver, modulator or transmitter can hold a considerable charge. As a result, a shock could be received from the HT circuit, after the equipment was switched off.

In addition, if no current at all is drawn from the HT line, the voltage rises, as explained, and this may place unnecessary strain on capacitors, especially with high voltage circuits.

To reduce these dangers, a bleeder resistor is wired across the HT supply. This resistor rapidly discharges the smoothing capacitors when the equipment is switched off. It also helps to stabilize the HT line voltage. Stabilization is best with a high bleeder current, but this imposes a severe load on the rectifier and transformer. Usually, however, a bleeder current of perhaps 10 per cent of the equipment consumption should be possible. The bleeder may consist of two or more resistors in series, across the HT supply, and acting as a potential divider, to provide reduced HT for some circuits.

*Voltage Regulation*

A particularly stable voltage supply may be required for some circuits, and a voltage regulator or stabilizer may then be used. A circuit for this purpose is shown in Fig. 69. The voltage drop in R1 depends on the current drawn by the regulator and oscillator

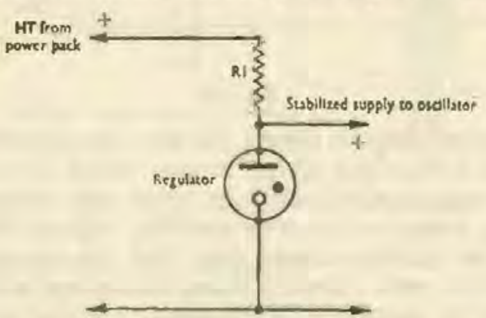



FIG. 69. Voltage regulation circuit to provide stabilized HT

or other circuit. If the voltage rises, the regulator passes a larger current, producing increased voltage drop in R1, so the voltage of the stabilized supply is maintained more nearly at its correct value. A typical small regulator would pass between 5mA and 30mA, and could be for 150V or other selected stabilized output.

Such regulators resemble valves and are inserted in a valve-holder. In amateur equipment, one is frequently employed to stabilize the HT voltage to a VFO. They are sometimes fitted in receivers, to stabilize the oscillator voltage.

CHAPTER SEVEN

# Aerials, Feeders, and Aerial Coupling

*Transmitting Aerials*

QUITE simple wire aerials are often used, and the same aerial is generally employed for both transmitting and receiving, as an efficient transmitting aerial can be expected to perform well while receiving. A relay or switch is used to connect the aerial to the transmitter or receiver, as required.

The distribution of current and voltage in an aerial influences the method of feeding the aerial. Fig. 70A shows a horizontal aerial wire, which is $\frac{1}{2}$-wave long at the operating frequency. As example, if the transmitter were working on 20m (15mc/s) the $\frac{1}{2}$-wave aerial would be about 10m long. (In the same way, a 1-wave, or full-wave aerial, also termed '2 $\frac{1}{2}$-waves', would be about 20m long, while a $\frac{1}{4}$-wave aerial would be about 5m long. (Lengths may be calculated in feet, as described later.)

In Fig. 70A, current is practically zero at the ends of the wire, but high voltages are present here. At the centre of the wire, current is large, but the voltage is low. It can thus be said that the $\frac{1}{2}$-wave aerial is high impedance at each end, and low impedance at the centre. Actual figures depend on the height above ground, and other factors, but the centre impedance of a $\frac{1}{2}$-wave aerial can be taken as being around 75 ohms. The end impedance could be 1,000 ohms, or more.

If the aerial at A were used on twice the frequency, or half the wavelength – that is, 30mc/s or 10m, instead of 15mc/s or 20m – it would be 2 $\frac{1}{2}$-waves long, as shown at D. D shows the distribution of current in the aerial wire. An aerial will be approximately a multiple of $\frac{1}{2}$-waves on harmonically related bands. For example, if a $\frac{1}{2}$-wave aerial were erected for 80m it would be a full-wave on 40m, 2 full-waves (or 4 $\frac{1}{2}$-waves) on 20m, and so on.

If the aerial is suitably fed it is thus possible to use it on several bands. Nor is there any need for the wire to be of *exact* length.

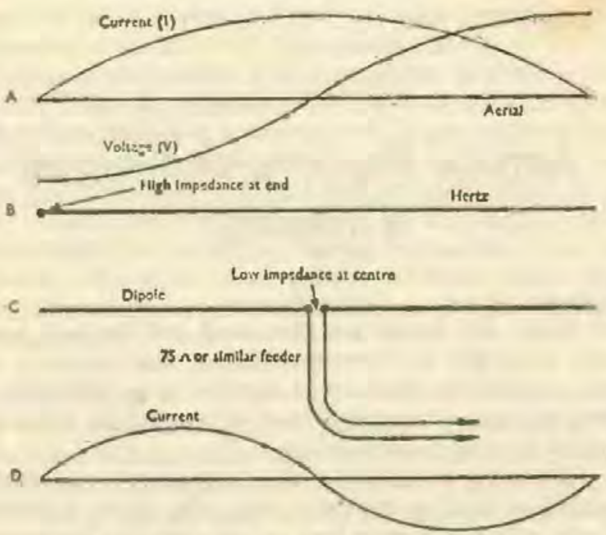



FIG. 70. Half-wave aerials A, B, and C. D is full-wave

For example, if it were cut for 3·65mc/s it would work satisfactorily over the 3·5–3·8mc/s band.

Due to end effects, the actual length of wire is not quite a $\frac{1}{2}$-wave, but only 0·95 of a $\frac{1}{2}$-wave. For wire aerials used on the 1·8–28mc/s bands, the length may be found directly in feet. The length of a $\frac{1}{2}$-wave aerial, in feet, is approximately:

$$\frac{468}{\text{Frequency in mc/s}}$$

For example, a $\frac{1}{2}$-wave aerial is to be cut for 14·1mc/s. What is its length?

$$\frac{468}{14{\cdot}1} = \text{approximately 33ft 2in}$$

When the aerial is 2 $\frac{1}{2}$-waves or more long, the 'end effects' operate only at the ends of the wire. So, if an aerial is intended for harmonic operation, its length in feet can be found from:

$$\frac{492(N-0{\cdot}05)}{\text{mc/s}}$$

where N is the number of $\frac{1}{2}$-waves.



For example, a wire which was to be 6 $\frac{1}{2}$-waves long, would be:

$$\frac{492(6-0{\cdot}05)}{\text{mc/s}} = \frac{492\times5{\cdot}95}{\text{mc/s}}$$

There is thus a slight difference between the exact length of a 3·5mc/s $\frac{1}{2}$-wave aerial, and a 2 $\frac{1}{2}$-wave (full-wave) 7mc/s aerial, for example. However, a suitable compromise length is usually satisfactory for harmonically related bands, such as the amateur bands.

*End Fed*

When the aerial receives power at one end, it is 'end fed', Fig. 70B. This feed point is high impedance. The end of the wire may go to the transmitter, if the latter can suit the impedance encountered. If not, the aerial is taken to an aerial tuner.

The length of wire will generally not be in a straight line because part of it will form the down lead to the transmitter. All the wire should be as far from ground, and earthed objects, as possible. There will be radiation from the down lead, which is actually part of the aerial.

End-fed aerials of this kind have the advantage of simplicity, and the same wire can be used successfully on several bands. Only one support (in addition to the house or chimney) may be required. End-fed aerials have the disadvantage that part of the radiating system (the down lead) is near the house, and this may cause TV interference. End-fed aerials are also liable to radiate harmonics, which may also cause interference. However, end-fed aerials are extensively used.

An aerial which is a $\frac{1}{2}$-wave long, and fed at the end, is an end-fed Hertz. If the aerial is a $\frac{1}{4}$-wave, fed at its lower end, this is a Marconi. The $\frac{1}{2}$-wave end-fed aerial has a high impedance feed point; but the end-fed $\frac{1}{4}$-wave has a low impedance feed point. Random lengths will present an impedance of some intermediate value. Impedance matching into such aerials is often possible with a $\pi$ tank, as described for transmitters.

*Marconi*

In the Marconi, the aerial is about a $\frac{1}{4}$-wave, and the earth, or a counterpoise, takes the place of the other $\frac{1}{4}$-wave. This is shown at A in Fig. 71, where the vertical wire forms the $\frac{1}{4}$-wave Marconi, and the earth acts as the lower ¼-wave. This in some ways resembles a vertical ½-wave fed at the centre.

A Marconi aerial needs a good earth system. An end-fed ½-wave is fed at a high impedance point, so resistance due to poor earthing is not too important. But the same earth resistance would cause bad losses, with the low impedance Marconi.

The actual aerial will often have part of its length horizontal, as at B, because a vertical support a ¼-wave high is impracticable on many bands.

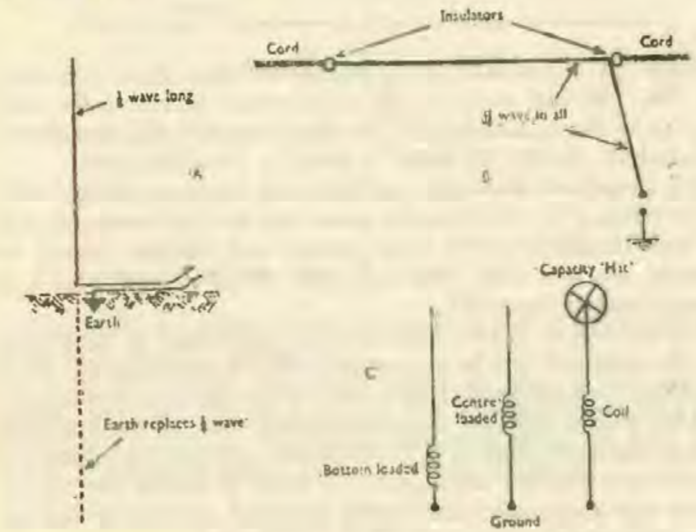



FIG. 71. Various Marconi type aerials

The Marconi is often employed where space is limited, so that a ¼-wave cannot be accommodated. Loaded Marconi aerials are also used, especially for mobile working. These are physically shorter than a ¼-wave, but the electrical length is increased by using a loading coil, capacity hat, or other device, as in Fig. 71C. The nearer the aerial is to being an actual ¼-wave, the smaller will the coil be.

*Dipole*

The ½-wave wire, in Fig. 70, has an impedance of about 75 ohms at the centre. So it can be cut here, and a 75-ohm or similar twin feeder may be connected, as in Fig. 70C. Radiation from the



feeder is very small, even if not negligible, and the feeder can be any length, and need not be measured. The aerial may thus be clear of the house and equipment, and the feeder can be run by any convenient route.

Such an aerial is termed a 'dipole'. The low impedance centre feed will only be suitable when the centre of a ½-wave comes here. So the aerial is cut for one band only, and cannot be used on other bands. If it were used on the 2nd harmonic, for example (next higher frequency band) it would be 2 ½-waves, so that 1 ½-wave would be found each side the feeder. The ends of these ½-wave sections are high impedance, so severe losses would arise with the low impedance feeder.

The centre-fed dipole has the advantage of low radiation from the feeder, and it is not an efficient radiator of harmonics. These facts may help to reduce TV interference. Its disadvantage is that it is generally employed for one band only.

*Zepp*

A Zepp aerial can be operated on several bands, and it has a horizontal portion, with a two-wire feeder at one end, as in Fig. 72. One wire of the feeder is connected to the horizontal portion, and the other feeder wire is supported by an insulator at its upper end, but is not connected electrically to anything here.

The horizontal, radiating section is a ½-wave, or number of ½-waves. It will usually be a ½-wave at the lowest operating frequency, and can then be operated harmonically on higher bands.

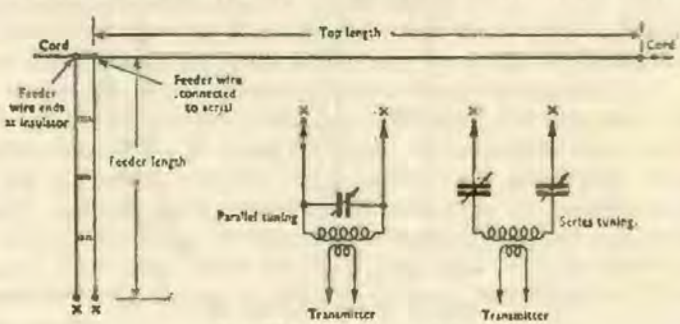



FIG. 72. The Zepp aerial

As end effects are slightly different from those experienced with other aerials, lengths are modified to suit.

The feeder consists of two wires separated a few inches from each other by insulated spreaders. It is coupled to the transmitter by either a series tuned, or a parallel tuned, circuit. If the length of the feeder is near a number of $\frac{1}{2}$-waves, parallel tuning is required. But if the feeder length is an uneven number of $\frac{1}{4}$-waves then series tuning is used. It may be necessary to employ series tuning on some bands, and parallel tuning on others.

The main advantage of the Zepp is that it can be used on several bands. Its main disadvantage is that there is likely to be some radiation from the feeder, which is not completely balanced. The tuner is also essential.

*Tuned Doublet*

A tuned doublet or tuned dipole can be used on several bands. It consists of a horizontal portion, with an open wire feeder descending from the centre, as in Fig. 73. One feeder wire is connected to each horizontal section. The horizontal portion is generally a $\frac{1}{2}$-wave long at the lowest operating frequency.

The doublet feeder resembles the Zepp feeder in construction. The insulated spreaders supplied for such purposes are about 5in to 6in long. The two wires of the feeder could be solid copper

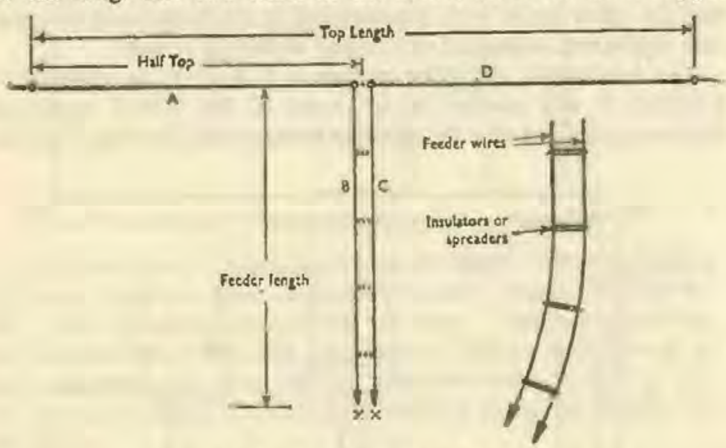



Fig. 73. Tuned Doublet aerial

wire, but a stranded wire, such as 7/26 (7 strands of 26 SWG) will be more easily handled. Spreaders are used at roughly 2ft intervals, or as required to keep the wire spacing fairly even.



A tuner is used at the transmitter ends of the feeders, X–X. If the length of half the top, plus the feeder, is a $\frac{1}{2}$-wave, or multiple of $\frac{1}{2}$-waves (that is, A plus B, Fig. 73) then parallel tuning is required. But if half the top, plus the feeder length, is a $\frac{1}{4}$-wave, or odd number of $\frac{1}{4}$-waves, then series tuning will be necessary.

The same tuner may be used, as indicated for the Zepp aerial. But tuning of the doublet feeder is not the same as that of the Zepp feeder, because the doublet feeder goes to the centre of the aerial, while the Zepp feeder goes to one end.

Many top lengths and feeder lengths can work quite well. If space is limited, the top length, plus twice the feeder length (that is, A, B, C, and D) need only total a $\frac{1}{2}$-wave, at the lowest working frequency. Otherwise, the top (A plus D) is a $\frac{1}{2}$-wave, at the lowest frequency.

Advantages of the tuned doublet are that it can work effectively on several bands, and that radiation from the feeder is not very great. Its disadvantage lies in the need for a tuner or coupler, and possibly having to change from parallel to series tuning, when changing bands.

*Harmonic Operation*

Harmonic operation of an aerial is possible when the aerial can be fed effectively at a number of harmonically related frequencies. This requires that the aerial should be end-fed, or be a Zepp, or tuned doublet. In these circumstances, a 3·5mc/s aerial could be used for 7mc/s (2nd harmonic), 14mc/s (4th harmonic), 21mc/s (6th harmonic), and 28mc/s (8th harmonic).

Harmonic operation is not feasible when the aerial is so designed that it can be fed effectively at only one frequency. A dipole, with 75 ohm feeder, is an example of such a single-band aerial.

Multiples of 14mc/s, 21mc/s, and 28mc/s, fall very near television frequencies. If these multiples, or harmonics, are present in the transmitter output, any harmonic type aerial will radiate them, and probably cause TV interference. To avoid this, a harmonic trap may be required between transmitter and aerial tuner. Low pass filters are also employed – these allow the transmitter signals up to 30/mcs to pass, but suppress higher frequencies.

Some actual lengths, for single-band and multi-band aerials, are as follows. The aerials can be 14 SWG wire, with one or two ribbed insulators at each suspension point.

*Amateur Band Aerials*

Half-wave dipoles, centre 75-ohm, or similar feeder of any length.

| *Band* | *Top Length* |
|---|---|
| 28mc | 16ft 6in |
| 21mc | 22ft 2in |
| 14mc | 33ft |
| 7mc | 66ft 6in |
| 3·5mc | 128ft |

*End-fed, total length*

| *Length* | *Bands* |
|---|---|
| 138ft | 3·5, 7, 14, 21, 28mc |
| 68ft | 7, 14, 21, 28mc |
| 33ft | 14, 28mc |

*Zepp*

| *Top* | *Feeder* | *Band* | *Tuning* |
|---|---|---|---|
| 137ft | 67ft | 3·5mc | series |
| | | 7mc | parallel |
| | | 14mc | parallel |
| | | 21mc | parallel |
| | | 28mc | parallel |
| 68ft | 33ft | 7mc | series |
| | | 14mc | parallel |
| | | 21mc | series |
| | | 28mc | parallel |

*Tuned Doublet*

| *Top* | *Feeder* | *Band* | *Tuning* |
|---|---|---|---|
| 136ft | 67ft | 3·5mc | parallel |
| | | 7mc | parallel |
| | | 14mc | parallel |
| | | 21mc | parallel |
| | | 28mc | parallel |
| 66ft | 66ft | 7mc | series |
| | | 14mc | parallel |
| | | 21mc | series |
| | | 28mc | parallel |
| 66ft | 33ft | 7mc | parallel |
| | | 14mc | parallel |
| | | 21mc | parallel |
| | | 28mc | parallel |



*Trap Aerials*

These are multi-band aerials, usually commercially made, in which the aerial is divided into several sections. A resonant coil or trap is placed between sections, and the whole may be centre-fed with co-axial line. Such an aerial permits operation on several bands, with a minimum of trouble. Other special feed systems, designed to achieve a similar result, are also occasionally used.

*Transmitter Coupling*

The RF output of the PA has to be carried to the aerial, and some form of coupling circuit and feeder will be employed. Most systems are quite simple. One important point is that the aerial may be high impedance (e.g. end-fed ½-wave) or low impedance (e.g. centre-fed ½-wave).

When the impedance of the feeder matches the feedpoint impedance of the aerial, there is a steady flow of power along the feeder to the aerial. Such a feeder is known as a non-resonant line or non-resonant feeder. Co-axial cable is a typical non-resonant feeder.

When there is an impedance mis-match between feeder and aerial, or when the feeder is tuned, there are excursions of voltage and current along the feeder. A typical tuned line is the open-wire feeder as described for the Zepp and tuned doublet.

*Non-Resonant Lines*

The impedance of a non-resonant line is the ratio of the voltage to the current. If the voltage is high, and current low, this is high impedance. If the voltage is low, and current high, this is low impedance.

An open wire line, of the same construction as described for a Zepp, would be acting as a non-resonant line if it terminated in its characteristic impedance. More usually, however, such open wire lines are tuned.

A co-axial line is one with a centre conductor surrounded by an outer conductor. High quality line may be semi air-spaced, but ordinary co-axial simply has an inner flexible wire, covered with low loss insulation, and an outer sheath of flexible wires. Such co-axial cable is used for a centre-fed ½-wave dipole, etc. It can be purchased in the required impedance.

Twin lines are available in which the two conductors are held side by side in insulating material. This type of feeder is termed a twin, or ribbon feeder, and is available in various impedances. High impedance twin ribbon has greater losses than an open wire line, because of the quantity of insulating material present, and the presence of conductive films of dust, moisture, etc.

The characteristic impedance of an open wire line can be calculated from the following:

$$\text{Impedance} = 276 \log_{10} \frac{2S}{D}$$

where S is the distance, in inches, between the centres of the wires, and D is the wire diameter in inches. (The calculation is only for open wire lines with fairly large spacing between wires.)

A twin line as described for the Zepp and tuned doublet feeder will have an impedance of roughly 600 ohms.

Non-resonant lines are also termed 'flat' because there is little or no excursion of current or voltage along them. Such excursions are termed 'standing waves' and arise when the impedance of the aerial does not match that of the transmission line or feeder. In practice, there will often be some standing waves on a line which should be flat, but losses are small if the standing waves are small. Any non-resonant line should terminate in its characteristic impedance. That is, the aerial should be so designed that the point at which the line is connected presents the same impedance as the characteristic impedance of the line.

When there is a smooth flow of power along a non-resonant line, it is said that the standing wave ratio is low. If the line does not terminate in its characteristic impedance, power will be reflected back along the line, and this causes standing waves. If these are severe, it is said that the standing wave ratio is high. A high standing wave ratio results in losses in the feeder, and may also cause radiation from the feeder. So standing waves should be low (or ideally absent) on any non-resonant feeder.

### *Resonant or Tuned Feeders*

A typical tuned feeder is that used with the Zepp or tuned doublet. This type of feeder can be operated with quite high standing waves, without objectionable losses. A feeder can be made resonant at a particular frequency, by adjusting its length.

Standing waves on an open wire line are not likely to cause much radiation, because the conductors are balanced, and losses are not likely to be important. Standing waves on a twin ribbon



feeder can result in bad losses, though radiation is not likely. With co-axial cable, standing waves will also cause losses, and radiation from the line is likely.

### *Transmitter Coupling*

Amateur transmitting equipment often has a $\pi$ output circuit, because this can be adjusted to operate into a wide range of impedances. An end-fed aerial might be operated directly from this circuit, as in Fig. 74A. This is practicable when no additional harmonic suppression is required, and when the aerial impedance is within the impedance range of the $\pi$ circuit. The transmitter is then loaded by adjusting C1 and C2, as previously described.

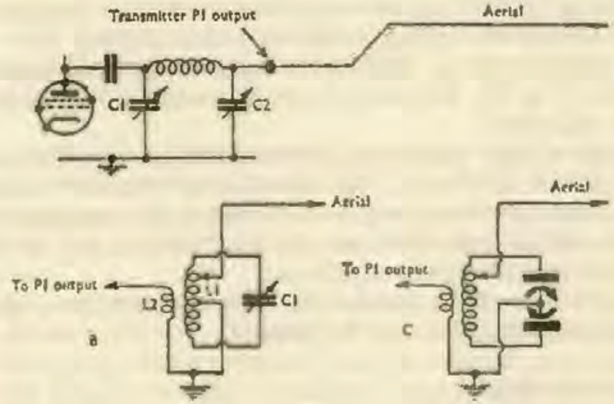



FIG. 74. Ways of connecting an end-fed aeria

When a dipole is operated with a 75-ohm or similar feeder, this is often taken directly to the $\pi$ output. With a co-axial cable, the outer sheath is taken to the earthed side of the transmitter output. The system is not balanced with respect to earth, but has the merit of simplicity. C2 requires to be adjusted to a fairly high capacity.

An end-fed aerial, that is a ½-wave or multiple of ½-waves, may have so high an impedance that it cannot be connected directly to the transmitter $\pi$ tank. It may also be necessary to use a harmonic trap, to reduce TV interference, and this unit may be intended for a 75-ohm or similar line. With a Zepp or tuned doublet, direct operation from the $\pi$ circuit will be impossible. These difficulties may be overcome by using an aerial tuner.

A typical tuner circuit is shown in Fig. 74B, and it may be used in this form for parallel tuning of Zepp or tuned doublet feeders, or for coupling an end-fed aerial which is a ½-wave, or multiple of ½-waves. For other than low power, the tuning capacitor C1 must have wide spacing, to avoid flash over. The coil L1 is tunable to the working frequency, and thus resembles the transmitter coil. L2 is a loop, of 2 or 3 turns, wound over the centre of L1, but insulated from it.

Fig. 74C shows a modified circuit. A split or 2-gang capacitor is used, and no centre tap is required on the coil. In Figs. 74B and 74C, an end-fed aerial is shown tapped to the coil, the tapping point being adjusted to secure suitable transmitter loading and tuning. Parallel tuning of twin-feeders is shown in Fig. 72.

For coupling at low impedance, series tuning is required, as described (Fig. 72). But parallel tuning is employed for coupling at high impedance.

As such a tuner is an impedance-matching device, it is sometimes called a 'Z Match'. The circuit from transmitter to tuner can be a short, random length of co-axial, and a harmonic filter may be inserted here, the circuit being adjusted so that the filter is operating at its correct impedance.

The tuner is often constructed as a separate unit, placed between the transmitter and the feeder.

*Radiation Resistance*

When an aerial is used for transmitting, it radiates power. If a resistance were placed in circuit, this could be of such a value that it dissipated the same amount of power as would be radiated by the aerial. The value of this imagined resistance is the radiation resistance of the aerial.

Radiation resistance is taken at the feedpoint, in a ½-wave dipole or other aerial fed at a point of high current. If the aerial is fed at some other point (say, one end) the radiation resistance is still taken as being at the point of high current (e.g. centre of a ½-wave).

*Directional Aerials*

If the aerial were a vertical rod or wire, above level ground, it would radiate with equal power in all directions. That is, signals would be of equal strength at all points of the compass.



The relative strength of radiation from an aerial can be shown by field strength diagrams. These may be in the horizontal plane, or in a vertical plane.

Fig. 75A shows the field strength diagram of a vertical aerial above level ground. The aerial radiates equally in all directions. That is, it is non-directional.

Fig. 75B shows field strength in a vertical plane. Radiation is strongest at an angle of 30 degrees, in this example, and falls away at higher and lower angles. The actual radiation diagram depends on the length of the aerial and its height above ground.

An aerial is often horizontal. If it is a ½-wave long, the field strength is as shown at C – the aerial radiates most strongly broadside to the wire, while signal strength falls off in line with the wire. Such an aerial is thus slightly directive, and gives strongest signals in directions broadside to the wire. The directional effect is very small.

It may be desirable to provide maximum signal strength in one direction, as when transmitting to a particular country, even at the expense of radiation in other directions. This can be done by using a type of aerial, which radiates in the required direction.

If another element is placed behind the aerial, as at D, this can be used as a reflector. The reflector is not electrically connected, but receives power by radiation from the original aerial element. For this reason, the original element is termed the 'driven element' while the reflector is said to be parasitically excited. The reflector can be 0·15 wavelength from the driven element.

A director may be placed in front of the driven element, and this also tends to increase signal strength in the required direction. The director is also parasitically excited, and can be about 0·11 to 0·2 wavelength from the driven element. Radiation is increased in the direction the aerial faces, as at D.

A reflector is a little longer than the driven element, while the director is a little shorter. Various lengths and element spacings are used. Reflector length can be found from:

$$\frac{501}{\text{Frequency in mc/s}}$$

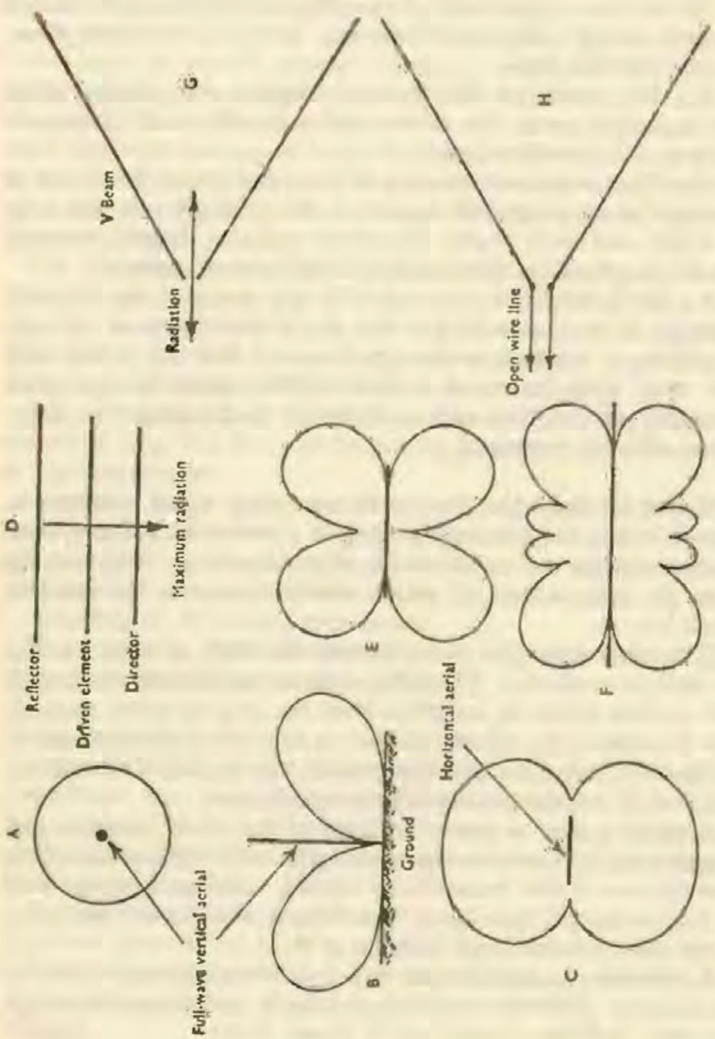



FIG. 75



Director length can be found from:

$$\frac{445}{\text{Frequency in mc/s}}$$

Directive aerials have a power gain, usually given in db. This gain is the increase in signal strength, compared with a dipole. For example, if the beam is twice as strong as the best signal from the dipole, the gain is 3db. (*See* Decibels.) An aerial consisting of a driven element and reflector may have a gain of about 5db. An aerial with driven element, director, and reflector (usually called a 3-element beam) would have a gain of about 7·5db.

If the aerial were fixed to a vertical mast, and could be rotated, the beam could be directed towards any point of the compass. This gives improved signals in the required direction. The effect is similar when receiving, resulting in better reception from the preferred direction, and reduced interference from other directions. Signal radiation, or pick-up, would be particularly low from the 'back' of the aerial. The relationship between radiation (or pick-up when receiving) from the front and from the back of such a directional aerial is termed the 'front-to-back ratio'. This could be perhaps 15db for a 2-element beam.

*Long Wires*

Wire aerials also have directional properties, which may be increased by using a wire several ½-waves long. E shows a wire 2 ½-waves long, with 2 radiation lobes. F is an even longer wire, 4 ½-waves long, and it has 4 lobes each side. The lobes towards the ends have an increased power gain. The power gain, for aerials of various length, is approximately as follows: 4 ½-waves, 1·5db; 6 ½-waves, 2·4db; 8 ½-waves, 3·3db; 10 ½-waves, 4·2db; 12 ½-waves, 5db.

Such aerials are termed 'long wires'. They are not uni-directional, but have equal lobes each side and end. Their length can be calculated as previously explained. They can be end-fed, or the length may form the top of a Zepp, and they can then be used on several bands. For example, about 136ft will be roughly 8 ½-waves on 28mc/s, 6 ½-waves on 21mc/s, 4 ½-waves on 14mc/s, and so on.

It is possible to add a second wire, of similar length, and at an angle to the first wire. This forms a V-beam. The angle between the wires is chosen so that the major lobes of radiation from one wire intensifies those from the other. If each wire is 2 ½-waves long, the gain is about 3db; for wires each 4 $\frac{1}{2}$-waves long, the gain is about 5·5db. Wires 2 $\frac{1}{2}$-waves long may be at 90 degrees, while wires 4 $\frac{1}{2}$-waves long may be at 70 degrees. An open wire line, as described for a tuned doublet, can be taken from the angle where the two wires meet, as at H in Fig. 75.

CHAPTER EIGHT

# Radio Waves, Propagation, Station Operating, Codes, Interference, Question Paper

### *Frequency and Wavelength*

RADIO waves travel at about 300,000,000 metres per second. If 300,000,000 waves were produced each second, there would thus be 1 metre between the crest of one wave and the crest of the next. Similarly, if 150,000,000 waves were produced each second, there would be 2 metres between crests.

Information about a radio wave may thus be given as a frequency (number of waves or oscillations per second) or as a wavelength (the distance between crests). If the information is in frequency, it may be converted to wavelength:

$$\frac{300{,}000{,}000}{\text{Frequency}} = \text{Wavelength}$$

Similarly, if the information is in terms of the wavelength in metres, it can be converted to frequency in cycles per second:

$$\frac{300{,}000{,}000}{\text{Wavelength}} = \text{Frequency}$$

Radio frequencies are high, being thousands, or millions, of cycles per second. So they are given in kilocycles (kc/s) and megacycles (mc/s):

1,000 cycles per second = 1kc/s
1,000,000 cycles per second = 1,000kc/s = 1mc/s

The calculations may thus be simplified, as follows:

$$\frac{300{,}000}{\text{F. (in kc/s)}} = \text{metres} \qquad \frac{300{,}000}{\text{Metres}} = \text{kc/s}$$

$$\frac{300}{\text{F. (in mc/s)}} = \text{metres} \qquad \frac{300}{\text{Metres}} = \text{mc/s}$$

For example, 200m = 1,500kc/s  Or 200m = 1·5mc/s.

The radio frequency wave is not audible to the human ear, but is interrupted or modulated to carry information, as already described. Forms of emission are:

A1. CW Morse, carrier interrupted by keying, requires superhet receiver with BFO, or oscillating detector.

A2. MCW (Telegraphy). An audio tone is imposed on the carrier and this audio tone may be heard with any receiver. Little used.

A3. Telephony (voice, music, etc.). Amplitude modulation.

A3A. Telephony, single-sideband or reduced carrier.

F1, F2, and F3, as A1, A2, and A3, but frequency modulation.

Television and other forms of emission are also available for Amateurs.

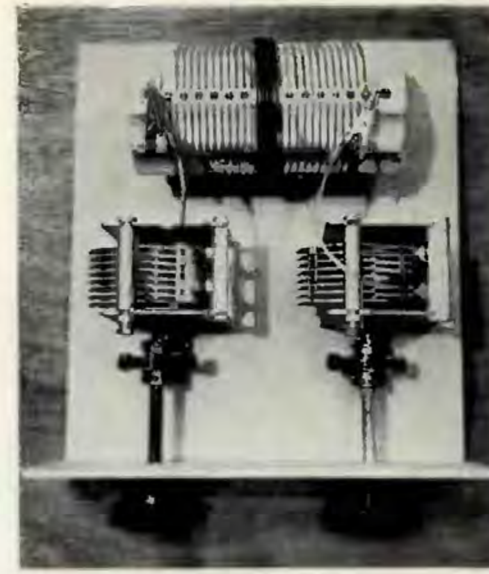
*Propagation*

The way in which radio waves travel depends on their frequency, the time of day, and other factors. Radio waves can have vertical or horizontal polarization, the orientation of polarization being that of the electrostatic part of the wave. A vertical aerial transmits a wave which has the electrostatic part of the component polarized vertically; a horizontal aerial transmits a horizontally polarized wave. The electromagnetic component is at right angles to the aerial, and right angles to the electrostatic polarization.

Waves may be reflected or refracted by conductive and semi-conductive surfaces or media, and are bent, twisted, and so changed that at a distance the polarization does not remain the same.

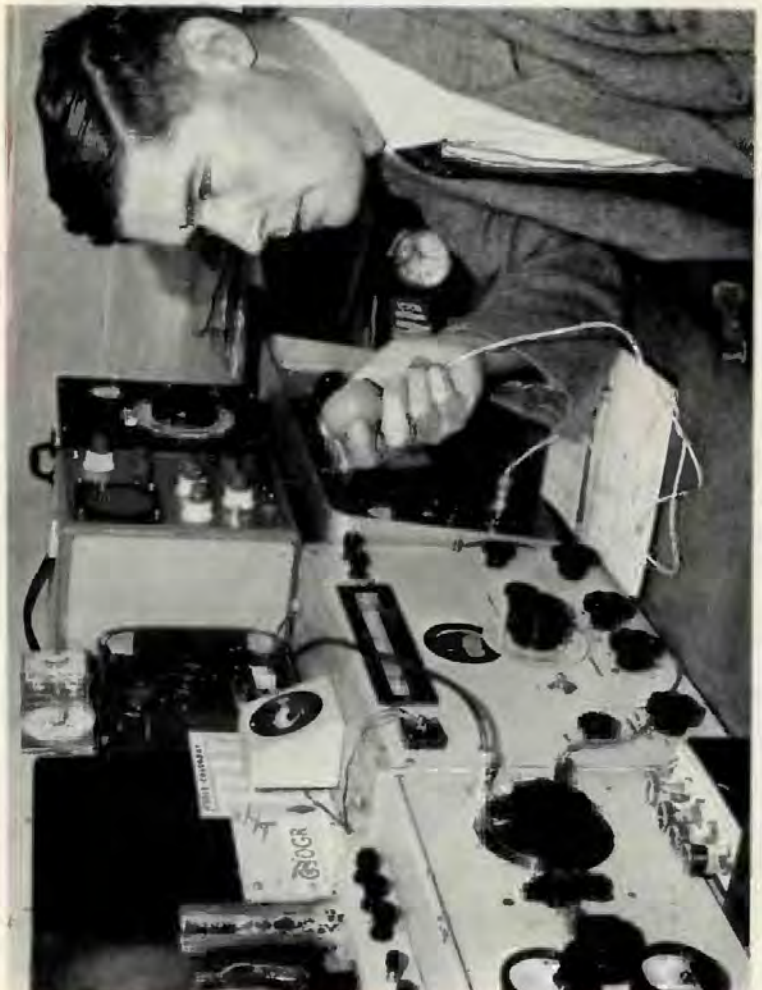
The radiated waves can reach a receiving aerial by travelling near the ground. On the SW bands, these ground waves soon grow weak, and their range is some miles only.

Waves which are radiated at a higher angle may pass out into space, and thus be lost for communication purposes. Or they may



12. 10–80m. aerial tuner for Zepp, tuned doublet, or end-fed Hertz (see aerials chapter). Clips permit series or parallel tuning on any band.

13. A number of QSL cards, such as may be obtained as confirmation of contact, and also collected by listeners.



14. Amateur station G30GR. Top, power pack, speaker, crystal calibrator, scope, wavemeter; bottom, aerial tuner, receiver, transmitter.



be reflected down to earth again by the ionosphere. The ionosphere has several layers, extending to a height of some hundreds of miles, and changes in character are caused by solar activity, arrival of night or day, sunspots, etc. Waves reflected back are sky waves, and propagation of these changes hour by hour, and month by month.

Long distance SW communication is by sky waves. Fig. 76 shows radiation from a transmitting aerial. The ground wave is soon attenuated and lost. Sky waves travel upwards at various angles. Some pass through the ionized layers and serve no useful purpose. Others are reflected back to earth. The distance at which a wave is reflected back is the 'skip distance'. It will be seen that

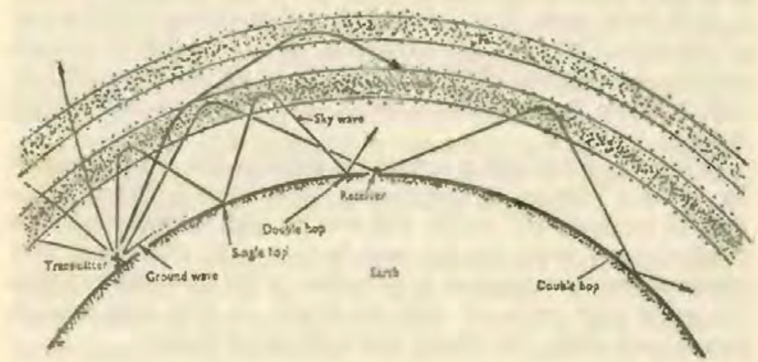



FIG. 76

waves radiated at low angles above the horizon have a much longer skip distance, under average conditions. So low angle radiation is particularly useful for working remote stations.

There is a general scattering of signals, so that a station may be heard over a considerable area, due to waves travelling at slightly different angles being reflected back to earth over a range of distances.

Conditions on the popular Amateur bands vary considerably, but a broad, general classification of expected results is possible:

1·8–2mc/s. Used for local contacts, up to a few hundred miles. Long-distance working occasionally achieved, but is rare.

3·5–3·8mc/s. Local contacts and near Europeans, occasional long-distance working, but not very usual.

7·0–7·1mc/s. Variable, and both short- and long-range working possible from time to time.

14·0–14·35mc/s. Much used for very long-distance working, and also medium distance. Very variable. When conditions are good, Australia, etc., may be heard or worked at suitable hours, also Near and Far East, and Africa may be anticipated, with American stations coming through strongly.

21·0–21·45mc/s. Somewhat similar to 14mc/s band, but often less active. Often gives good long-distance results, but may be giving poor results for many hours daily.

28–29·7mc/s. Effective for long-distance work during high sunspot activity, but otherwise variable. Gives very good distance working occasionally.

Each band varies from day to day, and according to the season of the year. There are also long-term variations, due to sunspot activity. An input of 150W is permitted on all bands except 1·8–2mc/s, where the maximum input is 10W. VHF and other bands are also available.

When signal strength at a receiving aerial varies, due to moment by moment changes in conditions, this is termed 'fading'. It is general on many HF bands, and also on high frequencies in the medium wave band. Fading may be caused by changes in skip distance, and by changes in polarization, or by the signal reaching the aerial over paths of different length, so that they tend to cancel each other. Distortion may accompany fading.

Fading

*Operating the Station*

From the actual operating point of view, little is required except the transmitter, with Morse key and microphone, a receiver, and aerial. Other items, such as frequency checking and measuring equipment, are covered in the next chapter.

The CW key should be conveniently placed a little from the edge of the table. Microphones are available with high stands, to place on the floor, or with table stands, or in lapel or hand-held types, or, occasionally, for resting on the chest. A table, bench, or desk will accommodate a typical layout of equipment.

It is convenient to power the station from a single 13A or 15A wall outlet, preferably switched. If this main switch is turned off afterwards, this assures no equipment is left running. Some spare sockets, for occasional operation of soldering iron, table lamp, or other items, will be useful. Each metal cabinet or chassis should



be soundly earthed, and a rule should be made never to perform interior or other hazardous adjustments to equipment without first switching off at the main outlet point. Remember that electrolytics may need discharging, if not provided with bleeders. Amateur transmitters may use HT voltages in the region of 450V to 1,000V or more, and such power circuits can give dangerous shocks. Usual care is also necessary to avoid shocks from mains circuits. If equipment is well made, and protected by earthed metal cabinets, little danger need exist.

Discharges from the aerial or feeder, as a result of lightning or accumulated static, should have a ready path to earth. If the aerial is fed with co-axial, with the outer sheath earthed, this will give some protection. But if the aerial is end-fed, coming directly to the transmitter, or uses tuned feeders, it may be well insulated from ground. The aerial or feeders should then be earthed in thundery weather, by an earthing switch, or by leads. A spark gap can be provided, with a low resistance connection to earth. The gaps have to be wide enough to avoid sparking while transmitting. A considerable static charge may arise on a long, high, well insulated aerial, even when no lightning is visible.

Receiver and transmitter are often controlled by a single switch which can be placed in 'Send' and 'Receive' positions. In the 'Send' position, the transmitter will be operating, and connected to its aerial, while the receiver will usually be muted, to prevent it being overloaded, or reproducing the radiated signal. Such muting can be arranged by shorting the receiver aerial terminal to earth (chassis), and by disconnecting the loudspeaker. With other than low power, shorting the aerial input of the receiver will probably be essential, to avoid possible damage to the receiver aerial coils. For 'Receive' the aerial will be switched to the receiver, and the transmitter will be off. A HT circuit is often opened, to accomplish this. Heaters are left running.

These functions can be carried out by a multi-pole two-way switch, which controls transmitter HT and other circuits, and transfers the aerial from transmitter to receiver. Or a relay, with the required number of contacts, may be used instead.

Most communications receivers have a 'Stand By' switch which silences the receiver, while leaving its heaters on. But changing from send to receive by means of a single switch is preferable.

Transmitters generally have a 'Net' or 'Tune' position, which allows early stages to be tuned up without actually radiating a signal. This also allows receiver and transmitter to be tuned to the same frequency, as the oscillator or exciter stages will radiate enough RF to be picked up on the receiver. (*See* p. 132.)

Two methods of switching the aerial from the transmitter to the receiver are shown in Fig. 77. With the first, an aerial tuner is used during transmitting, but the aerial is taken directly to the receiver. With the second method, the aerial tuner is in use for both transmitter and receiver, and in some cases this gives a slight improvement in reception. The latter method is also convenient for a Zepp or tuned doublet, where the tuner is required.

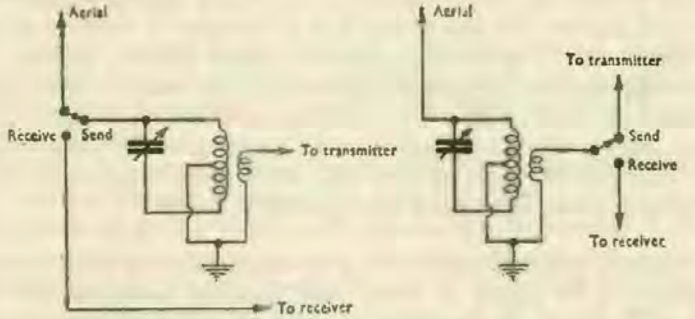



FIG. 77

The station is switched for receiving, and heaters warmed up. If long-distance working is in view, the receiver is tuned over one of the DX bands, such as 14mc/s. This naturally depends on conditions, and time of day, etc. For local contacts, the 1·8mc/s or 3·5mc/s bands might be selected.

If a station is heard calling CQ, the transmitter can be adjusted to this frequency. To do this, the Net or Tune switch is operated so that the oscillator can be tuned to the same frequency as the station heard, and grid drive and other tuning adjustments are made, including necessary tuning or loading of the PA. When the station ceases calling CQ and invites replies, the switch is turned to the transmit position, and a reply is made.

If no CQ calls are heard, or if those heard are unsuitable, a CQ call can be made. A clear channel should be sought with the aid of the receiver. The transmitter is then tuned to this channel,



and tuned up as described. The CQ call can then be made. This is an invitation to any listening station to reply.

With crystal-controlled equipment, working is usually started by transmitting a CQ call, because the transmitter is not tunable in the same way as one equipped with a VFO.

Call sign procedure is given in the Licensing Conditions mentioned in Chapter One. The call sign of the station with which it is desired to establish contact is given, followed by the operator's own sign. This is done both at the beginning and end of each period of communication. Call signs are often repeated several times, especially when opening contact. With long-distance working under difficult conditions, phonetic spelling is often used to avoid errors.

Log entries are made as described in the Licensing Conditions. These show time of beginning to operate, frequency, power, and mode of transmission (e.g. CW or Phone), call signs of stations contacted, closing down time, etc.

Phonetic spelling simply uses words whose initial letters correspond with the letters to be given. There is no generally accepted list. Some operators use their own words, but facetious words are to be avoided. Some operators use the names of well-known cities or countries, and common Christian names are also employed. For example, G3ABC might be given as 'George Three Able Baker Charlie' or as 'George Three America Baltimore Canada', etc. Phonetic spelling is not used when reception conditions make it pointless.

### *QSL Cards*

These are acknowledgement of a contact having been made, and are of particular interest when obtained from overseas countries. They give station call, time and date, and similar information. There is no point in obtaining or sending cards for each contact, but it may be desired to obtain at least one card from each overseas country worked. As they furnish proof of contact, they are necessary for some of the awards made by various organizations.

If much operating is done, a QSL card will not be wanted for each contact. Again, cards may not be required for contacts with other Great Britain stations, unless some particular aim is in view, such as working all counties on Top Band.

The actual operating done on any band naturally depends solely on the station owner. Some operators spend much time working rare, remote countries, or in increasing the number of countries worked. Others may use the D× bands seldom, but enjoy local contacts, while some transmit primarily to test aerials and equipment. Again, some operators very seldom employ Morse, while others are greatly interested in code working. There is also the opportunity for mobile and portable working, or in finding what can be achieved with very low power.

*Reports*

A phone or voice transmission will have a certain degree of intelligibility, and a particular strength (which may be influenced by fading). With Morse transmissions, the quality of the tone can also be reported. These details can be conveyed rapidly by the RST (Readability, Signal Strength, and Tone) code. For a phone signal, readability and signal strength are given as follows:

*Readability*

1 Unreadable.
2 Occasional words distinguished.
3 Readable with difficulty.
4 Readable with almost no difficulty.
5 Fully readable with ease.

*Signal Strength*

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

For example, 'Readability 5, strength 9' indicates very strong, perfectly readable signals. Such a report may be given as '5 and 9' or 5/9. Some receivers have meters indicating signal strength. Very strong signals indeed may be over 9, with this system, which is conveyed by a '9 plus' report.

With a CW transmitter, the stability and other factors will



influence the note or tone obtained at the receiver. So a Tone report is added.

*Tone*

1 Extremely rough note.
2 Very rough AC note.
3 Rough AC note.
4 Rather rough AC note.
5 Somewhat modulated note.
6 Modulated note.
7 Nearly DC note.
8 Good DC note.
9 Pure DC note.

With a CW transmission, three numbers, such as 589, thus convey readability, signal strength, and note.

*Procedure Code*

During ordinary CW working, various code signals can be used, in addition to the alphabet and numerals, given in Chapter One. Those generally required can be taken from the following:

| | | | |
|---|---|---|---|
| Full stop | .-.-.- | Comma | --..-- |
| Colon | ---... | Question mark | ..--.. |
| Apostrophe | .----. | Dash | -....- |
| Fraction bar | -..-. | Brackets | -.--.- |
| Underline | ..--.- | Break | -...- |
| Understood | ...-. | Wait | .-... |
| Error | ........ | Separation signal | .-..-. |
| Commencing signal | -.-.- | | |

To speed up CW working, a number of special signals exist, and many of these have been carried over into phone working. These signals begin with Q and form the Q Code:

QRI How is my transmission tone?
QRM Interference.
QRN Static interference.
QRO Increase power; high power.
QRP Reduce power; low power.
QRQ Send faster.
QRS Send slower.
QRT Stop sending; close down

| | |
|---|---|
| QRZ | Who is calling? |
| QSA | What is my signal strength? |
| QSB | Fading. |
| QSL | Acknowledgement card. |
| QSO | Communication. |
| QSY | Change frequency. |
| QTH | Location. |

These and other signals are used either as question or in the reply, as required. For example: 'What is your QTH?' Reply: 'My QTH (location or address) is . . .' The code is most suitable for speeding up CW contacts, but it is also used for voice working. For example: 'You are 5 and 9 with QRM. I am working QRP from temporary QTH here, with portable transmitter, so would appreciate a QSL card' may be used to indicate 'You are fully readable and very strong here, but with interference from other stations. I am working with low power from a temporary address, with a portable transmitter, so would appreciate a card acknowledging the contact.'

*Interference Prevention*

Transmitting and other equipment may cause interference to radio or TV reception. TV interference is most likely to be troublesome in areas where the TV signal is weak, and when the TV channels are near multiples of the transmitter working frequency. The trouble is also most likely when using higher frequency bands, such as 14, 21, and 28mc/s. Some interference arises because of the transmitter design, or aerial. In other cases, the receiver may be largely responsible. Interference is also more probable if the TV receiver or its aerial is very near the transmitter, or aerial.

*2nd Channel Interference*. This is explained in the section on frequency changers. Suppose a broadcast band superhet were tuned to 960kc (about 310m) and has a 470kc IF amplifier, then its oscillator would operate at 1,430kc. A signal 470kc higher in frequency could mix with the oscillator signal, and pass through the receiver. So an Amateur station working on 1,900kc (1·9mc) might break through and interfere with the required medium wave station.

This arises from receiver design. Modifications which will reduce the strength of the Amateur signal at the receiver, such as re-



siting the aerials, may help. A wavetrap, tuned to the offending signal and fitted at the receiver, can also be tried. Or it may be possible to avoid frequencies which will cause interference to fall upon required stations.

Spurious responses may also arise as a result of Amateur signals beating with harmonics of the receiver oscillator. In this way, Amateur signals in the 3·5–3·8mc band could be tuned in at various points on the medium wave band, in some circumstances.

Amateur signals may, of course, be tuned in on any receiver equipped with short wave bands, and reception of such signals cannot be termed interference. Interference is the unlawful presence of Amateur signals in such a way as to spoil reception of other programmes.

*Broadcast Band Interference* at no particular frequency may arise from 'swamping' of the receiver by strong signals from a near-by Amateur station. The Amateur station aerial or feeder should not run very near the receiver, or its aerial.

*Mains-borne Interference* can be caused by Amateur signals being carried on mains wiring, possibly to other houses. Mains circuits should be equipped with RF filters at the transmitter. If the interference continues when the transmitter is operating with a screened dummy load, instead of the transmitting aerial, then the aerial is clearly not responsible.

Ready-made and kit-form transmitters usually have RF filters and other precautions incorporated. RF filters consist of small RF chokes of suitable current carrying capacity in the power leads, with by-pass capacitors to chassis and earth.

*Harmonic Radiation*. TV receivers employ channels from 41·5 mc/s upwards, and multiples or harmonics of Amateur frequencies can fall on or near the TV channels. If these harmonics are present in the transmitter output, they will probably cause TV interference. A $\pi$ tank operating into a low impedance load discriminates against harmonics. Operating into a high impedance load (e.g. end-fed ½-wave aerial) is more likely to cause interference. If so, the transmitter can be operated into an aerial tuner, as previously described. A harmonic filter, or low-pass filter, may also be included in the output circuit of the transmitter. This filter is generally for use in a feeder of particular impedance (such as 75 ohms).

Amateur signals might also cause interference because of the strong local field strength. If so, a filter may be desirable in the receiver aerial feeder. Here, a high-pass filter, which allows TV signals to pass, but blocks Amateur signals on lower frequencies, would be employed.

Interference with a TV receiver may be heard as Amateur breakthrough on sound, or the interference may cause patterning on the screen, or may break up the picture. With a CW transmitter, clicks and interference will coincide with keying.

*Interference from Receivers.* An oscillating TRF receiver can cause interference, especially when it has no RF stage before the detector. If reaction is not sufficiently advanced to cause oscillation, no interference can arise.

A super-regenerative receiver could cause interference, as its detector is oscillating, and thus producing RF. Again, the presence of an RF stage, to isolate the aerial from the detector, would much reduce chances of interference.

With a superhet receiver, the local oscillator must remain in a state of oscillation. This may cause radiation, which could give rise to interference, either on the oscillator frequency, or on harmonics of this frequency. This effect is much reduced in a screened receiver.

*A Wavetrap* is sometimes wired from the transmitter output socket to chassis, and it can be tuned to the frequency of harmonics which may cause interference. In this form, it is series-tuned. The same type of trap may be wired from aerial to earth (chassis) at the receiver. If the trap has coil and capacitor in parallel, and is tuned to the undesired signal, it presents a very high impedance to this. In this form, it may be included in series with the aerial lead. Small traps for TV frequencies can consist of a few turns of wire, as a self-supporting coil, with an air-spaced pre-set capacitor (*see* Acceptor and Rejector Circuits). For broadcast bands, a trap can consist of a dust-cored coil, with pre-set or fixed capacitor. If the capacitor is fixed, the trap can be tuned over a narrow band of frequencies by adjusting the core.

The following Radio Amateurs' Examination question paper is reproduced by permission of the City and Guilds of London Institute.

*Eight questions in all are to be attempted, as under:*
*All four in Part 1 (which carry higher marks) and four others from Part 2.*

### Part 1

*All four questions to be attempted from this part.*



1. Licence conditions:
   (*a*) State the requirements in respect of the following:
   (i) Log-keeping. What entries should be made?
   (ii) Frequency control and measurement.
   (*b*) (i) What is meant by 'shared' bands?
   (ii) Which bands are shared? (15 *marks*)

2. With the aid of a diagram describe an 'artificial' aerial. How can an 'artificial' aerial be used to measure the power output of a transmitter? (15 *marks*)

3. Describe, with the aid of a circuit diagram, a frequency-stabilized CW telegraph transmitter. Comment on the method of keying. (15 *marks*)

4. List various types of interference that can be caused by an Amateur transmitter. Describe methods of abating the interference in each case. (15 *marks*)

### Part 2

*Four questions only to be attempted from this part.*

5. Describe the construction of a half-wave dipole aerial and indicate a method of coupling it to the transmitter. Show the voltage and current distribution in the aerial and the radiation pattern. (10 *marks*)

6. Describe any one method of checking that a telephony transmitter is not over-modulated. (10 *marks*)

7. Define thermionic emission and explain in simple terms how this effect is used in radio valves. (10 *marks*)

8. With reference to wave propagation describe briefly:
   (*a*) skip distance;
   (*b*) ground wave;
   (*c*) the causes of fading.

9. What is capacitive reactance? How does it affect the current flow in an a.c. circuit?
   Calculate the reactance of a 200 pico-farad capacitor at a frequency of 7mc/s. (10 *marks*)

10. What losses are encountered in inductors carrying high frequency currents?

    State how the losses are kept to a minimum in:

    (*a*) an air-cored inductor;

    and (*b*) an inductor with a core of magnetic material.

    (10 *marks*)

CHAPTER NINE

# Instruments, Test Equipment, Measurements

MOVING-COIL meters are used for many purposes. These have a magnetic gap, in which the moving coil is pivoted, as in Fig. 78. Two hairsprings complete the circuit to the coil, and also return the coil and attached pointer to zero, when no current flows. When current flows in the coil, it turns slightly, moving the pointer. The scale is linear, with equal divisions.

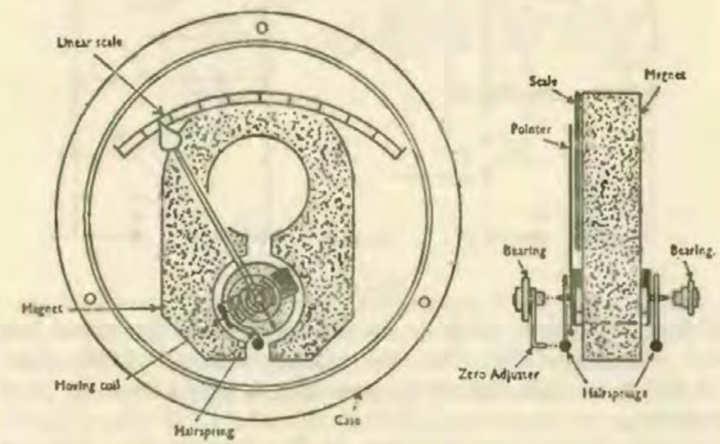



FIG. 78

Such meters are used for DC only. Sensitivity depends on the number of turns on the coil, and other factors. A general purpose meter might be a 1mA movement. This means that a current of 1mA will move the pointer to the full-scale reading. Very sensitive meters have a full-scale reading of 0·1mA (100$\mu$A) or less. Meters with full-scale readings of 5mA, and over, are often used.

From Ohm's Law, I=V/R. So any required DC voltage range can be obtained by connecting an appropriate resistor in series with the meter. For example, it is wished to measure 0–25V with the 1mA meter. Resistor value:

$$\frac{25}{0{\cdot}001}=25K$$

Similarly, 100K would give 0–100V and 250K would provide 0–250V. Fig. 79A shows the 3-range voltmeter circuit. R1 is 25K, R2 100K, and R3 250K. Resistor values should be accurate.

The meter coil itself has some resistance. Assume this is 100 ohms for the 1mA instrument. This resistance is in series with the external resistors. On high voltage ranges the error from this cause is so small that it is ignored. But on low voltage ranges it is significant. For example, for a 5V range with the 1mA meter,

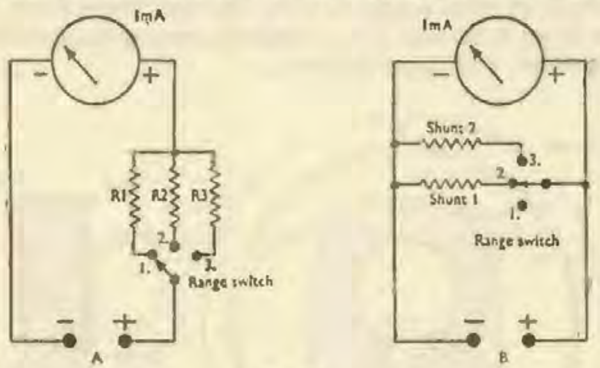



FIG. 79

the total resistance needs to be 5,000 ohms. As the meter coil itself contributes 100 ohms, the external resistor is 4,900 ohms. For this correction, the meter resistance is taken from the total resistance.

Currents higher than 1mA may have to be measured. This can be done with the 1mA meter by wiring a shunt across the instrument. The shunt is a low value, wire-wound resistor. If the shunt had nine-tenths the resistance of the meter, for example, nine-tenths of the current would pass through the shunt, and only one-tenth through the meter. So the 1mA meter would read 0–10mA. The required shunt resistance can be found from:

$$\frac{\text{Meter Resistance}}{(N-1)}$$



where N is the number of times the full-scale reading is to be increased. In the above example, N is 10, and meter resistance 100 ohms, so the shunt is 100/9 or 11·1 ohms.

To obtain various current ranges, a number of shunts may be switched into circuit, as in Fig. 79B. With the switch in position 1, no shunt is connected, so the instrument reads 0–1mA. In position 2, shunt 1 is in parallel with the meter, for the 0–10mA range. Position 3 brings in shunt 2, for 0–100mA or any other required range.

Resistance measurements often need to be made. From Ohm's Law, R = V/I. So if a battery of known voltage is added in series

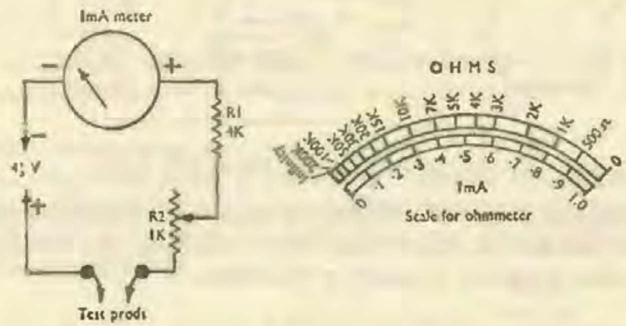



FIG. 80

with the meter, the current will be reduced if an external resistor is added, so the meter scale can be arranged to read resistances in ohms. Fig. 80 shows a popular circuit for this purpose.

R1 prevents a high current passing through the meter, if R2 is turned to zero. R2 is adjusted until the meter reads full-scale, with the test prods shorted together. This is Zero Ohms. If the test prods are applied to an unknown resistor or circuit, the meter will read less than full-scale. A typical ohms scale, for a 1mA meter and 4·5V battery, is included in Fig. 80. Scales for other meters and battery voltages may be worked out in the same way.

A general purpose test meter has several voltage, current, and resistance scales. A switch, or sockets, allows the required shunts, series resistors, or ohms circuit to be selected. Combining the circuits in Figs. 79 and 80 will give a 7-range meter, with three voltage ranges, three current ranges, and one ohms range. It would be used for DC only.

To measure AC voltages, an instrument rectifier is added, as in Fig. 81. This changes the AC to DC, so that the moving coil

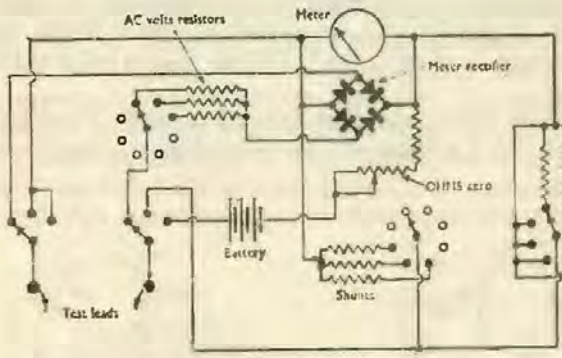



FIG. 81. Circuit of a multi-Range Test Meter

can respond. With low voltages, the scale is not completely linear, due to the rectifier. Fig. 81 also shows switching, etc., for the DC and other ranges of a complete test-meter.

*Other Meters*

A moving-coil meter, with thermocouple, is commonly used to measure RF currents. The RF current heats one element of the thermocouple, producing a small direct current, which operates the meter, as in Fig. 82. The thermocouple is often incorporated in the meter case. The scale is not linear, but crowded towards zero, as illustrated. Such meters are commonly utilized to show aerial current, or to find RF wattage, in conjunction with a known load resistor.

An AC/DC moving iron meter may be used to measure both DC and AC, but it is relatively insensitive. Actual construction varies greatly. An iron vane, to which the pointer is attached, may be drawn by magnetic force into a winding. Or magnetic repulsion may arise between a fixed iron piece, and a moving iron piece to which the pointer is attached. As there is no permanent magnet system, the pointer tends to move in the same direction, irrespective of which way the current flows. So it will read AC, as well as



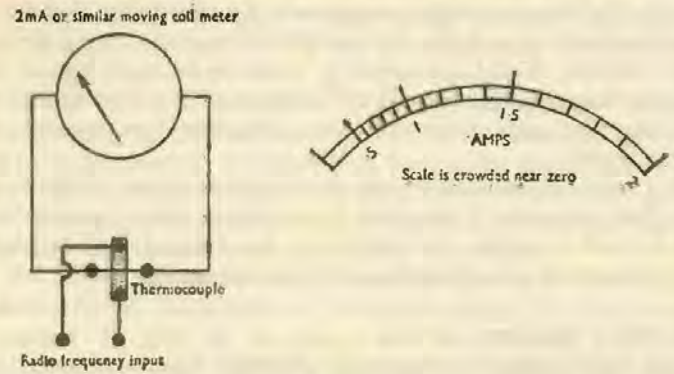



FIG. 82

DC. A moving iron meter with a permanent magnet is used in low cost instruments such as voltmeters, and operates with DC only.

*Frequency Measurements*

An absorption meter is the simplest method of checking frequency, especially to assure that correct harmonics are chosen. It consists of a tuned circuit, as in Fig. 83A, and plug-in coils permit use on several bands.

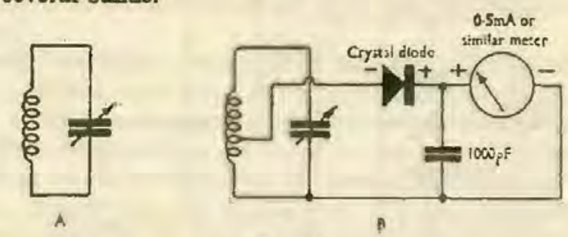



FIG. 83

RF energy must be present in a circuit checked with an absorption meter. The absorption coil is placed near the RF coil being checked. When the absorption meter is tuned to the same frequency as the circuit being investigated, it absorbs some RF energy. With an oscillator, amplifier, or PA, this causes a rise in anode current.

If a TRF receiver is adjusted so that it is oscillating, and the absorption meter coil is near the detector coil, oscillation will cease when the circuits are tuned to the same frequency.

After finding approximate resonance, the absorption meter coil can be moved away from the circuit coil, to avoid errors due to tight coupling. With loose coupling, moderate accuracy is possible. The instrument is also termed a 'Wavemeter'. It is very useful for checking harmonics, but not for exact frequency measurements in a small band.

If a crystal diode and 0·5mA or similar meter are added, as in Fig. 83B, resonance is indicated by maximum meter reading. If a short aerial is added, the instrument can also be used for field strength tests at some distance from the transmitter.

*Heterodyne Frequency Meters*

For highly accurate frequency checking, a crystal marker is satisfactory. If a 100kc/s crystal is used, harmonics can be heard at 100kc/s intervals, perhaps up to 30mc/s, according to the sensitivity of the receiver. Fig. 84 shows a typical circuit of this kind. Values for an EF39, 6K7, or similar valve are shown, with a Quartz Crystal Co., Ltd., Q5/100 crystal.

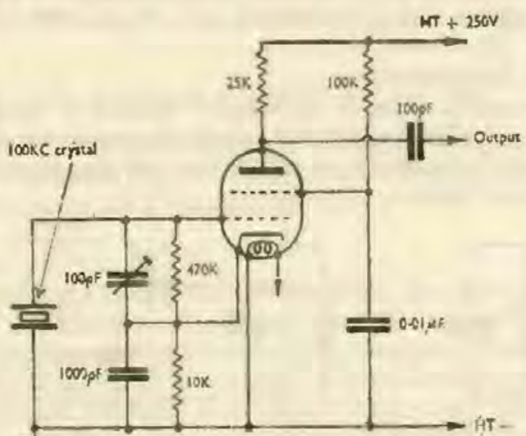



FIG. 84

To calibrate a receiver, the receiver is tuned to the appropriate harmonics, which are heard at 100kc/s intervals. For example, 1,800, 1,900, and 2,000kc/s will give calibration for Top Band. Harmonics at 3·5, 3·6, 3·7, and 3·8mc/s (3,500, 3,600, 3,700, and 3,800kc/s) will serve to calibrate the 80m band, and so on.



Higher harmonics grow progressively weaker. The marker signal is CW (not modulated) and is taken to the receiver aerial terminal.

To calibrate a transmitter VFO or tunable oscillator or signal generator, tune in the marker signal on the receiver, then tune the VFO or generator to zero beat with the marker signal, as heard in the receiver. Any difference in frequency between the crystal harmonic and VFO will produce an audible heterodyne. Care is taken to assure the correct harmonics are selected.

If a crystal of reliable make is used, with circuit values recommended for it, the frequency is accurate enough for all practical purposes. In Fig. 84, frequency can be modified slightly by adjusting the 100pF trimmer. The marker harmonic can thus be adjusted to agree with the BBC Light Programme on 200kc/s (which is maintained to a very high standard) or with the National Physical Laboratory transmissions on 2·5mc/s.

Harmonics of crystals of other frequencies are also suitable for frequency checks. For example, harmonics of a 500kc/s crystal will be heard at 500kc/s intervals, while a 1mc crystal will give harmonics at 1mc intervals.

If a receiver, oscillator, VFO, or other equipment is to be accurately calibrated, it should be switched on at least 20 minutes in advance, to reduce frequency drift due to changes in temperature.

Tunable heterodyne frequency meters have an extremely stable tuned oscillator, covering a fairly narrow band. On the fundamental frequency band, readings may be obtained direct. The signal from the generator, oscillator, or transmitter to be checked is tuned in on the receiver, and the heterodyne frequency meter is tuned so that its signal is at zero beat (the same frequency). The frequency can then be read on the heterodyne frequency meter dial. To check higher frequencies, harmonics of the heterodyne frequency meter may be used.

*Verniers and Interpolation*

A vernier scale allows reading to a high degree of accuracy, such as might be required for a frequency meter. In Fig. 85 the long scale moves against the short, fixed scale. The short scale is so arranged that 10 divisions equal 9 on the long scale. Each succeeding mark on the long scale thus comes opposite a mark on the short scale, allowing reading to 0·1 of a division.

In graphs, scales, etc., only a limited number of markings can be given. The positions of other readings, if required, may be arrived at by interpolation. Suppose the scale is marked only in

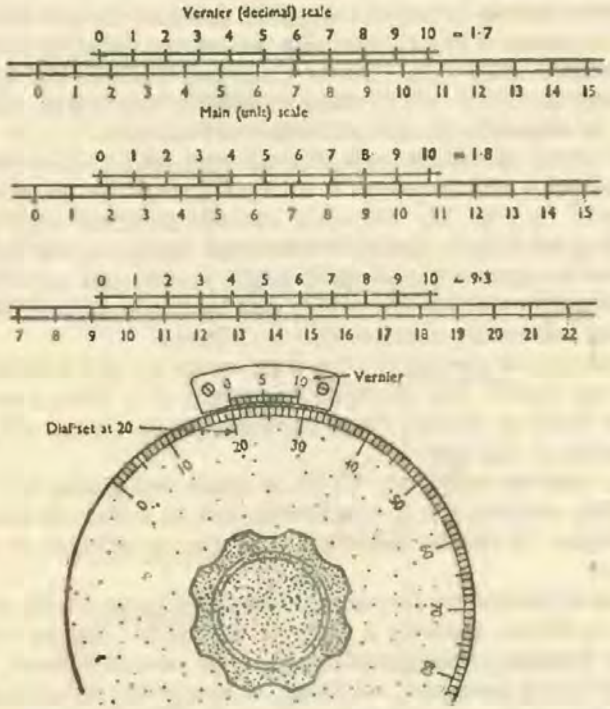



FIG. 85

intervals of 5. If it is required to read off along a vertical point from 12, for example, the position is seen to be two-fifths from 10, and three-fifths from 15.

In some instruments geared scales with a definite ratio are provided. For example, if a scale marked 0–100 rotates once, for a change in 1 figure on a 1–25 scale, then it is possible to read to 1 part in 2,500.

*Grid-dip Meters*

A grid-dip meter is a small oscillator, usually with an exposed plug-in coil. The oscillator grid current is shown by a meter. If a tuned circuit is brought near the grid-dip meter coil, and tuned to the same frequency, it draws RF energy. Oscillations drop in amplitude, and grid current falls. 'Grid-dip' indicates that resonance is shown by this dip in grid current.



A typical grid-dip meter circuit is shown in Fig. 86. Such instruments are often constructed in compact form, so that the coil can be brought near circuits to be tested. The grid-dip meter can be used as a signal generator, but high accuracy is not expected.

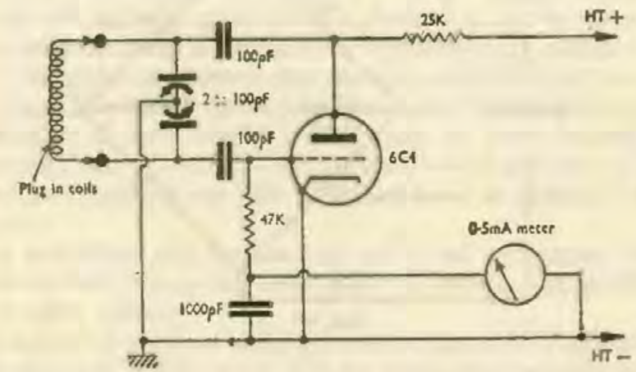



FIG. 86

Circuits to be tested with a grid-dip meter do not need to have any RF present. Resonances in transmitter circuits, etc., can thus be checked with the equipment switched off. Aerial resonance may be checked by coupling the grid-dip meter to the aerial.

*Capacity and Inductance Measurements*

Capacity can be checked by connecting the unknown capacitor in parallel with a known inductance, and finding the resonant frequency with the grid-dip meter. Inductance can be found by connecting the unknown inductance in parallel with a known capacity, and checking resonance. The method is only suitable for small values, such as may be used in RF circuits.

*Bridge*

A bridge is often used to measure resistance and capacity, and a bridge circuit is shown in Fig. 87. An oscillator or other source of AC supplies the input to the bridge. Headphones, or some other indicator, are connected to the points indicated. When the bridge is balanced, opposite arms cancel, and no signal is heard in the phones. The bridge may be balanced with a range of resistance, capacitor, or inductance values.

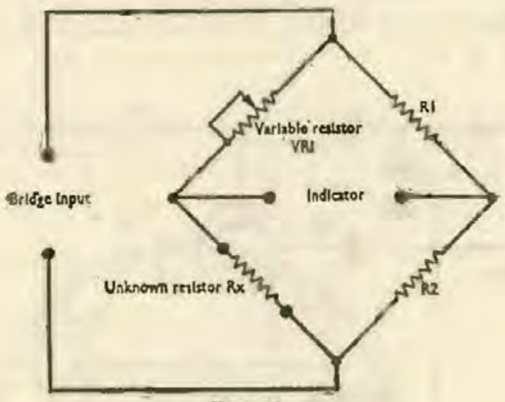



FIG. 87

If the bridge were to be used for resistance measurements only, a battery or other source of DC could provide the bridge input, and a meter with central zero could be employed as the indicator.

The variable resistor VR1 has a control knob and accurately calibrated scale. VR1 is adjusted until the bridge is balanced (zero with the indicating device). In these circumstances:

$$Rx=\frac{R2}{R1}\times VR1$$

If R1 and R2 are of the same value, unknown resistors Rx may be measured through the same range as available on the variable resistor VR1. To increase the range of the bridge, a switch is generally fitted, so that a number of resistors may be selected for R1 and R2. These may be in multiples of 10, or as convenient. As example, assume VR1 is 1,000 ohms, R1 100 ohms, and R2 1,000 ohms, and that the bridge is balanced when an unknown resistor



Rx is connected, and VR1 is adjusted to 600 ohms, as shown by its scale.

$$Rx=\frac{1,000}{100}\times 600=6,000 \text{ ohms}$$

*Artificial Aerials*

An artificial aerial (AA) is some non-radiating load into which RF power may be fed, so that the transmitter aerial need not be connected. A simple AA is an electric lamp, and domestic lamps of 15W to 100W are commonly used. Such a lamp is suitable for phone, but not if the transmitter is to be keyed during tests.

An electric lamp will radiate some RF energy. Household lamps are suitable up to 30mc/s. Radiation can be reduced by enclosing the lamp in an earthed, ventilated metal casing.

A better AA is a large carbon resistor, of suitable resistance and wattage. This can be almost wholly non-inductive. For low power, a number of small carbon resistors may be wired together. For example, four 300 ohm 5-watt resistors would provide a 75-ohm load, and handle about 20W. This load could be used for CW and phone.

A transmitter may be tuned up and tested with power running into the AA. This avoids unnecessary radiation, and interference with other operators.

An AA is sometimes useful in locating causes of TV interference. For example, if TVI ceases with the transmitter working into the AA, but returns when the usual aerial is connected, then the interference is probably radiated by the aerial or feeder. If interference remained with the AA, then it is probably caused by radiation from the transmitter, or may be carried on mains wiring.

Speech quality, modulation level, and similar tests can be made with the transmitter connected to the AA.

*PA Input and Output*

The PA input requires to be known, and is the product of anode voltage × anode current. For example, a PA draws 120mA at 600V. What is its DC input? 120mA = 0·12A. 0·12 × 600 = 72 watts. Input must not exceed 10W for Top Band, or 150W for other bands, as described.

The RF output of the PA stage can be found from $I^2 \times R$. This requires that a suitable non-inductive resistor R receive power from the transmitter, and that a RF meter in series with the resistor is used to show I. The resistor is connected to take the transmitter output, as described for an artificial aerial.

As example, assume that the transmitter delivers 0·5A into a 100-ohm load. RF power $= I^2 \times R = 0{\cdot}5 \times 0{\cdot}5 \times 100 = 25$ watts. Doubled current would result in a four-fold increase in power (not two-fold). For example, 1A into 100 ohms $= 1 \times 1 \times 100 = 100$W.

Efficiency in the stage is the relationship between input and output. For example, assume the DC input to the PA is 50W and the stage delivers 30W of RF power. The efficiency is:

$$\frac{30}{50} \times \frac{100}{1} = 60 \text{ per cent}$$

*Modulation Percentage*

An oscilloscope can be used to determine the depth of modulation in order that over-modulation can be avoided. The output of the transmitter can be taken to the vertical plates of the scope, via a small capacitor. The transmitter may be operating into a dummy load (artificial aerial) or into its usual aerial. The scope is switched to provide a fairly rapid horizontal scan.

In these circumstances, the unmodulated radio wave will produce a trace or display resembling that at A in Fig. 88.

When modulation is applied from an audio-oscillator, peaks and troughs will appear, as at B. When the troughs reach zero, this is 100 per cent modulation. To avoid over-modulation, the transmitter is usually operated at a little under 100 per cent modulation. As the human voice changes rapidly in tone and volume, it is less easy to determine when 100 per cent modulation is reached, if the voice is used instead of an audio-oscillator.

The unmodulated carrier amplitude is indicated by A. The peak amplitude is B, and the trough amplitude is C. The upwards modulation percentage =

$$\frac{B-A}{A} \times 100$$

The downwards modulation percentage =

$$\frac{A-C}{A} \times 100$$



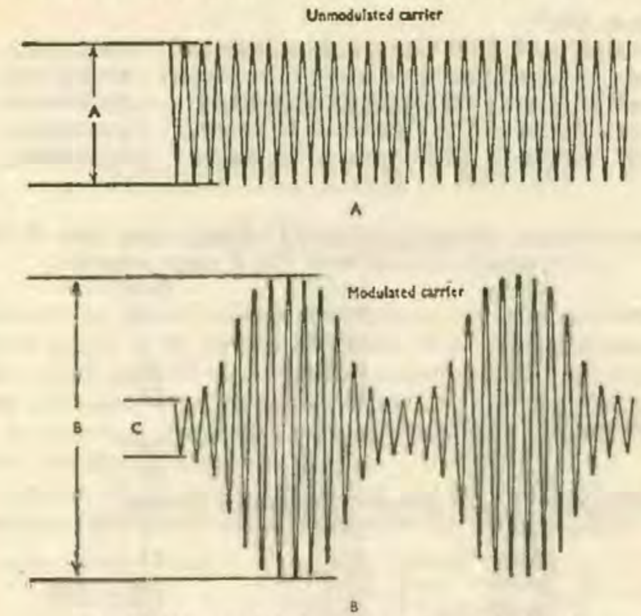



FIG. 88. How modulation percentage may be found

If the modulator output is balanced, upwards and downwards modulation will be the same. Over-modulation, likely to cause interference, is illustrated in Fig. 56 at E.

## COILS

*Amateur Band coils for crystal oscillators, etc. 150pF tuning capacitor 1in diameter former.*

| | |
|---|---|
| 1·8mc (160m) | 64 turns 24 SWG enamelled, side by side. |
| 3·5mc (80m) | 32 turns 22 SWG enamelled, side by side. |
| 7mc (40m) | 17 turns 22 SWG enamelled, spaced by wire diameter. |
| 14mc (20m) | 13 turns 20 SWG enamelled, spaced by wire diameter. |
| 21mc (15m) | 7 turns 20 SWG enamelled, spaced by wire diameter. |
| 28mc (10m) | 5 turns 18 SWG enamelled, spaced by wire diameter. |

*Coils for PA and transmitter aerial tuning. 150pF tuning capacitor.*
1 8mc (10W) 60 turns 24 SWG enamelled, side by side, on 1¼in dia. former.

*For up to 150W:*

| | | |
|---|---|---|
| 3·5mc | 30 turns 18 SWG spaced by wire diameter | (1½in former). |
| 7mc | 15 turns 18 SWG spaced by wire diameter | (1½in former). |
| 14mc | 8 turns 18 SWG spaced to 1in length | (1½in former). |
| 21mc | 5 turns 18 SWG spaced to 1in length | (1½in former). |
| 28mc | 3 turns 18 SWG spaced to 1in length | (1½in former). |

*General coverage coils on 1½in diameter formers, wound with 18 SWG wire spaced by wire diameter. 150pF tuning capacitor.*

| *Metres* | *mc/s* | *Turns* |
|---|---|---|
| 8–15 | 37–20 | 2½ |
| 12–25 | 25–12 | 5 |
| 19–43 | 16–7 | 10 |
| 25–55 | 12–5·5 | 15 |
| *Wound with 22 SWG:* | | |
| 55–100 | 5·5–3 | 30 |
| 100–200 | 3–1·5 | 55 |
| *22 SWG spaced by wire diameter, ¾in diameter formers:* | | |
| 12–25 | 25–12 | 9 |
| 15–34 | 20–9 | 13 |
| 20–43 | 15–7 | 19 |
| 26–55 | 11–5·5 | 26 |
| 55–100 | 5·5–3 | 52 |

Absorption meter coils, 150pF capacitor, 1½in diameter formers:
9–30m (33–10mc) 8 turns 20 SWG occupying 1in
30–95m (10–3·2mc) 28 turns 24 SWG occupying 1in

*Note:* Exact coverages depend on stray capacity, etc. Frequency may be increased by removing turns, increasing spacing of turns, using smaller diameter former, or reducing capacity. Frequency may be reduced by adding turns, placing turns closer together, using larger former, or increasing capacity.

CHAPTER TEN

# Semiconductor Diodes and Transistors

SEMICONDUCTOR diodes and transistors are small and need no heater supply as do thermionic valves. Point contact diodes contain a small piece of semiconductor material such as germanium, with a tungsten wire bearing on its surface, Fig. 89, and operate up to very high frequencies. The inter-electrode capacity is very small, but the current rating limited.

Junction diodes have small N-type and P-type crystals formed together, rectification taking place over the junction region. The

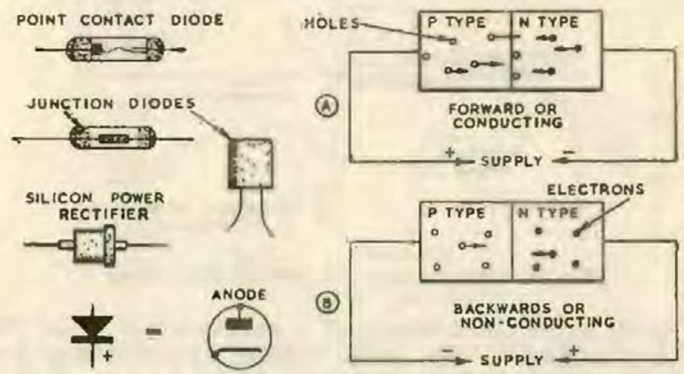



FIG. 89. Semiconductor diodes and polarity compared with thermionic diode

crystals may be germanium, and the N-type or negative material has small impurities added so that there is a surplus of negative electrons. The P-type or positive material has other impurities and a deficiency of negative electrons. This deficiency results in positive 'holes' (Fig. 89) which can pass through the material. The diode is enclosed in a case and usually has wire ends.

The movement of electrons and holes in the junction region causes a potential barrier. If the voltage applied has the polarity at A, Fig. 89, the movement of electrons and holes reduces the barrier, so that current flows readily. If the polarity is changed to B, the barrier is raised and little current flows. A is the 'forward' or conducting direction, and B the backwards, reverse, inverse or non-conducting direction. There is a small backwards leakage current, usually unimportant.

A junction diode may be used instead of a thermionic diode as detector, to provide AVC voltages, as a noise limiter, or for power rectification, etc. For high voltages, silicon junction diodes are more suitable, able to withstand higher temperatures, and have a lower backwards current. Junction diodes are produced in many kinds, to suit the purposes in view. They may be destroyed if their voltage or current ratings are exceeded.

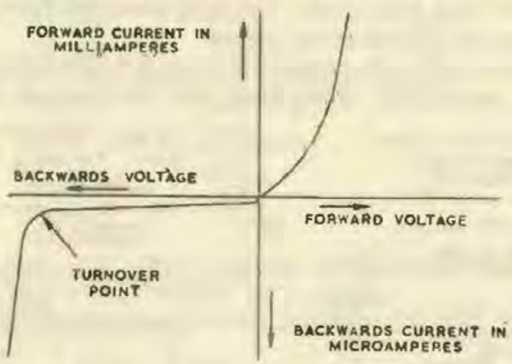



FIG. 90. Characteristics of a semiconductor diode

Fig. 90 shows characteristics of a semiconductor diode. The forward resistance is low, so the forward current is large with a small potential. The normal reverse current is very small and so is not given on the same scale. This inverse current only increases slightly with increased voltage, until there is a sudden rapid increase at the turnover voltage, which may destroy the junction.

*Transistors*

A PNP transistor has an emitter of P-type material, a base of N-type material, and a collector of P-type material, Fig. 91. Germanium transistors are made by fusing emitter and collector



pellets on a thin central base crystal, with wires for external connections.

Fig. 91 includes some methods used to identify leads. Transistor A has a red dot near the collector, B has emitter and base wires close together and extra space to the collector lead, and C has leads positioned as shown. Other methods are also employed. Some high frequency transistors have an earthed screen lead between base and collector (Fig. 94).

PNP transistors are connected with the emitter to positive. NPN transistors have N-type emitter, P-type base, and N-type collector, and a slightly different circuit symbol (Fig. 91). The emitter goes to supply negative. Connecting a transistor the wrong way may destroy it.

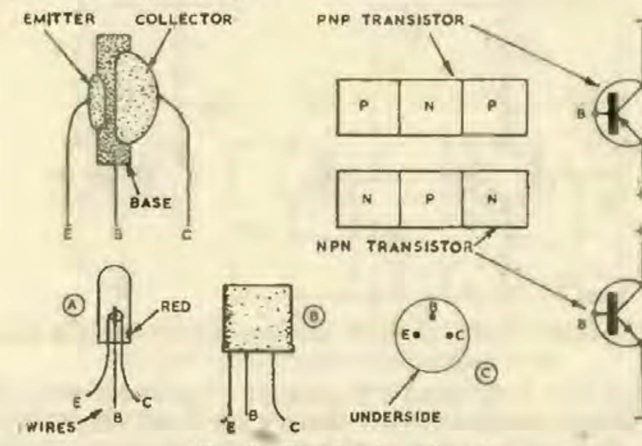



FIG. 91. Details of transistors

A transistor is a current amplifier and small changes in base current can cause large changes in collector current. Base and collector currents added form the emitter current. As example, with a small transistor emitter current might be 2mA, collector current 1·9mA, and base current 0·1mA (100uA).

In Fig. 92A the emitter is taken to positive line, and the meter reads collector current through the collector load R1. The potentiometer VR1 allows base potential and thus base current to be adjusted. Commencing with VR1 slider S at positive, collector current is extremely small. Rotating VR1 to make the base more negative causes a rapid rise in collector current. The base may only require to be very slightly negative, relative to the emitter, for maximum safe collector current.

If an applied signal moves base B (Fig. 92A) negative, collector current increases. Therefore the voltage drop across R1 is greater and collector C moves in a positive direction. Should base B swing positive, collector current falls, voltage drop in R1 is less, and collector C moves negative. So there is a 180 degree change in phase between input and output. Since input is effectively between base and emitter, and output from collector and emitter, the circuit is termed common emitter, or grounded emitter. A common emitter stage offers high current and voltage gain, and has medium input and output impedances. It is often used.

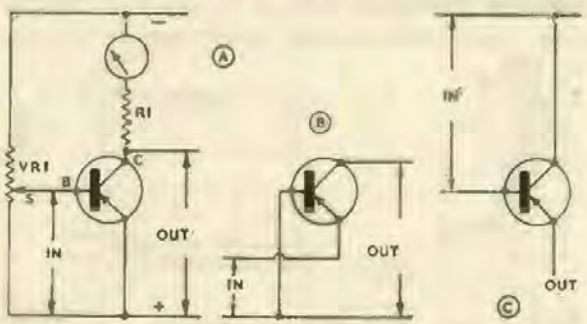



FIG. 92. Common emitter, common base and common collector circuits

A stage may be operated with common or grounded base, Fig. 92B. There is no phase reversal between input and output. Input impedance is low, and output impedance high. A given transistor can work at a higher frequency than in a common emitter circuit. Signals are applied between emitter and base, and taken across base and collector. Current gain is under 1, but as the input impedance is low and output impedance high, high voltage gain and medium power gain are possible. The circuit is common in VHF equipment.

A transistor may operate with input effectively between base and collector, and output from emitter and collector. This is the common collector (or emitter follower) circuit C. The input impedance is high, output impedance low, and this is occasionally useful. There is no phase reversal between input and output, current gain is high, but power gain obtainable is low.



*DC Stabilization*

Fig. 93A is a simple common emitter audio amplifier. Base current is supplied through R1. R4 is the collector load. Capacitors C1 and C2 provide direct current isolation from other stages. There is no stabilization of operating conditions, so performance is likely to vary and be unsatisfactory with changes in temperature, or if the transistor is replaced by another of the same type.

At B (Fig. 93) the base is supplied by the divider R1 and R2. Base B will be held substantially at the same potential if R1 and R2 are of low value. With moderately high values the base potential will be reasonably constant, for small changes in base current.

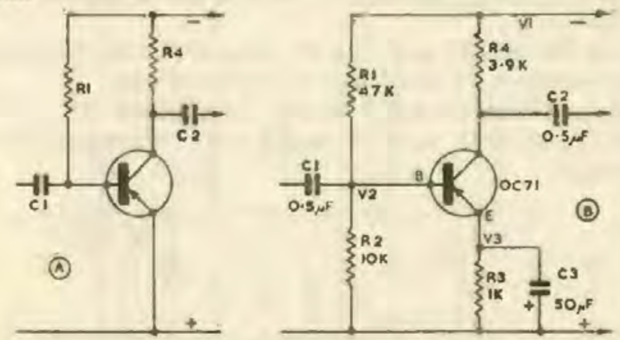



FIG. 93. Audio amplifier for low signal levels

Emitter current flows through R3. If collector current rises, then emitter current also increases and the voltage drop across R3 is larger. Emitter E thus moves more negative. Since base potential B is substantially stable, base B is now less negative relative to emitter E. This reduces collector current. Alternatively, should collector current fall, the reverse happens. Voltage drop in R3 falls, so base B is more negative relative to emitter E, thereby shifting the bias to help maintain collector current. So any transistor of similar type will work satisfactorily, even with changes in battery voltage or temperature. C3 is for audio by-pass purposes.

Assuming base current as zero in Fig. 93B, base potential V2 above the positive line depends on the values of R1 and R2. V1 is the supply voltage. If R1 and R2 are very low in value, unnecessary current is drained from the supply, and audio input to the base is shunted. If V1 is the line potential and V2 the base potential, then:

$$\frac{R2}{R1 + R2} \times V1 = V2$$

Suppose V1 is 6V, R1 50k and R2 10k.

$$\frac{10}{60} \times 6 = 1V$$

(R1 is actually the nearest standard value of 47k.) Again, suppose V1 is 6V, and V2 is to be 1V, and the potential divider resistors R1 and R2 may draw a bleeder current of 1mA. Potential across R2 is to be 1V, with 1mA flowing. From V/I = R (p. 25), 1/0·001 = 1,000 ohms for R2. Potential across R1 is to be 6V − 1V = 5V, so 5/0·001 = 5,000 ohms (nearest preferred value is 4·7k).

In Fig. 93B with V1 at 6V and R1 50k and R2 10k, the potential divider current is V1/(R1+R2) = 6/60,000 = 0·1mA.

Suppose emitter current is 0·9mA. Drop across R3 is I × R = 0·0009 × 1,000 = 0·9V at E. So base B is 0·1V more negative than the emitter.

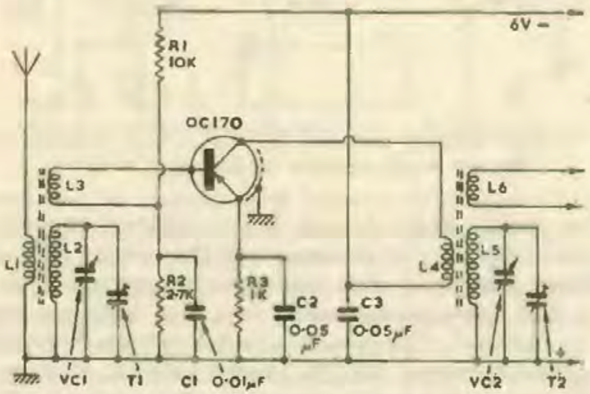



FIG. 94. Transistor radio frequency amplifier

### *RF Amplifier*

Fig. 94 is a typical transistor radio frequency amplifier for 1·8–30mc/s or general use. L1 is the aerial coupling winding, L2 being tuned to the wanted frequency by VC1. L3 is the base coupling winding, and R1 and R2, with by-pass capacitor C1, supply the base through L3. R3, with by-pass capacitor C2, is for emitter bias.



The transistor is a screened RF type. Its collector is coupled to the second tuned coil L5 by the primary L4. L6 supplies the following stage base (probably a mixer).

VC1 and VC2 will normally be ganged, and T1 and T2 are trimmers for aligning the tuned circuits, in conjunction with adjustable cores for L2 and L5, in the normal way. For general use, VC1 and VC2 would be about 315pF each, and trimmers T1 and T2 30pF or 50pF.

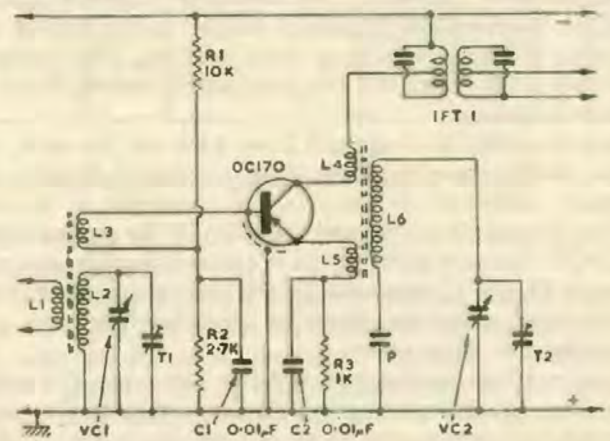



FIG. 95. Transistor mixer stage

Coils L2 and L5 tune a single waveband. For other bands, additional coils are selected by change-over switching. For simplicity, small plug-in coils are sometimes adopted in home constructed equipment. Both L2 and L5 tune simultaneously to the same frequency, which is that of the wanted transmission.

### *Mixer Stage*

Fig. 95 is a typical self-oscillating frequency changer. L1 may be connected to the aerial, or to a RF amplifier.

In compact portable transistor receivers for general use, L2 is generally wound on a ferrite rod, and this acts as a self-contained aerial. L1 may then be omitted, or may couple an external aerial, when available.

L2 is tuned to the frequency of the wanted transmission by VC1, which is one section of the ganged capacitor VC1/VC2. L3 is the base coupling winding, supplied from R1 and R2.

L6 is the oscillator tuned circuit, and has collector and emitter coupling windings L4 and L5. R3 is for emitter bias, and C1 and C2 are by-pass capacitors. L6 is tuned to the oscillator frequency. This differs from the signal frequency by the intermediate frequency, and is usually higher. For example, if L2 were tuned to 2mc/s (2,000kc/s) and the intermediate frequency is 470kc/s, L6 may be tuned to 2,000+470=2,470kc/s. Then mixing of the signal frequency (2,000kc/s) and oscillator frequency (2,470kc/s) gives an intermediate frequency output corresponding to the difference (470kc/s) as with a valve superhet. The intermediate frequency transformer IFT1 is permanently tuned to the intermediate frequency.

Since frequency coverage of L2 and L6 is not the same, L6 has a series padder capacitor P. Its value is chosen so that the correct frequency difference (470kc/s in this example) is maintained between L2 and L6 throughout the swing of the ganged capacitor VC1/VC2. The coils generally have adjustable cores, and parallel trimmers T1 and T2 allow the circuits to be aligned and trimmed, as with valve equipment. Coils for other bands may be selected by switching or other means.

Some receivers employ two separate transistors for oscillator and mixer. An oscillator coil may be connected to the oscillator transistor in a similar way to L4, L5 and L6 in Fig. 95. Output from the oscillator may be taken to the emitter of a transistor used for mixing only. Signals received are applied to the base of the mixer transistor as by L3 in Fig. 95, and the mixer output goes to the first IF transformer.

*IF Amplifier*

Fig. 96 is a typical 2-stage intermediate frequency amplifier, as used in many all-wave receivers. R1 supplies the mixer and RF stages.

R2 from negative to the intermediate frequency transformer IFT1, and R4 and VR1 in series to positive, supply the base of the first AF117. R3 provides emitter bias. C2 and C3 are by-pass capacitors.

R5 and R6 supply the base of the second AF117 through IFT2, with R7 for emitter bias. Diode D1 provides demodulation or



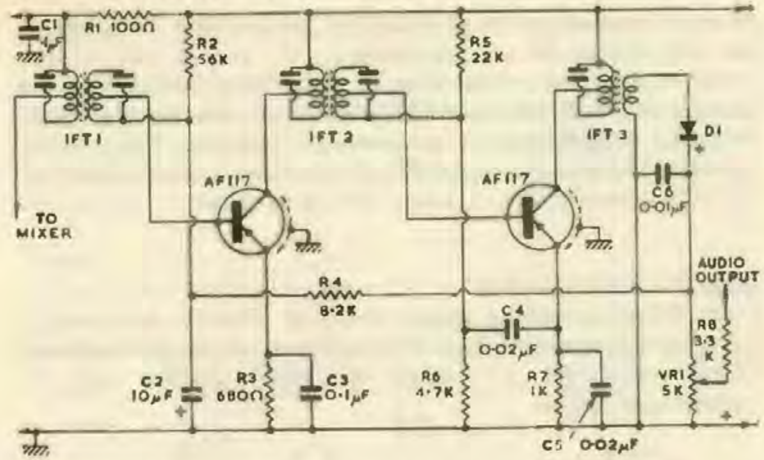



FIG. 96. 2-stage 470kc intermediate frequency amplifier

detection so that an audio signal is obtained across VR1, the audio volume control.

IFT1 and IFT2 have tuned primaries and secondaries, tapped to allow a suitable impedance match for the transistors. In some circuits, only the primaries are tuned. Tuning is by adjustable cores. IFT3 generally has an untuned secondary for the diode.

Many general coverage receivers have a 470kc/s or similar intermediate frequency. If a receiver is especially designed for short wave reception, a higher frequency, such as 1·6mc/s, may be employed. This gives greater freedom from 2nd channel or image interference, as in a valve receiver (p. 77). Crystal filters are also used, or double superhet circuits, to obtain both good freedom from 2nd channel interference, and good adjacent channel selectivity.

Transistors of the type shown need no neutralizing. Other transistors may have to be neutralized. This is arranged by connecting small fixed capacitors between the IF transformers (or a network of capacitors and resistors) to neutralize unwanted internal feedback in the transistors.

*Automatic Volume Control*

In Fig. 96 AVC bias is applied to the first AF117 through R4. If a very strong signal is received, rectification by the diode D1 causes a positive potential to appear across VR1. This reaches the base through R4, reducing gain.

When signals are weak, little or no positive bias is obtained through R4, and the first AF117 operates at maximum gain. In this way, amplification is automatically reduced with powerful signals, to help counteract fading, and to give a more equal output with transmissions of widely varying strength.

*Class A Audio Amplifier*

Small audio amplifier stages operate in Class A, as does Fig. 93B. Bias is so arranged that the transistor conducts for the whole of the audio cycle. The output may supply another stage, or operate headphones.

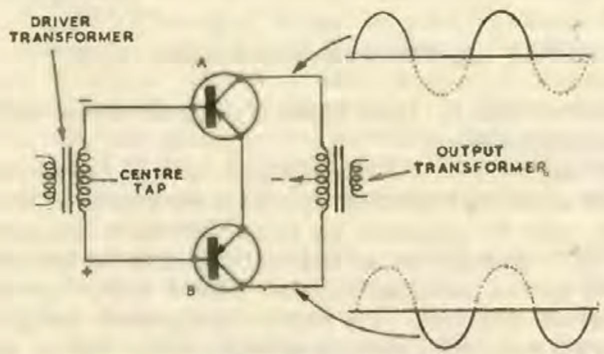



FIG. 97. Operation of transistors in push-pull

The current taken is large if much power is to be obtained. So Class A is only used (1) when low power amplification is wanted, or (2) when a large current is not important, as with a car radio run from an accumulator.

*Class B Audio Amplifier*

For large power output with low battery drain, two transistors are used in push-pull. Fig. 97 shows one method. Bias is arranged so that collector current is very low. Audio signals are applied to the primary of the driver transformer. This component has a centre tapped secondary and the tap is earthed at audio frequency. So when one end swings negative, the other swings positive.



In Fig. 97, transistor A is swung into the conducting region so supplies half a cycle of output. When A is conducting, B is cut off. For the next half cycle, transistor B receives negative drive and conducts, while A is cut off. So each transistor handles half of the audio cycle, and their outputs are combined in the centre tapped output transformer, to operate a loudspeaker, etc. See also p. 57.

*Driver*

The OC81D audio amplifier in Fig. 98 can drive a push-pull output pair. The 9V negative supply is reduced by R1, and decoupled by C2, to supply earlier stages of a typical receiver.

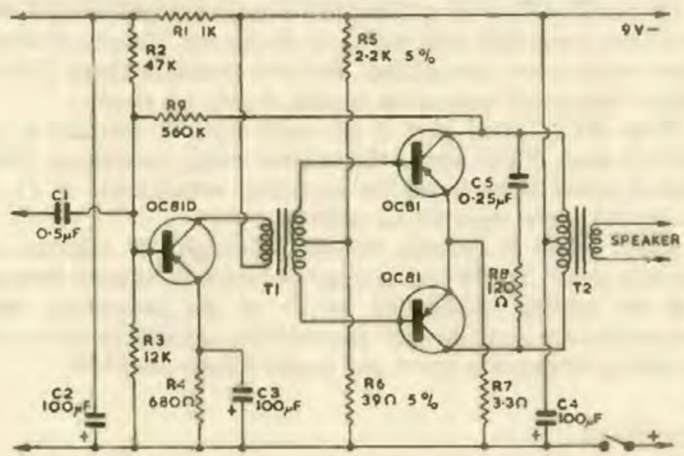



FIG. 98. Driver and push-pull output for ½ watt to 1 watt

R2 and R3 supply the base, while R4 with audio by-pass capacitor C3 supplies emitter bias for stabilization. Coupling capacitor C1 goes to the previous circuit – a low-level audio amplifier, or the diode stage of a receiver, Fig. 96. The driver transformer T1 has a centre-tapped secondary.

*Push-Pull Output Stage*

In Fig. 98 two OC81 transistors are used. The base supply is through T1 secondary, from the divider R5 and R6. These resistors are close tolerance to avoid wrong operating conditions from the spread in values of 10 per cent resistors. R7 is a common emitter resistor.

Each OC81 conducts for approximately half of the audio cycle, as explained, and the outputs are combined in T2. With such a circuit, the no-signal current of the transistors is only a few milliamperes. But with increased volume the transistors are driven more into the conducting region, and drain may be 20–30mA with good volume, rising to peaks of 45mA or more at great volume. A meter in the battery circuit will show this. Average current drain depends largely on volume.

*Negative Feedback*

C5 and R8 across the primary of T2 suppress higher frequencies, as C5 reactance falls with increased frequency. Without feedback these components are optional. But with feedback phase shifts at higher frequencies may cause trouble if they are omitted.

When R9 is added, part of the audio signal is returned to the OC81D base. If this assists the original signal, oscillation arises. This is cured by reversing the secondary connections of T1, or taking R9 to the other OC81 collector.

When phase is correct, feedback through R9 opposes the original signal. This is termed negative feedback. If some frequencies are unduly emphasized by T1 or the transistors, these frequencies are most strongly returned through R9. So the overall frequency response is better and higher fidelity obtained.

*Heat Sinks*

For 1 watt output, the transistors are placed in clips which are bolted to a metal chassis, or to aluminium plates at least 5×7cm, which form heat sinks. They conduct heat away, allowing a higher operating current without damage to the transistors. The amplifier can be operated at lower maximum volume with no heat sink. R7 can then be 5·6 ohms.

*Transistor Terms*

An increase in temperature can change transistor characteristics so that more current flows. The heavier current further raises temperature. This is called 'thermal runaway' and may continue until the transistor is destroyed. It is avoided by DC stabilization and heat sinks.



As operating frequency rises, delay in the movement of hole carriers reduces efficiency. That frequency at which the current gain has fallen to 0·7 of its original value is called the 'Cut-off Frequency' or 'Alpha Cut-Off Frequency'. An average audio type transistor would be unsuitable for RF purposes because its cut-off frequency would be too low.

The 'Alpha' of a transistor = *Change in Collector Current/Change in Emitter Current* and might be about 0·95. The ratio of the output resistance to the input resistance is the 'resistance gain' and may be large. Suppose the output resistance is 4,000 ohms and the input resistance 50 ohms, the resistance gain is 80. *Alpha × Resistance Gain = Voltage Gain*. Suppose Alpha is 0·95 and Resistance Gain 80. Voltage Gain = 0·95×80=76.

# Index

*(Including Abbreviations)*

**F. G. Rayer** is a licensed amateur radio transmitter and a designer of electronic equipment. He has exhibited at London radio shows and is the author of *Repair of Domestic Electrical Appliances* and other books.

Printed in Great Britain

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Amateur Radio

ARCO